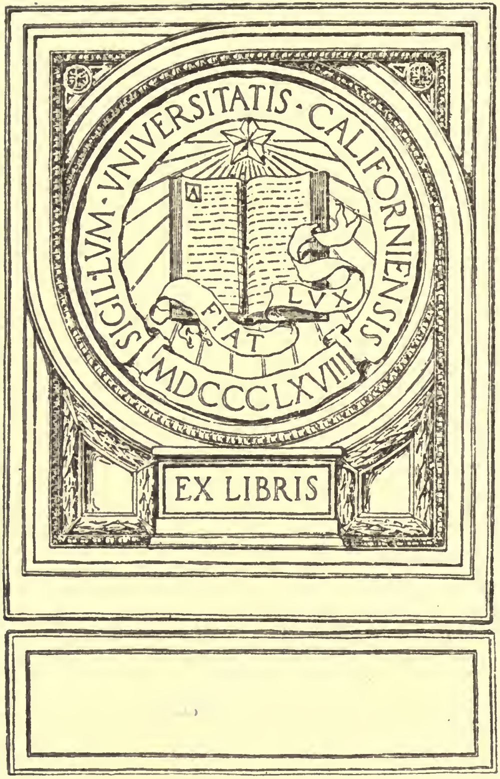
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An Outline of the Metallurgy of Iron & Steel.

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BY

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PREFACE.

THIS book was prepared to meet a need which the first Author had felt in his teaching, viz., a book which, in one volume of moderate size, would cover the whole field of the Metallurgy of Iron and Steel.

That the book has, to some extent at least, met this need is evidenced by the fact that a second edition has been called for.

This edition has been carefully revised, and some chapters have been re-written, so that they may bring the information up to the present condition of our knowledge. Considerable attention has been given to the latest work in connection with the metallography and heat treatment of the metal.

The difficulty of selection from the vast mass of material now available is very great, and the Authors have done their best to give an account of all the more important developments in processes and plant, whilst retaining as much of the older processes as is necessary to an understanding of modern developments. A few processes which are no longer in use are described on account of their historical interest.

In such a work as this it is impossible that there should be much that is new, and the Authors wish to express their indebtedness to the writers who have gone before, particularly to Dr. Percy and Sir I. Lowthain Bell, who have passed away; and to Prof. Howe, Mr. H. H. Campbell, Dr. Stead, and other great workers who are still with us.

The Authors have to thank the Councils of the various Societies for permission to use matter in their Proceedings, the Editors of various Technical Journals, and many private friends who have given help in various ways.

In most cases the source of information and illustrations are acknowledged in the text or notes; but if this has been inadvertently omitted the Authors tender their sincere apology for the oversight. In the preparation of such a book, making use of notes accumulated through years of teaching, it is not always possible to ascertain the source from which information was obtained.

To readers—especially students—the Authors would point out that no text-book can be more than a guide to reading. The books quoted should be referred to wherever possible, and no opportunity should be lost of referring to the original papers, as only by so doing can a real insight be obtained into the methods of the men who have made and are making the great industry, and whose influence for good in the world cannot be over-estimated; and one cannot make much progress himself till he has mastered the methods of those who have gone before.

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ERRATA.

Page 5, line 5, "HO_2" should be "H_2O."

Page 5, line 19, should read "potassium permanganate or potassium bichromate," &c.

Page 23, bottom line, Total should be "7,334,351."

Page 23, line 4 up, Worcester total should be "51,574."

Page 23, line 6 up, should read "Northampton 315,066," and insert "Lancaster 516,159."

Page 24, line 1, should read "Glamorgan and Denbigh 820,389."

Page 24, line 12, should read "6,234,589."

Page 24, line 16, should read "605,930."

Page 47, line 16 up, "Ferros" should read "Ferrous."

Page 52, lines 2 and 20, "Grôudal" should read "Gröndal."

Page 52, line 25, after "rotary" add "furnace."

Page 62, line 13 up, line omitted should read "stalactites. The reactions by which the cyanides are formed are"

Page 107, Fig. 52 is "Diagram of Blast Pressure."

Page 166, page number 66 should read 166.

Page 256, line 10 up, "Graphitic carbon content" should be "3·180 per cent."

Page 270, line 10 up, "18,794" should read "18,792."

Page 275, line 13, "Phosphus" should read "Phosphorus."

Page 302, line 19, "41458·1" should read "54007·6."

Page 308, line 18, "CO" should read "CO_2."

Page 365, Fig. 167 is inverted.

Page 433, line 23, "stee" should read "steel."

Page 485, line 10, from bottom, "$MnSi_2$" should read "Mn_7Si_2."

Page 493, Fig. 220, after "containing 1·6 per cent" add "Phosphorus."

PART I.

CHAPTER I.

INTRODUCTORY.

> "It was a just remark of Solon to Crœsus, who showed him all his treasure: 'Yes, sir; but if another should come along with better iron than you he would soon master all this gold.'"—*Bacon.*

Importance of Iron.—Iron is certainly the most important of the metals, "the master metal," which commands all the rest. It is to it that, to no small extent, is due the present social and industrial position of the civilised world. There can be no better test of the industrial development of a community than the amount of iron which it requires to meet its demands, and the development of civilisation is most intimately connected with the growth of the iron and steel industries. There is no article used in the arts or in daily life in the production of which iron, in some form or other, has not been used, and it is impossible to imagine the condition to which the world would be reduced if the production of iron and steel were to cease or to be seriously curtailed.

Pure Iron.—Though iron is the most abundant and most widely distributed of the metals, and is very readily reduced from its compounds, it is so difficult to obtain it in a state of purity that pure iron is only a chemical curiosity. Iron combines so readily with most of the other elements that it unites with them at the moment of its liberation, and subsequent purification is a matter of extreme difficulty. Commercial irons sometimes contain more than 99·5 per cent of iron, but the removal of the remaining ·5 per cent of impurity is very troublesome.

Various methods for the preparation of pure iron have been suggested; they are all chemical laboratory methods, and involve as the first stage the preparation of a pure iron salt.

Matthiessen, first prepared pure ferric oxide by heating pure ferrous sulphate and sodium sulphate till decomposition was complete, and washing this with hot water till soluble salts were removed. The ferric oxide thus obtained was reduced by hydrogen in a platinum crucible, and the resulting spongy metal melted in a lime crucible by the oxy-hydrogen flame. Varrentrap electrolysed a solution of ferrous sulphate and ammonium chloride, using an iron plate as cathode, and expelled the occluded hydrogen from the precipitated iron by gentle heating. Peligot prepared pure ferrous chloride and decomposed this by ignition in hydrogen. W. McGillivray, acting under the direction of the late Professor Dittmar, has used this method with considerable success.

Pure iron is white—almost silver white—in colour, and has a brilliant metallic lustre. The physical properties of the pure metal have been but little studied.

Chemical Properties.—The symbol for iron is Fe, and its atomic weight is 55·85 (O=16), but for practical purposes it may be taken as 56. It forms two series of salts, the ferrous as $Fe\ Cl_2$, in which its equivalent is 28, and the ferric as $Fe_2\ Cl_6$, in which its equivalent is 18·66.

Iron is not oxidised by dry air or oxygen at ordinary temperatures, but at a red heat it becomes covered with a film of oxide, and at a white heat it burns. In moist air, containing carbon dioxide, it rusts rapidly, a brown hydrate being formed. It dissolves readily in most acids, hydrogen being evolved, and ferrous salts formed except in the presence of oxidising agents, which convert the ferrous into ferric salts. It precipitates copper and many other metals from their solutions.

Passive Iron—Iron is not dissolved by concentrated nitric acid (sp. gr. 1·4), but is rendered "passive." In this condition it is not soluble in dilute nitric acid, nor does it precipitate copper from its solutions, and it is strongly electro-negative to ordinary iron. Strong neutral solutions of silver nitrate, peroxide of hydrogen, and some other substances, also have the power of rendering iron passive. The passivity may be removed by rubbing, heating in reducing gases, placing in contact with zinc, and other methods. The passive condition is usually thought to be due to the formation of a thin film of black oxide on the surface of the metal, but this is not by any means certain.*

Physical Properties.—Iron crystallises in the cubic system, though perfect crystals are very rare. Its specific heat is 0·113795, and its coefficient of expansion for heat is 0·00001220. It is a poor conductor of heat and of electricity. There are probably several allotropic modifications of iron, to which reference is made in the chapter on Microstructure of Iron and Steel. In commercial irons the physical properties are so much modified by the foreign constituents which are present, that those of each variety are best discussed separately.

Magnetism.—One property which is possessed more or less by almost all varieties of commercial iron, and by almost all in a far larger degree than by any other metal, is that of becoming magnetic under certain conditions. When a piece of soft iron is brought into a magnetic field—that is, into a space under the influence of magnetic force—it at once becomes a magnet. The softer the iron—that is, the more free it is from impurities—the more powerfully magnetic will it become, and the more quickly will it reach the highest degree of magnetisation which it is capable of attaining in that magnetic field. This capacity for magnetisation is called magnetic permeability. It is high in nearly pure iron, low

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*For a full discussion of "Passive Iron," see a paper by J. S. de Benneville, "Journal of the Iron and Steel Institute," 1897, vol. 2.

in steels containing much carbon, and *nil* in steels containing a large proportion of manganese. When the iron is removed from the magnetic field its magnetic power may disappear or it may be in part retained, the metal thus becoming a permanent magnet. This power is called magnetic retentivity. The magnetic retentivity of pure iron is very low, so that the magnetism disappears, almost completely, whilst it is high in hard steels. For the cores of electro-magnets and similar purposes it is essential that the permeability of the metal should be high, and its retentivity low, and therefore soft iron is always used ; whilst for making permanent magnets a high retentivity is essential. The foreign constituents present in iron have a great influence on its magnetic properties, and in all cases magnetic permeability seems to disappear at a red heat, owing to the passage of the iron into an "allotropic" form.

Iron Oxides.—Iron combines readily with oxygen, and three oxides are known.

Ferrous Oxide.—FeO (protoxide of iron).—This oxide is hardly known, either in the anhydrous or hydrated condition, as it passes into a higher state of oxidation with extreme readiness.

Ferric Oxide.—Fe_2O_3 (peroxide of iron).—This body occurs as a red powder, whence it is often called red oxide of iron ; it is also known as jeweller's rouge, chalcothar, bole, and by many other names. It is largely used as a polishing agent, as a pigment, and for other purposes. Ferric oxide is readily prepared by heating ferric hydrate, ferrous carbonate, ferrous sulphate, or any iron salt containing a volatile acid, to redness with free access of air.

$$(1)\ Fe_2(OH)_6 = Fe_2O_3 + 3H_2O$$
$$(2)\ 2FeCO_3 = Fe_2O_3 + CO + CO_2$$
$$(3)\ 2FeSO_4 = Fe_2O_3 + SO_2 + SO_3$$

The more finely the salt is powdered, and the lower the temperature of ignition, the better is the colour of the product.

Ferric oxide is soluble in hydrochloric acid, ferric chloride (Fe_2Cl_6) being formed, but if it has been ignited, it dissolves with great difficulty. Solution may, however, be much accelerated by the addition of a fragment of tin. Nitric and sulphuric acids also dissolve the oxide, but less readily than does hydrochloric. On heating to strong redness, ferric oxide loses oxygen, and passes into the condition of black oxide. It is readily reduced by carbon, hydrogen, or other reducing agents, below a red heat.

Ferric Hydrate.—$Fe_2(OH)_6 = Fe_2O_3 3H_2O$.—When ammonia or caustic soda is added to a solution of a ferric salt a red-brown precipitate of ferric hydrate falls. On boiling this becomes darker and more granular, losing water and passing into a lower hydrate ($2\,Fe_2O_3, 3\,H_2O$) and by partial drying other hydrates containing less water can be obtained. All the ferric hydrates are readily soluble in acids ; on heating they lose water and are converted into the oxide.

When iron is exposed to moist air containing carbon dioxide it becomes covered with a brown film of rust, which is a hydrate of uncertain composition. The formation of rust will be fully discussed later.

Black Oxide.—Fe_3O_4 (triferric-tetroxide, magnetic oxide).—When steam is passed over red-hot iron the iron is oxidised, black oxide of iron being formed and hydrogen liberated.

$$(4)\ 3\,Fe + 4H_2O = Fe_3O_4 + 8H.$$

When iron is heated to redness in air, it becomes covered with a black scale (iron scale), which is essentially black oxide, though the composition is not perfectly definite. On the outside it has approximately the composition Fe_2O_3 or Fe_3O_4, according to the temperature at which it was formed ; but on the inside, nearer the metal, it approaches to FeO or rather Fe_2O_3, x Fe O where x is a comparatively large number. When iron burns in air or oxygen the black oxide is formed. When the black oxide is dissolved in hydrochloric acid it yields a mixture of ferrous and ferric chlorides

$$(5)\ Fe_3O_4 + 8\,HCl = Fe_2Cl_6 + FeCl_2 + 4\,H_2O,$$

and therefore it is frequently regarded as being a mixture or molecular compound of ferrous and ferric oxides (Fe_2O_3, FeO), whence it is often called ferroso-ferric oxide, and this formula is borne out by most of its reactions. The black oxide is readily reduced by reducing agents under the same conditions as the red oxide, and no hydrates of it are definitely known. There is probably a lower oxide Fe_6O_7, the magnetic suboxide, which is also magnetic, and several still lower oxides have been supposed to exist, though they have not been isolated.

Iron Chlorides.—Iron forms two chlorides, the ferrous ($FeCl_2$) and the ferric (Fe_2Cl_6), corresponding to the two oxides.

Iron Sulphates.—Ferrous Sulphate.—$FeSO_4$ (Copperas, green vitriol).—This salt is readily obtained by the action of sulphuric acid on the metal, the hydrates or the carbonate, and by the oxidation of sulphides under the influence of air and moisture. It crystallises in pale green crystals containing seven molecules of water ($FeSO_4\,7H_2O$.) On exposure to the air the crystals turn brown from the formation of ferric sulphate, or a mixture of a basic sulphate and hydrate, by oxidisation. Solutions of the salt also oxidise readily. Ferrous sulphate is of considerable importance in metallurgy, and is used as a precipitant for gold and for other purposes.

Ferric Sulphate.—$Fe_2(SO_4)_3$—is a white salt, which, however, has a great tendency, in solution, to yield brown basic salts.

Ferrous Carbonate.—$FeCO_3$.—This salt is difficult to prepare, as in the presence of moisture it oxidises with extreme readiness. It, however, occurs abundantly in nature. When heated it is decomposed, an oxide being left, carbon dioxide being evolved if air be present, and a mixture of carbon monoxide and carbon dioxide if air be excluded. (Equation 2, page 3.)

It is soluble in acids, carbon dioxide being evolved, and in water containing carbonic acid, a bicarbonate being formed.

$$(6)\ \mathrm{Fe\ CO_3+HO_2+CO_2=FeH_2(CO_3)_2},$$

which is soluble in water. On exposure to the air the bicarbonate is decomposed, ferric hydrate being precipitated.

$$(7)\ \mathrm{2\ Fe\ H_2\ (CO_3)_2+O+H_2O=Fe_2O_3\ 3\ H_2O+4\ CO_2}.$$

This reaction has played an important part in the genesis of iron ores, and, on account of it, the streams, in the neighbourhood of deposits of carbonate ores, throw down, on exposure to the air, rusty deposits of hydrate. When solutions containing ferrous carbonate come into contact with carbonate of lime, the latter is slowly dissolved and replaced by the iron salt, or by ferric hydrate.

Solutions of Iron Salts.—Solutions of ferrous salts are pale green or colourless, those of ferric salts are usually yellow. Ferrous salts in solution are readily oxidised on exposure to the air, or by oxidising agents, such as chlorine, bromine, nitric acid, potassium, permanganate of potassium, bichromate, &c., ferric salts being formed which, in the presence of acid, remain in solution, but in neutral solutions are partially precipitated as basic salts. All the ferrous salts, except the silicates, are soluble in water or acids.

Ferric solutions are stable in air, but, if neutral, tend to deposit basic salts, and on boiling the whole of the iron may, in many cases, be precipitated. Ferric salts in solution are readily reduced by reducing agents, such as hydrogen sulphide, sulphur dioxide, nascent hydrogen, stannous chloride, &c., the solutions becoming colourless or green.

Iron Silicates.—A considerable number of ferrous silicates are known, but they are of little importance in the metallurgy of iron. They have the general formula, x Fe O, y Si O_2, and contain varying proportions of ferrous oxide and silica. When the ratio $x : y$ is greater than 2 : 1 the silicate is basic, and when less than 1 : 1, it is acid. The silicates are black in colour and fusible, the more fusible the more iron they contain. They are not readily reduced by carbon unless there be some base present to combine with the silica, which would be liberated. On being heated in air, oxygen is taken up, and a mixture of ferric oxide and silica is left.

$$(8)\ \mathrm{2\ FeO,\ SiO_2+O=Fe_2O_3+SiO_2}.$$

In an oxidising atmosphere, this mixture is refractory, but in a reducing atmosphere, oxygen is removed, and the fusible silicate is reformed.

Iron Sulphides.—Iron and sulphur combine readily at a red heat to form ferrous sulphide (Fe S). Other sulphides of iron occur in nature.

Iron Phosphides.—Iron and phosphorus combine readily when they are heated together, fusible phosphides being formed. Several of these are known, Fe_3 P being the most important. This phosphide is also formed when ferrous phosphate is heated with carbon or other reducing agent.

$$(9)\ Fe_2\ (P\ O_4)_3 + 12\ C = Fe_2\ P_3 + 12\ C\ O.$$

Silicon and Iron.—When silicon and iron are heated together or when iron oxide and silica are very strongly heated with carbon, the silica is partially reduced, and the silicon combines with the iron. A definite silicide (Fe Si) has been isolated ; it dissolves readily in molten iron and remains in solution on solidification.

Iron and Carbon.—The compounds of carbon and iron are of the utmost importance in the metallurgy of iron and steel. Only a brief reference will be made to them here, full discussion being reserved till later.

When iron and carbon are very strongly heated together the metal will take up, under suitable conditions, about 4·5 per cent of carbon. When the metal solidifies a portion of this carbon may separate in the form of flakes of graphite, or occasionally in amorphous masses (temper carbon). The amount of carbon which will separate and the amount which will remain in combination vary much according to circumstances. A definite carbide having the formula Fe_3 C, and containing, therefore, 93·3 per cent of iron, has been isolated, and exists in most varieties of iron and steel. The carbon may also exist uniformly diffused, though the iron, either in solution or as a carbide, containing a much larger proportion of iron.

When iron is dissolved in hot acid the combined carbon escapes in combination with the hydrogen as hydrocarbons, whilst the graphite remains in the insoluble residue.

Iron Alloys.—Iron alloys readily with most metals. Those alloys which are of commercial importance will be discussed later.

Iron occurs in commerce in several forms. These may be classified in various ways. The arrangement given below, though not by any means scientifically perfect, includes all varieties, and is convenient for practical purposes.

1. Cast or Pig Iron.—Iron containing over 1·5 per cent of carbon, with considerable quantities of other impurities, such as silicon, phosphorus, &c.

2. Malleable or Wrought Iron.—Iron containing not more than ·25 per cent of carbon, which has been prepared by processes in which it was welded together from pasty masses without fusion. It always contains intermixed slag and oxides.

3. Steel.—All forms of iron (except wrought iron) containing only the ordinary impurities and less than 1·5 per cent of carbon.

The varieties of steel are so many that it is impossible to frame a more satisfactory definition. Ordinary steel contains more than ·5 per cent of carbon, and becomes hard when it is heated to redness and cooled in water. Mild steel contains less than ·5 per cent of carbon, and does not sensibly harden when quickly cooled from a red heat.

There is, however, a regular gradation from the very mildest steel to the hardest tool steel, so that the difference is one of degree and not of kind, and it is impossible to draw a strict line of demarcation between the different varieties.

Mild steel is always made by fusion processes, and is, therefore, free from intermixed oxide and slag. Hard steel may be made by fusion processes (cast steel), by the cementation of wrought iron (shear steel), or by welding from pasty masses (puddled steel). The two last-named forms contain intermixed oxide and slag.

Mild steel is sometimes called ingot iron, malleable iron being then called weld iron; hard steel prepared by fusion is then called ingot steel, and that prepared without fusion weld steel. This nomenclature was proposed by an American committee, but has never come into general use.

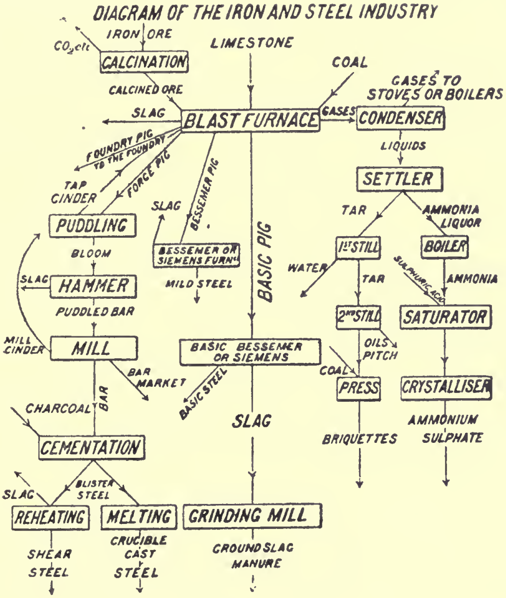

FIG. 1.

The varieties of iron and steel are so different that they might be regarded as different metals, and they must receive separate consideration.

Any variety of commercial iron can be prepared direct from the ore, or from any other, but it has become the almost universal practice to prepare pig iron first, and use that as the raw material for the preparation of the other varieties. The manufacture of pig iron will, therefore, be considered first.

Fig. 1 gives a diagrammatic view of the modern iron and steel industries.

CHAPTER II.

SOURCES OF IRON.

Iron in Nature.—Iron is the most abundant and widely distributed of the useful metals. It occurs in a very large number of minerals, sometimes as an essential, sometimes as an accessory constituent. It is present in many rocks, and in small quantities in many animals and plants. Of minerals containing iron only those which are of practical importance will be described; the student requiring further details or particulars as to the methods of recognising the minerals in the field or in the laboratory must consult a treatise on mineralogy.

Iron Minerals.

Meteoric Iron.—Native iron does not occur in sufficient quantity to be of commercial importance. Many rocks contain small quantities of the metal disseminated in minute specks, and in a few instances masses have been found which have been formed by the accidental reduction of oxides. The only other form in which native iron is found is that of meteorites. These vary in size from small fragments up to masses several tons in weight. They occur quite irregularly, and have fallen on the earth from space outside. They vary very much in composition, but some, known as siderites, consist almost entirely of metallic iron, whilst others, the siderolites, are composed of a mixture of metallic iron and earthy matter. The siderites are iron, always alloyed with nickel, and containing small quantities of other elements, such as carbon, phosphorus, silicon, and sulphur. The metal is white and brilliant, but the outside of the mass is usually covered with a black glaze of fused black oxide, formed by oxidation at the high temperature produced by the friction of the meteorite against the air on its way to the earth.* Meteoric iron may, in prehistoric times, have been used for the preparation of tools and weapons.

Magnetite.—$Fe_3 O_4$.—This mineral, known also as black or magnetic iron ore, has a black colour, a metallic lustre, and gives a black streak.† It is magnetic, some specimens showing distinct polarity—that is, attracting one end of a magnetic needle and

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*See the "British Museum Handbook of Meteorites," issued by the Trustees. Price 3d.

†The streak is the colour of the trail of powder left when the mineral is drawn over a hard surface, or when it is scratched with a file. The colour of the streak is often quite different from that of the mineral in mass.

repelling the other—whilst others attract either end indifferently. Its hardness is about 6, and its specific gravity 4·9 to 5·2. It is the richest of all iron minerals, pure Fe_3O_4 containing 72·4 per cent of iron. It is soluble in hot hydrochloric acid, yielding a mixture of ferric and ferrous chlorides. The chlorides formed are usually not in the molecular proportions required for the formula Fe_2O_3 FeO, sometimes the one, sometimes the other, being in excess, whence it is inferred that the mineral is Fe_3O_4, mixed with a certain amount of Fe_2O_3, or FeO, as the case may be, or else a molecular compound x Fe_2O_3 y FeO, where x and y are usually nearly unity.

Franklinite.—Fe_2O_3 (Fe Zn O).—This mineral may be regarded as being the magnetic oxide in which the ferrous oxide is completely or partially replaced by oxide of zinc. It resembles magnetite in all its properties, except that the streak is brownish, and that it is either non-magnetic, or only feebly magnetic. The zinc is often partially replaced by manganese. Franklinite occurs at Hamburg, N.J., associated with red zinc ore (ZnO).

Chromite (Chrome Iron Ore) — Cr_2O_3, FeO. — This mineral is very similar to the two described above. Its hardness is 5·5, its specific gravity about 4·5, and its streak brown. It may be regarded as being magnetite, in which all, or most of the ferric iron is replaced by chromic oxide. Its composition rarely corresponds exactly with the formula given above—ferric iron, aluminium and manganese being generally present. It is used in the manufacture of chrome irons, and is the source of the chromium of commerce.

Magnetite, franklinite, and chromite are members of a group of minerals called the spinels, which resemble one another very closely, and which have the general formula R_2O_3 RO, where R_2 may be Fe_2 Al_2 Cr_2 Mn_2, and R may be Fe Zn Mn Mg. All these elements may be present in the same sample, so that the composition of the minerals is very variable, special names being given when some one element predominates.

Ilmenite (Titaniferous Iron Ore).—The composition of this mineral is somewhat uncertain. It is usually regarded as being Fe_2O_3, in which part of the Fe is replaced by Ti, so that the formula is written $(Ti\ Fe)_2\ O_3$; on the other hand, it may, with greater probability, be regarded as a ferrous titanate (FeO, TiO_2) always mixed with ferric oxide. The proportion of iron and titanium varies very much in different specimens. It is black in colour, with a metallic lustre, and gives a black or brown streak ; its hardness is 5 to 6, and it is sometimes magnetic. Ilmenite occurs in Norway, Sweden, the United States, and Canada. The magnetic iron sands which occur with gold ores frequently contain ilmenite.

Hæmatite. — Fe_2O_3. — This mineral is very widely distributed, and occurs in many forms. It varies in colour from bright red to black, and its streak is red or reddish brown. Its hardness is about 6, though earthy varieties are often much softer, and it is occasionally magnetic. When pure it contains 70 per cent of iron. It is soluble in hydrochloric acid, ferric chloride being formed.

The most important varieties are :—

Kidney Ore.—This occurs in red or black masses, reniform or kidney shaped, usually with a metallic lustre. It is generally in masses, showing both a concentric and radial structure with an amorphous portion in the centre. The streak is red.

Specular Ore.—This mineral occurs in flat, tabular crystals, having a brilliant lustre, whence the name. When the crystals are small, and non-adherent, it is called micaceous iron ore. The streak is reddish brown.

Red Raddle (Red Ochre, &c.).—The mineral in this form has a fine red colour, and is often soft enough to soil the fingers.

Limonite (Brown Hæmatite). — 2 Fe_2O_3, 3 H_2O. — This mineral occurs in amorphous, stalactitic, or reniform masses, sometimes with a distinct radial structure. Its colour varies from black to brown ; the lustre may be sub-metallic or dull, and the streak is brown. The hardness is about 5 to 5·5, though the earthy forms are much softer. It contains, when pure, 60 per cent of iron and 14·4 per cent of water, the water is readily expelled on gentle heating, ferric oxide being left. It is readily soluble in hydrochloric acid.

Göthite—Fe_2O_3, H_2O—and **Turgite**—2 Fe_2O_3, H_2O.—These hydrates are intermediate in composition and properties between hæmatite and limonite. They are black or brown in colour, and give a dark brown streak.

Siderite (Chalybite ; Spathic Iron Ore).—$FeCO_3$.—This mineral occurs in amorphous, botryoidal or crystalline masses. The crystals are very flat rhombohedra, the faces often being curved. Its colour is grey or buff, with a pearly lustre, and the streak is white. Its hardness is about 4. It is readily soluble in acids with effervescence, ferrous salts being formed. When pure it contains 48·3 per cent of iron, but this is almost always partially replaced by manganese. On exposure to air and moisture it is rapidly converted into hydrate, the action commencing at the surface, and in time extending through the whole mass.

Pyrites—FeS_2.—This is the most abundant and widely distributed of the iron minerals. It has a brass yellow colour, and a metallic lustre, and gives a black streak. Its hardness is about 6, and its specific gravity about 5. When struck with a steel edge it throws off sparks with a distinct odour of burning sulphur. It occurs in granular masses, often of very large size, in rocks of various ages, sometimes in isolated crystals or groups of crystals (cube or pentagonal dodecahedron), in layers in coal, and in nodules with a radiating structure or replacing shells, or other animal remains. When pure it contains 53·3 per cent of sulphur. It is largely burned for sulphur in the manufacture of sulphuric acid, and is therefore often called sulphur ore. It very often carries copper and gold.

Exposed to moisture it oxidises rapidly, evolving a considerable amount of heat, and expanding so much that it frequently breaks up the rock containing it. The oxidation is somewhat complex. Ferrous sulphate is formed, and sulphur separated

$$(10)\ FeS_2 + 4\ O = FeSO_4 + S.$$

On further exposure basic ferric sulphate is formed, and sulphuric acid is liberated, so that the washings from oxidising pyrites are strongly acid.

Marcasite (White Iron Pyrites).—$Fe\ S_2$.—This mineral has the same composition as pyrites, but is paler in colour, and oxidises much more readily.

Whilst Iron Pyrites and Marcasite have the same empirical formula, there is no doubt but that the inner structure of the two is different.

Pyrrhotine (Magnetic Pyrites)—$Fe_n\ S_{n+1}$ usually approximating to $Fe_7\ S_8$.—This mineral is similar to pyrites. It contains less sulphur, and specimens vary much in composition. Its colour is somewhat darker than that of pyrites. Its hardness is about 4, and it is magnetic.

Mispickel (Arsenical Pyrites)—FeAsS.—This mineral is white in colour, has a metallic lustre, and a hardness of about 6. It gives sparks when struck with a steel, and a distinct odour of sulphur dioxide and arsenious oxide.

IRON ORES.

In order that a deposit may be considered as an ore of a metal, it must contain the metal in such quantity and in such condition that it can be profitably extracted. Hence a deposit of mineral may or may not be an ore according to the condition in which it occurs ; its abundance, its purity, the means which exist for transport, &c., and a deposit, at one time valueless, may at another, under changed conditions, become valuable.

All iron ores contain one or more of the minerals already described mixed with more or less non-ferrous earthy material or gangue. Hand specimens may often be obtained quite free from gangue, but in mass the gangue is always present in larger or smaller quantity, and therefore the percentage of iron in the ore will always be less than in the mineral, which is its essental constituent. The richness of iron ore depends on the composition of the mineral and on the amount of gangue with which it is mixed.

CLASSIFICATION OF IRON ORES.

Iron ores may be classified in various ways, but the most convenient for purposes of study is that based on the nature of the mineral they contain.

1. Oxide Ores.—The iron is present as oxide with or without water of combination.

- (*a*) *Black Ores* :—
  - α—Magnetites contain magnetite.
  - β—Franklinites contain franklinite.
  - γ—Chrome ores contain chromite.
  - δ—Titaniferous ores contain ilmenite.
- (*b*) *Red Ores* contain hæmatite.
- (*c*) *Brown Ores* contain limonite, göthite or turgite.

2. Carbonate Ores.

- (*a*) *Spathic Ores* contain siderite with but little clay or bituminous matter.
- (*b*) *Clayband Ores* contain siderite, with a considerable amount of clayey matter.
- (*c*) *Blackband Ores* contain siderite, with but little clay, but a considerable amount of bituminous matter.

Magnetites.—There are no workable deposits of magnetite in Great Britain, though small quantities occur in Cornwall and elsewhere. The principal European deposits are those of Norway and Sweden. There the mineral occurs in masses often of great size in granite, gneiss, slate, and other metamorphic rocks, probably of Laurentian or Cambrian age. Most of these ores are nearly free from sulphur and phosphorus, and the gangue is of such a nature as to be easily fluxed away. Hence, they are very valuable iron ores. Some Scandinavian magnetites contain sulphur and phosphorus ; these, however, are not exported. Magnetites occur in considerable abundance in Canada and the United States. As a rule, magnetites are fairly free from sulphur and phosphorus, but this is by no means always the case, some deposits containing a considerable quantity of pyrites, which much diminishes their value. Several deposits of magnetites exist on the Mediterranean coast of Spain, some of which are now being worked.

Franklinites.—These are only worked in one locality, viz. : New Jersey, U.S.A.

Chrome Ores.—These can hardly be regarded as being ores of iron, since the quantity used for iron smelting is very small in comparison to that used for the manufacture of chromium salts. The principal sources of chrome ores are the Urals and Euobœa in the Greek Archipelago.

Titaniferous Ores.—These are of little importance. When the amount of titanium is large, they are very difficult to smelt. The best known deposits are those of Canada, which are of Cambrian age.

TABLE I.—Examples of Black Ores.

	1	2	3	4	5	6	7	8
Magnetic Oxide of Iron .	65·86	72·250	51·78	57·29	83·884	40·05	..	..
Ferrous Oxide	1·456	1·500	..	..	·548	..	..	36·63
Ferric Oxide	..	..	17·06	26·29	..	42·03	31·41	..
Zinc Oxide	..	..	..	..	..	·06	32·83	..
Manganese Oxide	·890	2·056	·15	..	Trace.	1·58	25·84	..
Chrome Oxide	..	..	..	..	..	..	..	45·13
Lime	7·620	5·200	6·20	..	·504	5·260	..	5·10
Magnesia.............	4·540	4·140	·13	..	5·290	·36	..	3·79
Alumina	1·080	2·600	·50	..	·336	·350	·21	3·17
Silica	14·38	9·784	21·80	11·12	8·651	1·45	10·21	1·87
Phosphoric Anhydride .	·002	·0009	·61	·04	·018	·008	..	..
Arsenious Anhydride ..	..	..	..	..	..	Trace.	..	..
Carbon Dioxide........	..	..	..	..	..	2·15	..	..
Sulphur	·171	·038	·08	·28	·090	..	..	..
Water, &c.	4·001	2·423	1·69	..	·690	3·70	..	..
	100·	100·	100·	95·02	100·02	96·988	100·50	95·69
Iron, per cent	48·56	53·20	49·22	59·64	60·82	58·25	21·99	28·57
Phosphorus, per cent ..	·00088	·004	·2684	·0176	·0079	·0035		

1 Dannemora.
2 Dannemora.
3 Norberg, Sweden.
4 Canada
5 Spain, Marbela.
6 Spain, Sierra de Bédar.
7 Franklinite.
8 Chrome Ore.

Red Ores, Hæmatites.—The only important British locality of these ores is Cumberland and North Lancashire. The deposits here are irregular masses or veins, mostly in carboniferous limestone, but also in silurian rocks (Water Blean) and in granite (Eskdale). The ores are brownish red to black in colour, usually hard and dense, sometimes with a metallic lustre, sometimes dull, and sometimes almost talcy. Kidney-shaped masses are common, and these are often of very large size. The ores of this district are very free from sulphur and phosphorus, and the gangue is silica or carbonate of lime. Small deposits of hæmatite occur in Cornwall, North Wales, and Staffordshire, but they are only of local importance. In Canada hæmatites occur in Devonian rocks, and in the United States they are very abundant, especially in the States of Missouri and Michigan. In the former is "Pilot Knob," a mass of hæmatite about 200 ft. thick mixed with silicious matter, and in the latter are the Lake Superior deposits, which consist of red hæmatite and specular ore lying in masses in metamorphic rocks. The gangue is mainly silica and the ores are low in phosphorus. Another important set of deposits are those known as the Clinton ores. They extend through the States of Wisconson, Ohio, Kentucky, New York, Pennsylvania, Tennessee, Georgia, Virginia, and Alabama. The ore is red hæmatite, passing sometimes into ferruginous limestone, and is of Silurio-Cambrian age. It contains too much phosphorus to be valuable for making Bessemer pig, but is now largely used for the manufacture of foundry iron. Specular ore occurs in the island of Elba, at Seriphos in Greece, and a few other places in Europe. The first-named is the only deposit of commercial importance. The Elba ores are easily worked, though they are too dense for use in small furnaces ; they are free from sulphur and phosphorus, and the gangue is mainly silica.

TABLE II.—Examples of Red Ores.

	1	2	3	4	5	6	7	8
Ferric Oxide	84·410	76·45	92·85	70·00	91·45	83·20	85·14	84·00
Ferrous Oxide	..	Trace.	..	..	2·34	..	..	..
Manganese Oxide	·320	Trace.	..	..	..	2·39	3·43	1·90
Silica	7·360	8·74	2·625	26·42	3·99	3·26	4·60	3·20
Alumina	·970	·74	1·44	..	1·40	1·57	1·32	..
Lime	·706	4·28	Trace.	1·70	·51	5·82	1·62	4·60
Magnesia..............	·110	·31	Trace.	..	·22	..	·43	..
Copper Oxide	..	..	..	..	..	..	·03	..
Carbon Dioxide........	1·090	3·20	..	1·34	..	..	·70	..
Phosphoric Anhydride .	·030	·04	·045	·20	·14	·08	·04	Trace.
Sulphur	·004	..	·040	..	..	·03	·01	..
Water	5·000	6·44	3·35	..	..	3·65	2·76	* 6·000
Alkalies	..	·1	..	..	..	..	..	..
	100·000	100·3	100·35	99·66	100·05	100·00	100·08	99·70
Iron, per cent	59·087	53·57	64·395	49·000	65·840	58·24	59·598	58·80
Phosphorus, per cent ...	·0132	·018	·0198	0·88	·0616	·0350	·0176	..

1 Cumberland, Hodbarrow.
2 Cumberland, Stank.
3 Specular Ore, Elba.
4 Nova Scotia.
5 Iron Mountain, Missouri.
6 Algeria.
7 Spain, Garruchia.
8 Spain, Campanil.

* And carbon dioxide.

Hæmatites are imported from Algeria (Mokta) and from Spain, but as most of the Spanish ores are " brown ores," they will be considered under that head, and from Cuba, the Cuban ores are arsenical.

Brown Ores.—These ores are very widely distributed, and are usually of more recent date than the red or black ores, and in many cases they have been produced by the surface oxidation of carbonates under the influence of air and moisture. In Great Britain they occur in the Forest of Dean in carboniferous limestone, in Northamptonshire as surface deposits produced by the oxidation

TABLE III.—Examples of Brown Ores.

	1	2	3	4	5	6	7	8
Ferric Oxide	60·91	89·76	52·20	62·43	79·270	76·750	79·460	77·270
Ferrous Oxide	..	..	..	4·75	..	..	..	·50
Manganese Oxide	Trace.	·04	..	·28	·900	·060	2·390	..
Lime	1·60	·49	7·13	2·80	Trace.	·150	2·340	·45
Baryta	..	..	..	..	..	..	·310	..
Magnesia	·06	·40	·57	·59	·150	·250	·544	Trace.
Alumina	8·03	·63	7·64	10·19	1·100	4·200	·274	1·89
Copper Oxide	..	..	..	..	..	..	..	07
Lead Oxide	..	..	..	..	..	..	..	1·59
Silica	13·24	1·570	15·15	8·40	8·88	7·415	7·250	6·720
Phosphoric Anhydride	1·02	·13	1·26	..	·027	·105	·036	·064
Arsenious Anhydride	..	..	..	..	..	..	..	1·24
Antimony Oxide	..	..	..	..	..	..	..	·13
Carbon Dioxide	..	..	4·92	..	..	..	..	..
Sulphur	·03	..	..	..	·012	·180	·111	·520
Water, &c.	15·35	7·05	11·37	10·36	10·30	10·80	7·040	7·350
	100·24	100·07	100·24	99·80	100·629	99·905	99·755	97·794
Iron, per cent	42·64	62·83	36·54	47·4	55·49	53·73	55·62	54·47
Phosphorus, per cent	·4488	·0572	·5544	·0118	·0118	·0462	·0158	·0281
Arsenic	..	..	..	..	..	..	..	·808

1 Lincolnshire.
2 Forest of Dean.
3 Wellingborough.
4 Antrim.
5 Spain, Rubio.
6 Spain, Santander.
7 Spain, Garruchia.
8 Spain, Rio Tinto.

of carbonates, and in Lincolnshire they form very similar deposits. All these are of secondary age. These ores all contain a considerable quantity of phosphorus, and are therefore not suitable for making Bessemer pig. The gangue usually contains a good deal of lime and but little silica. The ores are usually soft and friable, though there is every gradation between hard brown hæmatite, and soft, incoherent bog iron ore.

In Antrim an ore occurs containing a large quantity of alumina, replacing ferric oxide ($x\ Fe_2O_3\ y\ Al_2O_3 z\ H_2O$). This Irish aluminous ore is usually nearly free from phosphorus, and is valuable where an aluminous flux is required. When the quantity of iron is small, it is called bauxite, and is used as a source of aluminium.

Spanish Ores.—These ores are now of enormous importance to this country, and are very largely imported. The deposits which have been most extensively worked up to the present are those in the neighbourhood of Bilbao. These have for many years yielded about 3,000,000 tons of ore a year. The ores raised are of four kinds :

(1) *Campanil.*—This is a red ore. It is dark red or purple in colour, fairly hard, and contains about 55 per cent of iron. The gangue is mainly carbonate of lime (which often occurs in large opaque white crystals) with but little silica. This is the variety most in demand, but is now becoming scarce.

(2) *Rubio.*—This ore is yellow or brown in colour, and may be soft or hard. The lumps often have a very vesicular character, and hollow nodules are common. It contains a good deal of water, about 50 per cent of iron, and the gangue is silicious.

(3) *Vena.*—This ore is dark purple in colour. It is very soft, and contains about 60 per cent of iron. It only occurs in small quantity.

(4) Carbonate ores occur, and are calcined before export.

All these ores are nearly free from phosphorus, and largely used in the manufacture of Bessemer pig, and Campanil is a favourite ore for use in the Siemens steel process.

Iron ores are also abundant on the south coast of Spain, and there deposits are now being worked on a considerable scale, and there is no doubt that in the near future the output from this district will be enormously increased.

Among the more important of these ores may be mentioned :

Porman.—This ore occurs near Carthagena. It is a dark red ore, sometimes containing magnetite. The gangue is silica. It is fairly free from phosphorus, and contains about 55 per cent of iron.

Almeria.—This ore is hæmatite. It contains but little sulphur or phosphorus.

Aguilas.—This is a red hæmatite containing about 50 per cent of iron and very little phosphorus, with a silicious gangue.

Garruchia.—Both red and brown hæmatites occur. They are nearly free from sulphur and phosphorus.

Marbella.—This ore, which occurs near Malaga, is a magnetite of excellent quality, with a silicious gangue.

Sevilla.—These ores are brown and red hæmatites, nearly free from phosphorus, containing about 60 per cent of iron, with a silicious gangue.

Huelva.—This is a hæmatite ore, but contains arsenic.*

Spathic Ores.—These ores consist essentially of ferrous carbonate. The only deposit of pure spathic ore in Great Britain is that of the Brendon Hills, in Somersetshire. This ore is a massive carbonate of a buff colour containing 13 per cent or 14 per cent of manganese oxide, occurring in rocks of Devonian age and a smaller deposit occurs at Weardale, in Durham. Spathic ores are often associated with lead and zinc ores. There is a vast deposit, forming a bed of some 500 ft. thickness, in Erzberg, in Styria.

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*For further particulars see Wilson "Iron Ores of the Mediterranean Seaboard," "Journal of the Iron and Steel Institute," vol. ii., 1894.

Impure spathic ores are much more abundant. As already mentioned, the Northamptonshire brown ores are oxidised carbonates, and at a moderate depth the unaltered carbonate is reached. It is a soft, granular, oolitic mass of a yellowish-green colour, and very frequently occurs in nodules. It contains 60 per cent to 70 per cent of ferrous carbonate, in the form of oolitic concretions, the gangue being mainly silica. Phosphorus is present in considerable quantity.

Spanish Carbonates.—Carbonate ores occur at Bilbao, underlying the Rubio (which is probably an altered carbonate), and are known as *cabonado de hiero.* Until recently these have only been worked to a very limited extent, but considerable quantities are now being exported. The ore is calcined at the mine, so as to reduce the weight. Being free from sulphur and phosphorus, it can be used for the manufacture of hæmatite iron.

Cleveland Ores.—These are the most important of the spathic ores of this country. They occur in the district of Cleveland, in the north of Yorkshire, not far from Middlesbrough, where they are smelted on a large scale. The deposits are of lias age, and consist of beds of ironstone separated by bands of shale, having an aggregate thickness of about 20 ft. The two principal beds are known as the Avicula and the Pecten beds, on account of the abundance of these shells in them. The ore forms a granular or oolitic mass of a greenish colour, not unlike the Northamptonshire carbonates, and consists mainly of ferrous carbonate, with some ferrous silicate, and a good deal of carbonate of lime. The deposits are very fossiliferous, and therefore contain a good deal of phosphorus. The ore yields about 30 per cent of iron.

Clayband Ironstone.—This is an impure carbonate, which occurs abundantly in the coalfields of South Wales, Yorkshire, North and South Staffordshire, Shropshire, and Derbyshire. The deposits consist of carbonate of iron, mingled with clay or shale. Sometimes the ore is distributed evenly through the beds, but very frequently it is aggregated into concretionary nodules. The ore may be of any colour from white to black, this depending on the nature of the intermixed clay, and it usually looks like a fine-grained shale, but is much denser. Being fossiliferous, phosphorus is always present. The ores, as raised, contain about 30 per cent or less of iron.

Blackband Ironstone.—This ore was discovered by D. Mushet, in 1801, in the Lanarkshire coalfield, it having been previously called by the miners "wild coal," and thrown away as useless. It consists of carbonate of iron mixed with a considerable quantity of coaly matter—often enough to render it combustible—with or without clay. It is usually black or brown in colour, and frequently has a distinctly banded structure. Many beds of this ore seem to be seams of coal which have become impregnated with carbonate of iron, and in some cases beds of blackband ironstone have been observed to pass gradually into coal. Blackband ores may contain up to 35 per cent of iron and they are high in phosphorus.

Unfortunately the Lanarkshire blackband is rapidly becoming exhausted. Blackband ironstones occur in small quantities in North Staffordshire and in South Wales.

TABLE IV.—EXAMPLES OF CARBONATE ORES.

	1	2	3	4	5	6	7	8
Ferrous Oxide	37·80	43·84	29·89	50·18	30·96	36·75	47·85	46·53
Ferric Oxide	2·56	·81	..	5·31	1·15	1·19	1·51	·65
Manganese Oxide	·46	12·64	..	1·00	·73	·31	·35	2·54
Alumina	10·46	..	2·11	..	26·50	5·30	1·10	1·22
Lime	5·90	·28	10·96	·870	9·34	2·69	1·46	2·44
Magnesia..............	3·71	3·63	2·44	3·21	1·84	5·18	3·16	1·33
Silica	11·53	·08	23·49	3·60	3·11*	9·73	1·58	1·93
Carbon Dioxide........	20·30	38·86	30·37	36·28†	22·13†	30·66	33·68	30·45
Phosphoric Anhydride .	1·13	..	·74	..	·26	·59	·58	·69
Sulphur	·31	..	Trace.	Trace.	·10	·13	·30	·16
Carbonaceous Matter ..	1·05	..	..	..	·10	6·57	7·69	10·47
Water	4·52	·18	..	..	2·39	·89	·58	1·47
	100·00	100·32	100·00	100·45	99·61	99·99	99·84	99·92
Iron, per cent	31·27	33·87	23·31	42·85	24·94	28·50	38·38	36·33
Phosphorus, per cent ..	·497	..	·326	..	·114	·260	·256	·304

1 Cleveland Ore.
2 Brendon Hills.
3 Northamptonshire.
4 Bilbao.
5 Clayband.
6 Clayband, Scotch.
7 Blackband, Scotch.
8 Blackband, Staffordshire.

* And alumina. † And water.

Sulphide Ores.—Ores containing large quantities of sulphides are of no value for the direct extraction of iron, but pyrites is used in large quantity for the manufacture of sulphuric acid. The residue after burning out the sulphur is called "Blue Billy," or "Burnt Ore," and is occasionally used for smelting, but as it always retains a considerable quantity of sulphur, it is not well suited for the purpose. After the extraction, by the wet process, of all copper that may be present a finely-divided residue or "purple ore" is left, which is free from sulphur. It is in too fine a state of division for direct smelting, but it is moulded into bricks and then used in the blast furnace. In the state of powder it is used for stopping the bells of the blast furnace, and for fettling puddling furnaces.

GEOLOGICAL DISTRIBUTION OF IRON ORES.

As will have been noticed from the instances already given, iron ores occur in rocks of many ages. The magnetites of Sweden, and of many other localities, are probably of Laurentian or Cambrian age, and therefore perhaps the oldest deposits in the world and the rocks have undergone considerable metamorphism. The ores of Furness and many other hæmatite districts are in silurian or carboniferous limestone rocks.

The spathic ores of the Forest of Dean and some claybands and blackbands belong to the carboniferous limestone period, whilst most clay and blackband ironstones occur in the coal measures. Many of the brown and carbonate ores are in secondary rocks, such as the oolite and the lias, whilst some bog ores belong to the recent period. As a general rule, though there are many exceptions, black and red ores belong to the paleozoic, and brown ores to the mesozoic, period.

In most cases it is only possible to decide the age of the rocks in which the ores occur—not of the ores themselves—for usually the ore was not formed when the rock was laid down, but has been produced subsequently by other changes. The Forest of Dean ores, for instance, occupy caverns in carboniferous limestone, so that not only must the rock have been deposited, but the caverns must have been formed by solution of the rock before the ore was deposited. The hæmatite ores of the Furness district exist both silurian and carboniferous limestone rocks. If, therefore, they are all of the same age, they must be, at least, as recent as the carboniferous limestone.

It has been stated, as a rule, that the older the ore is the less phosphorus and sulphur will it contain. This, however, is not borne out by facts, and there seems to be no relation between the age of an ore and its freedom from deleterious impurities.

Geographical Distribution of Iron Ores.

Great Britain.—Iron ores are very abundant in Great Britain. They are, however, mainly impure carbonates of poor quality, only suitable for making foundry pig. The only British ores pure enough for the production of Bessemer pig are those of Cumberland and Furness. Large quantities of Spanish and other ores are therefore imported.

Europe.—Iron ores are abundant in various parts of Europe. Those of Spain and Scandinavia have already been described. Belgium, Germany, and France have considerable deposits, mostly brown or carbonate ores, which are used locally, but are only exported to a very small extent. Russia also has an abundance of iron ore.

America.—America is specially rich in iron ores. Canada has an abundance, those of Nova Scotia being probably the most important. The Canadian ores include clayband ironstones, brown and red ores, magnetites, and titanites. Up to the present they have not been extensively worked. In Newfoundland there are extensive deposits which are being worked on the Canadian boundaries.

In the United States iron ore deposits are largely developed.

All varieties of ore occur, but only the richer hæmatites and magnetites are worked. In South America but little has been done. There are large deposits in Brazil which have been but little worked.

The following analyses of the ores from the Lake Superior Region may be of interest :—

	Vermillion Range.	Gogetic Range.	Meriomac Range.	Mesabi Range.	Marquette Range.
Iron	65·01	60·72	56·29	63·22	61·52
Phosphorus	·08	·05	·08	·04	·09
Silica	3·89	3·63	11·77	3·77	6·48
Manganese	·04	2·44	·23	·59	·36
Alumina	1·20	1·49	1·27	1·21	1·99
Zinc	·48	·11	1·61	·41	·71
Magnesia	·17	·11	1·82	·12	·49
Sulphur	Trace.	·01	·004	Trace.	·014
Organic matter and Volatile	2·22	9·00	3·93	10·70	2·30

Asia and Australia.—The iron deposits of Asia have been very little explored. India has valuable magnetites—which are said to resemble those of Sweden—and hæmatites, and the coal measures contain ironstones. None of these deposits have been extensively worked. Deposits of iron ore occur in New South Wales, Victoria, and Tasmania. They are mainly magnetite, and red and brown hæmatites, and though but little has been done with them up to the present, they promise to be of great importance in the future.

Africa.—The ores of Algeria have already been mentioned; they are largely imported into Europe for making Bessemer pig. Iron ores have been found in South Africa, but they are at present entirely undeveloped.

IMPURITIES IN IRON ORES.

Impurities present in an iron ore may either be in the mineral itself or in the intermixed gangue, and in the latter case they may be sometimes separated by dressing. The most important impurities are (1) sulphur, which may be present as intermixed pyrites ($Fe\ S_2$), or as calcium sulphate, and (2) phosphorus (usually stated in analyses as phosphoric anhydride (P_2O_5), which is present as calcium phosphate ($Ca_3\ P_2\ O_8$), or as ferrous phosphate ($Fe_3\ P_2\ O_8$). Arsenic is sometimes present, especially in some Spanish and Cuban ores. Antimony is less frequent; copper, lead, and zinc are often present; and gold and some of the rare metals are occasionally met with.

VALUE OF IRON ORES.

The value of an iron ore depends primarily on the amount of iron which it contains, but it is not directly proportional thereto, the value increasing or decreasing more rapidly than the percentage of iron.

Increase in the percentage of gangue, or, what comes to the same thing, decrease in the percentage of iron, involves additional expense in many ways, and thus decreases the value of the ore by a larger amount than that due merely to the absence of the iron.

This additional expense is due to :—

(1) Increased cost of carriage, it costing as much to carry a ton of poor as of rich ore, so that the cost per ton of iron will be greater in the former case.

(2) Increased cost of raising the material to the furnace top and charging.

(3) Increased wear and tear of the plant, as the poorer the ore the more will have to be handled for each ton of iron.

(4) Increased cost of fluxes required to flux away the gangue.

(5) Increased fuel required to melt the larger amount of slag produced.

(6) Increased cost of disposing of the refuse slag.

It is evident that as the amount of iron in an ore decreases, a point will ultimately be reached when the ore would only just be worth smelting if it could be obtained for nothing, and therefore it would have no commercial value. The amount of gangue which would have this effect will, of course, vary with the conditions of working. An ore raised near the furnace can be smelted profitably when it would not pay to transport it any distance, so also an ore which needs no flux—or is self fluxing—would be cheaper to work than one requiring a large quantity of limestone, and, obviously, the less the cost of handling the poorer the ore it will be just possible to work. Hence, poor ores are only used when they occur on the spot, whilst rich ones may be carried long distances, especially by sea. In this country under ordinary circumstances an ore with less than 20 per cent of iron would be valueless for smelting, whilst in America the limit is said to be about 40 per cent.

Purchase of Ores.—It is obvious that the price to be paid for an iron ore must vary with the amount of iron which it contains, and as the percentage may vary very considerably in ores from the same mine there must be some agreement as to the basis of value. In some cases, where the demand is very great, the mine owner can fix a price per ton without any guarantee as to the quantity of iron present. The usual basis, however, is a fixed price per unit for a fixed percentage, with an addition if it be higher, and a rebate if it be lower, in a fixed proportion. Such an arrangement for a hæmatite ore of good quality, for instance, might be 3d. a unit for a percentage of 55, with an addition of 4d. a unit for each unit above 55, and a rebate of 4d. a unit for each per cent below.

On these terms the value of an ore containing 55 per cent of iron would be 55 × 3 = 165d. = 13s. 9d. a ton ; one containing 60 per cent would be worth (55 × 3) + (5 × 4) = 185d. = 15s. 5d. a ton ; whilst if the ore contained only 50 per cent the value would be (55 × 3) — (5 × 4) = 145d. = 12s. 1d., and so on for other percentages, not varying too much from the standard, in this case 55 per cent.

Influence of Impurities on the Value of an Ore.—The value of an ore for many purposes is much diminished by the presence of certain impurities. For making Bessemer pig and for use in the Siemens steel process the ore must be free from phosphorus. Hence the great demand for Spanish and similar hæmatites. For making ordinary foundry pig, phosphorus up to ·5 per cent is not objectionable, whilst for the manufacture of basic pig a much larger quantity is required. The influence of the presence of impurities in an ore will depend therefore on the purpose for what the metal is to be used.

Iron Ores may be classified in various ways :—

I.—According to the Nature of the Gangue.

(1) *Silicious Ores.*—Those in which the gangue is mainly silica or silicious minerals. For example : Cumberland hæmatites and many Spanish ores.

(2) *Aluminous Ores.*—In which the gangue contains a large proportion of alumina. For example : Antrim ores.

(3) *Calcareous Ores.*—In which the gangue is mainly carbonate of lime. For example : Campanil ore.

(4) *Argillaceous Ores.*—In which the gangue is mainly clay. For example : Clay band ironstones.

(5) *Bituminous Ores.*—In which the gangue is mainly coaly matter. For example : Blackband ironstones.

The name, of course, implies only the predominance of one form of gangue, not the absence of others. A silicious ore may, for instance, also contain carbonate of lime.

II.—According to Impurities Present.

(1) *Phosphoric Ores.*—Those which contain a considerable quantity of phosphorus, say more than ·05 per cent.

(2) *Sulphurous Ores.*—Those which contain a considerable quantity of sulphur.

(3) *Manganiferous Ores.*—Those which contain much manganese.

(4) *Arsenical Ores.*—Those which contain arsenic, &c.

These classes are not mutually exclusive, a phosphoric ore, for instance, may also be sulphurous.

British Iron Ore Supply.—As the local ores become used up this country will have to depend more and more on imported ores. Owing to the long sea board and the fact that so many of the works are situated near the sea, import is comparatively easy, and the large export of coal from the iron districts by giving a return cargo tends to reduce the cost, so that foreign ores are bought so cheaply that they can compete with the local ores. The result will be that in some cases it may be cheaper to import foreign ores than to work the native deposits until there is a falling off in foreign supply. The reserves of home ore workable are estimated at:

	Tons.
Carboniferous	34,000,000,000
Secondary	5,000,000,000
Other ores	500,000,000
	39,500,000,000

The average content being 30 to 35 per cent. This gives a reserve of 13,000,000,000 tons of iron.*

At present the United Kingdom produces about 15,000,000 tons of ore per year, which is equal to about 5,000,000 tons of iron, so that the iron ore resources of the country are fully equal to the demands that the future can make upon them.

The larger proportion of these ores probably could not be worked at a profit at present, but before they are needed probably improved and cheaper methods of working will be devised, so that ores now considered useless may be rendered available.

IRON ORE AVAILABLE FOR FURNACES IN 1909.

	Tons.
Raised in United Kingdom	14,979,979
Foreign Ores Imported	6,328,623
Purple Ore from Burnt Pyrites	593,301
	21,901,903
Less Ores Exported	8,149
Total available	21,893,754

PIG IRON PRODUCED IN UNITED KINGDOM, 1909.

County.	Tons.
England :—	
Cumberland	722,869
Derby	645,660
Durham	1,112,640
Lincoln	475,091
Monmouth	334,066
Stafford	765,554
Worcester	51,374
Yorkshire (Cleveland)	2,437,464
York (West Riding)	292,274
	7,152,692

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* See Report on the Iron Resources of the World, by Dr. Anderson, International Geological Congress, Stockholm, 1910.

	Tons.
Wales :—	
Glamorgan	1,002,048
Scotland :—	
Ayr and Lanark	1,377,247
Total	9,531,987
Less Exported	1,140,695
Total available for Home Consumption	8,391,292

IRON ORE OUTPUT, 1909.

District.	Tons.
Scotland	697,276
Cumberland and Lancashire	1,558,595
Yorkshire	6,191,172
Staffordshire	902,565
Lincolnshire	2,037,363
Northamptonshire	2,875,659
Other Counties	649,369
Ireland	68,002
Total	14,979,979

IMPORTS OF IRON ORE, 1909.

Countries.	Tons.
Algeria	481,632
Australia	457
Belgium	14,673
British East Indies	5,165
France	119,159
French Isles in Pacific	5,558
Germany	1,663
Greece	261,166
Italy	7,074
Netherlands	17,688
Newfoundland	62,079
Norway	185,819
Portugal	7,654
Russia	34,771
Spain	4,725,914
Sweden	290,198
Tunis	107,526
Other Countries	427
Total	6,328,623

Iron Ore Mined, &c., in U.S.A., in Millions of Long Tons.

District.	1905.	1906.	1907.	1908.
Lake Superior	34·353	38·522	42·245	26·015
Southern States	7·175	7·450	7·585	5·900
Other States	3·050	3·265	3·125	1·875
Total Mined...............	44·578	49·237	52·955	33·790
Ore Consumed.............	45·216	50·032	50·256	33·508
Pig Iron Produced	22·992	25·307	25·781	15·936

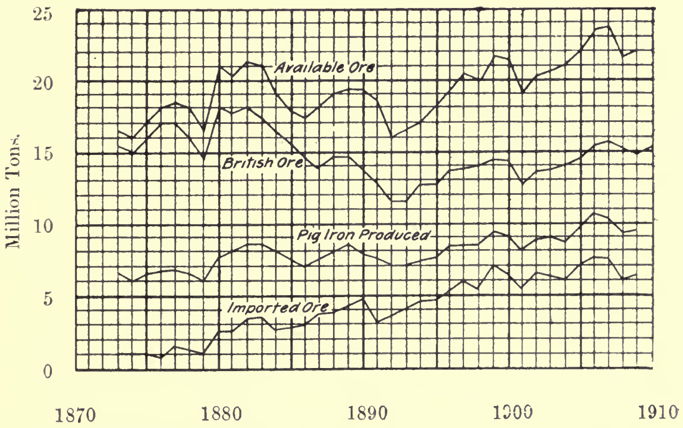

Fig. 2.—Fluctuations in British Ore and Pig Iron Production 1873–1910.

PART II.

CHAPTER III.

PIG IRON.

Properties of Pig Iron.—Pig iron may be defined as iron containing over 1·5 per cent of carbon, with a considerable amount of other impurities. The amount of iron present will usually be about 94 per cent, but it may fall below 90 per cent, or may rise to 96 per cent. Pig iron is, therefore, the most impure form of commercial iron. It is readily fusible, some forms giving a very fluid, easily flowing liquid, whilst others, in the fused condition, are more or less viscous. The specific gravity of pig iron is about 7·5, but it varies considerably in different samples, a grey iron has a much lower specific gravity than the same iron when chilled. The melting point is usually given as 1,200 deg. C. (2,192 deg. Fah.), but this also varies with the composition of the iron.

Impurities in Pig Iron.—The foreign elements present in pig iron are carbon and silicon, which may be regarded as essential constituents, since they are always present in considerable quantity, and unless they were present the metal would not be pig iron, and sulphur, phosphorus, arsenic, manganese, copper, and more rarely other elements, which may be regarded as accidental constituents or impurities, since they may be absent or present in very varying quantities, and even if they were entirely absent the metal would still be pig iron.

Carbon.—The amount of carbon present in ordinary pig iron varies from 1·5 to 4·5, usually being about 3·5, though some alloys, which, however, cannot properly be called pig iron, may contain much larger quantities. When iron is melted in contact with carbon, carbon is absorbed till about 9 per cent may be taken up on solidification. Up to 4·5 per cent may be retained, but the presence of other elements in the iron may increase or decrease the quantity which can be held in the solid iron.

When ordinary pig iron is dissolved in dilute acid part of the carbon which it contains escapes in combination with the evolved hydrogen, and part remains in the insoluble residue as black flakes. The carbon, which is carried off with the hydrogen, is no doubt present in combination with the iron, and at the moment of liberation it is attacked by the nascent hydrogen liberated at the same time, and converted into gaseous or liquid hydro-carbons. This carbon is called combined carbon. The carbon, which is not acted on by acids, is not in combination, but is scattered through the mass in the form of black flakes of graphite. It is therefore called graphitic carbon.

Combined Carbon.—This is one of the most important constituents of pig iron, and has great influence in determining its character. It may vary from about ·1 per cent, or even less in a very grey iron, to 3 per cent or more in hard white iron.

Turner gives the following percentage of combined carbon as being suitable for various purposes :—*

Extra soft silicious grey pig	·08	per cent.
Soft cast iron	·15	,,
Maximum tensile strength	·47	,,
Maximum transverse strength	·70.	,,
Maximum crushing strength	1·00	,,

It will be seen that increase in the amount of combined carbon gives increased hardness, and up to a certain point increased strength. The combined carbon is usually present as a definite carbide Fe_3C, but if the iron has been quickly cooled it may be present in another form.

Graphitic Carbon.—This has decidedly less effect on the properties of the iron than the combined carbon, though the presence of the flakes of graphite, by interfering with the homogeneity of the metal, weakens it. As a rule, soft irons contain much graphite, hard irons little or none, the actual quantity varying with the total amount of carbon present. It is sometimes stated that soft irons contain more carbon than hard irons ; this, however, is by no means always the case. In some cases part of the graphitic carbon is present not in flakes, but in minute amorphous grains, as in the case of the " black heart " irons.

Silicon.—This element is always present in pig iron, and, unlike carbon, it seems capable of being taken up in unlimited quantity, pig iron containing 10 to 15 per cent of silicon being regularly made. Silicon is known in several allotropic modifications, and from its great similarity to carbon it has often been thought that it, too, should occur in iron in two forms, combined and graphitic. The existence of graphitic silicon in pig iron has not been proved, all attempts to obtain it having failed. The amount of silicon in ordinary pig iron varies from 1 per cent or more, rarely less, to about 3·5 per cent, though sometimes it is considerably higher. When the amount of silicon reaches 5 per cent the metal is hard and brittle, and breaks with a fracture having a bright, almost glassy, lustre ; it is therefore called glazed iron.

Silicon has very great influence on the properties of pig iron, and for all purposes its presence in small quantities is advantageous,

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* " Iron," p. 191.

though the percentage which is best varies with the qualities required in the iron. The percentage which gives the best results for certain qualities is given by Turner :—*

For	crushing strength..............	·80 per cent.
,,	modulus of elasticity	1·00 ,,
,,	specific gravity (in mass)	1·00 ,,
,,	tensile strength	1·80 ,,
,,	softness and general working qualities	2·50 ,,

Within limits, therefore, the presence of silicon is decidedly advantageous, but any increase above the figures given for the maximum of each property causes a very rapid decrease.

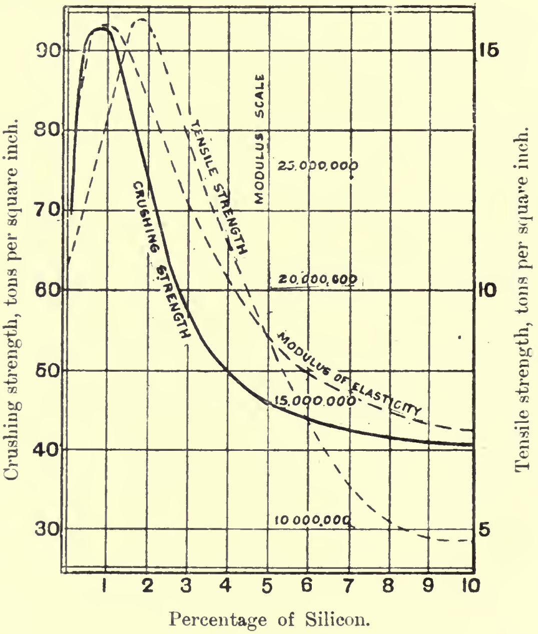

Fig. 3.

The curve, Fig. 3, from Turner's paper, gives a good idea of the influence of varying quantities of silicon on the strength and hardness of the metal. Whilst these figures and the curve are only strictly true for iron of the same composition as that with which the experiments were made, there is no doubt that the principle will hold good with all irons, though the exact percentage which would give the maximum strength may vary somewhat.

The influence of silicon on the properties of pig iron is two-fold, direct and indirect. The direct action is in the direction of making

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*J.C.S., xlvii., p. 912.

the metal hard and brittle, the silicon dissolving in the iron, but until the quantity of silicon becomes large this action is overshadowed and completely hidden by the indirect action. The presence of silicon tends to throw the carbon out of the combined and into the graphitic condition, thus reducing the amount of combined carbon and softening the metal, this softening effect being greater than the direct hardening action of the silicon, so that the first action of the silicon is, apparently, to soften the iron.

Silicon also tends to prevent the absorption of sulphur by fused pig iron, and therefore irons high in silicon are usually low in sulphur.

Sulphur.—This element is always present in small quantities, rarely above ·15 per cent. The tendency of sulphur seems to be to throw the carbon into the combined condition, and thus to make the metal hard and white ; its influence, therefore, being exactly opposite to that of silicon. Sulphur is a very objectionable element in pig iron. If more than ·05 per cent be present the metal is not suitable for use in steel making, and even for foundry work it tends to give unsound castings.

Phosphorus.—This element is always present in pig iron in quantities varying from a mere trace up to 3 or 4 per cent. Phosphorus tends to impart fluidity to the metal, and therefore is advantageous in iron to be used in making fine castings. When present in larger quantity than ·5 per cent it somewhat reduces the tensile strength of the iron, and when it reaches 2 per cent the metal becomes hard and brittle. Phosphorus does not seem to exert any very decided influence on the condition of the carbon,but by delaying solidification it tends to allow the separation of a larger proportion of the graphite, and thus indirectly may soften the metal.

Manganese.—This element is usually present in small but varying proportions, rarely exceeding 2 per cent, except in specially prepared manganiferous irons. Its presence, even in small quantity, favours the elimination of sulphur, and hardens the metal. Large quantities increase the power of the metal to take up carbon. The influence of manganese, up to about 1·5 per cent, on the properties of iron is very slight, though its tendency is to harden and make it more brittle, and to increase the shrinkage during cooling, the action being more marked the lower the percentage of silicon which is present.

Aluminium.—This element is never present in pig iron, but suggestions have been made to add it, but the results have not been such as to lead to its general use. Its action is very similar to that of silicon, it seems to increase the strength and decrease shrinkage, and if it rises above two per cent to diminish the total carbon.

Other Elements.—Titanium, copper, arsenic, lead, tin, and other elements are sometimes present, usually in very small quantity, and they have little influence on the character of the pig.

VARIETIES OF PIG IRON.

Several varieties of pig iron are made to meet the needs of the various branches of the iron and steel industry, and of engineers.

Hæmatite or Bessemer Pig.—This contains very little phosphorus and sulphur, and is mainly used in the manufacture of mild steel, and occasionally for foundry work; it is always made from materials which contain little phosphorus and sulphur. The sulphur should not exceed ·02 per cent, or the phosphorus ·05 per cent.

Basic Pig.—This is pig iron made for use in the basic steel process. It is very low in silicon (less than 1 per cent), and contains from 1·5 to 4 per cent of phosphorus.

All-mine Pig is pig iron made without the addition of cinder (or slag). The term is only used in Staffordshire.

Cinder Pig is pig iron made from a charge containing a good deal of slag from puddling or re-heating furnaces. It is always high in phosphorus.

Cold-blast Pig.—All ordinary pig irons are now made in furnaces supplied with hot air, but for special purposes irons made with cold air are preferred; these are called cold-blast irons. They are usually low in silicon. Strictly speaking the name should indicate only the method of manufacture, without reference to the quality of the metal. Charcoal-cold-blast iron is iron made in furnaces with charcoal as a fuel and with a cold blast. Cold-blast irons are now made only to a very small extent in this country. The following is an analysis of a cold-blast pig:—

Combined Carbon	0·50
Graphite	2·50
Silicon	·93
Phosphorus	·45
Sulphur	·08
Manganese	·56

Foundry Pig.—This is the variety of pig which is used in the foundry for the preparation of iron castings. It varies very much in composition, according to the nature of the ore from which it is made. It usually contains from ·7 to 1·2 per cent of phosphorus, 3 to 4 per cent of carbon, 2 to 3·5 per cent of silicon, and the usual other constituents. The varieties of foundry pig are further distinguished by the locality where they are made; thus Middlesbrough pig is made in Middlesbrough from Cleveland ores, Scotch pig in Scotland, and so on. This geographical classification was of great importance years ago when only local ores were used in each district, but it is of little value now, as imported ores are largely used either alone or in admixture with those raised in the district. Pig iron is also often marked with the name of the works where it is made, *e.g.*, Gartsherrie, Glengarnock, &c., or the maker's name or other brand. Some brands have a high reputation, and fetch a higher price in the market than others. In many cases this is due not so much to any superiority in the pig as to the reputation acquired by the brand in the past, and whilst some makers use every means to secure uniformity of composition, so that their iron shall be always the same, others pay very little attention to this. As a general rule the brand is of little value in indicating the quality or composition of the iron.

The following, from an "Iron Trades Circular," will give an idea of the relative prices of the various kinds of pig iron, though it must be remembered that the prices are constantly fluctuating, and that they do not vary in the same ratio, and that the cost of carriage to the place where the metal is to be used must be added, so that it is often cheaper to buy an expensive iron from a works close at hand than a less costly one from a distance :—

PRICE OF PIG IRON. 26TH MAY, 1911.

Cleveland,	No. 1	50/6
,,	No. 3	47/–
,,	No. 4	46/6

	No. 1.	No. 3.	No. 4.
Gartsherrie	61/6	56/6	..
Coltness	81/–	58/6	..
Summerlee	62/6	57/6	..
Langtown	63/–	58/–	..
Clyde	60/–	55/–	..
Carnbroe	59/6	55/6	..
Glengarnock	63/6	58/6	..
Dalmellington	56/6	54/6	..
Carron	62/–	57/–	..
Lincolnshire	..	52/6	50/–
Derbyshire	..	53/6	51/–
Cumberland hæmatite	65/–	..	..
Welsh hæmatite	68/6	..	..
Staffordshire	57/–	52/6	49/–
Staffordshire, cold blast	115/–	..	..
Northampton	..	54/–	48/–
Notts.	..	56/6	52/–

GRADING OF PIG IRON.

Pig iron of any variety is divided into a series of grades. The grading varies in different districts, the most common classification being Nos. 1, 2, 3, and 4, mottled and white, No. 4 being often subdivided into No. 4 foundry and No. 4 forge. Nos. 1, 2, 3, and 4 foundry are called foundry pigs, the others are forge pigs. In Staffordshire the grades used are Nos. 1, 2, 3, 4, 5, 6, 7, and 8, and in America Nos. 1, 2, 3, 4. 5, 6, 7, 8, 9, and 10, the last number in each case being white

A pig of iron is broken across and the grade is judged from the appearance of the fracture. This method of grading, depending as it does on the judgment of an individual, though almost universal, is most unsatisfactory. There is no recognised standard for any number, and, therefore, the grading at different works, or at the same works at different times, is by no means uniform. The extremes, No. 1 and white and mottled, are sufficiently well marked, but the intermediate grades are quite uncertain ; a pig might quite readily be called No. 1 by one man and No. 3 by another. In many works no No. 2 is made, and, as the number of the iron made is not under complete control, this means that any which should be No. 2

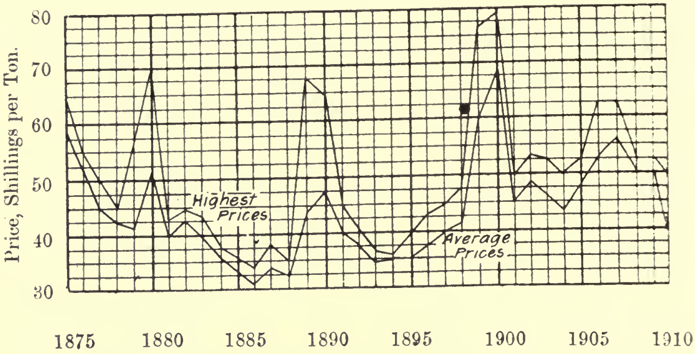

FIG. 4.—Fluctuations in Price of Cleveland Pig Iron, 1875–1910.

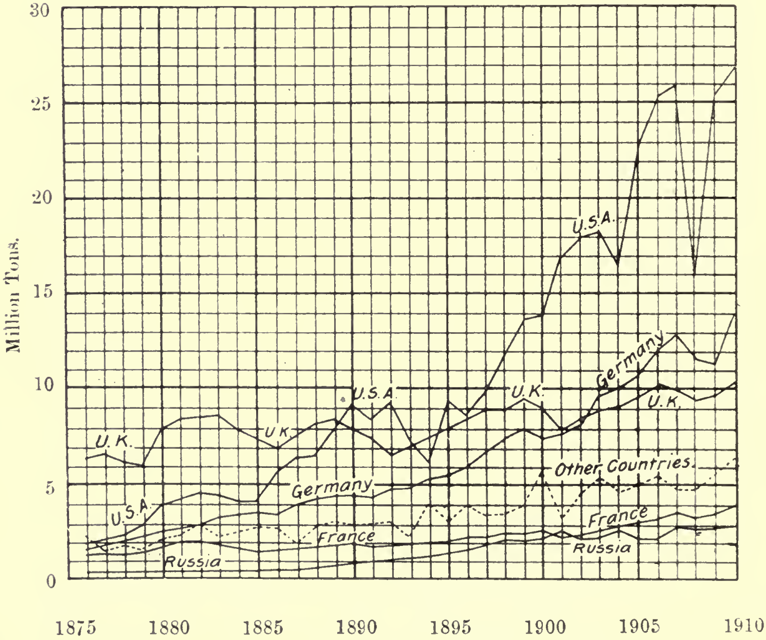

FIG. 5.—Pig Iron Produced in Principal Countries of the World, 1876–1910.

is called either 1 or 3, according to circumstances. At one works No. 2 is made, but No. 3 is classified into—No. 3 Hard, No. 3 Medium, No. 3 Soft. Nos. 1 to 4 are often called grey irons, to distinguish them from mottled and white.

Fig. 6.—No. 1 Iron.

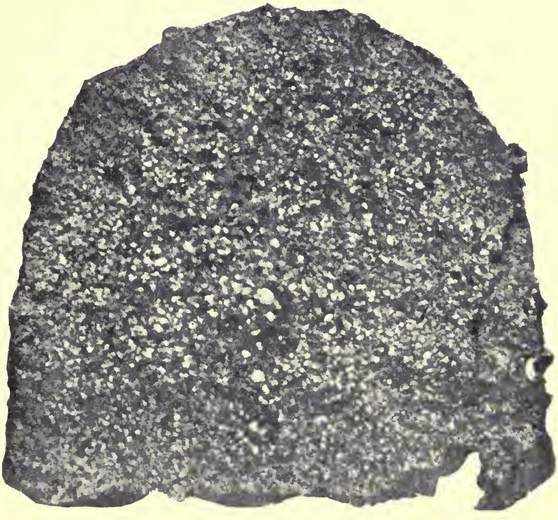

Fig. 7.—No. 3 Soft Iron.

No. 1 Pig Iron.—The pigs of this grade break with a highly crystalline fracture, which is largely made up of black flakes of graphite. It is soft and weak, having a tensile strength of about

7 tons; it melts to a very fluid liquid, which runs into the finest interstices of the moulds, and so can be used for making the finest castings; it gives no sparks or splashes as it pours from the ladle,

Fig. 8.—No. 3 Special Iron.

Fig. 9.—No. 3 Foundry Iron.

and, as it cools, a thick scum or kish separates and comes to the surface. This kish consists mainly of graphite, but contains some iron. No. 1 is usually, though not always, high in carbon, and nearly the whole of the carbon is in the graphitic condition. The combined carbon is usually below ·3 per cent, the silicon is usually high, and the sulphur low. This grade is used mainly for very fine castings, or for mixing with lower numbers to increase their fluidity. No. 1 hæmatite pig is used in making steel.

SPECIMEN ANALYSIS OF NO. 1 IRON.

	1	2	3	4	5	6
Iron	92·08	91·90	92·08	92·28	91·987	92·78
Graphite	3·52	3·20	3·50	3·00	3·505	2·12
Combined carbon .	·18	trace	·25	·25	·123	·16
Silicon	2·85	3·50	3·50	2·80	2·85	2·75
Sulphur	·03	·05	..	·02	·035	·02
Phosphorus	·03	1·67	·90	·65	·850	1·28
Manganese	1·31	·68	1·75	1·00	1·015	1·89

1. Hæmatite.
2. Cleveland.
3. Glengarnock.
4. Gartsherrie.
5. Carron.
6. Frodingham.

FIG. 10.—No. 3 Close Iron.

No. 2 Pig Iron.—This iron breaks with a crystalline fracture, the crystals being somewhat smaller than those of No. 1, and the flakes of graphite are less distinct. It is stronger and harder than No. 1, and as it is poured from the ladle it splashes a little. As it cools from fusion it throws up less kish than No. 1, and the combined carbon should not be above ·4. This iron is used in the foundry for light castings.

Fig. 11.—No. 3 Hard Iron.

Fig. 12.—White Summerlee Pig Iron.

No. 3 Pig Iron.—This iron is still closer grained than No. 2, the flakes of graphite being smaller and less conspicuous.

It throws off abundant sparks as it is poured from the ladle, and on cooling from fusion it throws up but little scum. The combined carbon is about ·6 per cent. This metal is used for ordinary foundry work, and heavy castings.

No. 4 Pig Iron.—This is finer in grain, and paler in colour. It shows no perceptible flakes of graphite, and on cooling from fusion throws up no kish. It contains about ·9 per cent of combined carbon. No. 4 forge is similar, but the grain is still smaller. It is paler in colour, harder, and contains more combined carbon. No. 4 is only used for rough castings, and for mixing with the lower numbers. It is also used for the preparation of malleable iron.

SPECIMEN ANALYSIS OF NOS. 2, 3, AND 4 IRONS.

	1	2	3	4	5	6
Iron	91·351	93·00	92·70	92·06	91·52	95·33
Graphite	2·782	1·78	2·80	3·00	3·16	2·14
Combined carbon .	·330	·40	·50	·50	·48	·50
Silicon	2·40	4·00	2·30	2·00	2·59	1·33
Sulphur	·037	·01	·050	·04	·08	·09
Phosphorus	1·340	·90	·650	·90	1·57	·56
Manganese	1·720	3·4	1·00	1·50	·60	·25

1. Lincolnshire No. 2
2. Glengarnock No. 2
3. Gartsherrie No. 3
4. Glengarnock No. 3
5. Cleveland No. 3
6. Staffordshire No. 4

Ordinary analyses of pig iron do not show any well-marked connection between the grade and the chemical composition ; this, no doubt, being due to the irregularities in the grading. The following analyses, selected for the purpose, show the relation which should hold :—

HÆMATITE PIG (C. H. Ridsdale) :*

	1.	2.	3.	Forge.
Graphitic carbon	3·52	3·40	3·10	2·30
Combined	·18	·25	·36	·79
Silicon	2·85	2·60	2·08	1·35

FOREST OF DEAN HÆMATITE (Pattinson and Stead) :*

	1.	2.	3.	4.	Mottled.	White.
Graphitic carbon ...	3·897	3·660	3·020	2·865	2·375	·825
Combined	·395	·570	1·075	1·065	1·316	2·387
Silicon	1·073	·975	·587	·728	·401	·305

If the total carbon be the same, the combined carbon should increase, and therefore the graphitic should decrease, and the silicon also

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* Turner's "Iron," p. 212.

should decrease as the numbers rise. These changes are, however, never very regular, the fracture depending somewhat on conditions other than chemical composition.

White Iron.—This stands at the other end of the series. It is hard and brittle, the fracture is close grained, white, and shows no signs of separated graphite. The metal melts at a lower temperature than does grey iron, but remains more or less viscous, so that it is never fluid enough to cast well, and is, therefore, unsuited for foundry work. Nearly the whole of the carbon is present in the combined condition, there being less than 1 per cent of graphite. The silicon is usually low, and the sulphur is often high.

Mottled Iron.—This is intermediate between white and grey iron. It consists of a matrix of white iron, through which are scattered specks of grey iron.

SPECIMEN ANALYSIS OF WHITE AND MOTTLED IRON.

	1	2	3	4
Iron	94·98	91·76	92·52	93·56
Graphitic carbon	·10	trace	·25	1·84
Combined carbon	2·90	3·25	2·10	1·20
Silicon	·91	3·50	2·72	1·10
Sulphur	·30	·05	·11	·25
Phosphorus	·71	1·72	·88	1·40
Manganese	·10	·72	·42	·65

1. American white. 3. Scotch white.
2. Cleveland white. 4. Mottled.

Change of Grade.—The appearance of the fracture, by which the grade is determined, depends on many conditions, not only the composition, but the rate of cooling having great influence. Whilst the iron is in a liquid condition the whole of the contents are in stable combination, there being no tendency for one element to separate from another, except perhaps in cases where the carbon is very high, when a small portion may separate and rise to the surface, even while the mass remains liquid. As soon as solidification commences, the equilibrium is disturbed, and the iron does not solidify as a whole, but rather as a mixture of substances of different melting points. During solidification, part of the carbon may separate in the form of graphite, and rise to the surface as kish, but the larger portion will not separate till solidification has gone too far to allow of this, and thus it remains disseminated through the metal. The slower the cooling, other things being equal, the more readily can the graphite separate ; therefore, the slower the cooling the larger will be the percentage of graphite and lower will be the number of the iron. On the other hand, if the cooling be very rapid, the carbon will not have time to separate before the metal has become quite solid and rigid, and the carbon will be retained in the combined form. Rapid cooling, therefore, whitens and hardens the iron. Advantage is taken of this in chill casting.

The carbon in white iron is to a certain extent in a state of unstable equilibrium, and rearrangement may take place even below the fusion point. If a piece of white iron be heated for a long time to near its melting point, some of the carbon will be liberated as graphite, in a finely divided form, and the iron will become grey. Any change by which silicon is added or removed will have a great effect on the grade of the iron. The removal of silicon tends to whiten it, and the addition of silicon to make it grey on account of the tendency of silicon to throw the carbon into the graphite condition.

Micro-structure of Pig Iron.—A study of the microscopic structure of pig iron is of the utmost importance, and this is fully discussed in a later chapter.

Improved Method of Grading.—Various methods of grading have been suggested so as to get rid of the uncertainty of that at present in use. The one which has found most favour, though it has not come into practical use, is the classification based on the percentage of combined carbon which is present, or, as this may vary according to the way in which the metal has been cooled, on the percentage of silicon. This may be determined accurately enough by measuring the shrinkage of bars cast under each condition.

Action of Acids on Pig Iron.—Pig iron is readily dissolved in acids, a bulky residue of graphite and silicon, or silica, being left. When hydrogen is evolved it always has a very unpleasant odour, due to the presence of hydro-carbon gases. A portion of the silica, formed by the oxidation of the silicon, always passes into solution, but it can be removed by evaporating the solution to dryness, and taking up the residue with hydrochloric acid once or twice.

Tests for Pig Iron.—The tests usually applied to cast iron are few and simple, a great deal being usually left to the skill and judgment of the founder.

The metal, if intended for structural purposes, is cast into a bar 3 ft. 6 in. long, 2 in. deep, and 1 in. wide. This is placed on supports 3 ft. apart, and loaded in the centre until it breaks. Good iron is usually specified to stand 28 cwt., but sometimes specifications give as low as 25 cwt., or as high as 30 cwt. If the weight be multiplied by 84 it gives approximately the weight in pounds which would be required to break a standard bar 1 ft. long and 1 in. square. The tensile strength of cast iron varies very much; it is usually taken as being from 10 to 15 tons to the square inch, and the crushing strength is about 30 or 40 tons. Engineers frequently specify that castings are to be made of some particular brand of iron. This is, however, an absurdity, and usually shows that the engineer does not know exactly the properties which he requires for his work.

Pig Iron Alloys.—A considerable number of alloys of iron with other metals are now made in the blast furnace for various purposes. These may be regarded as being pig iron in which the iron is partly replaced by other metals.

Silicon Iron (Siliconeisen).—This is pig iron containing up to 15 per cent, or occasionally more, of silicon. It has a white colour, a bright lustre, and breaks with a highly crystalline fracture. It resists the action of moisture and acids better than pig iron. It is used to some extent in the foundry, and in steel making.

Ferro-silicon containing up to 60 per cent Si is made by reduction in the electric furnace.

Spiegeleisen.—This is pig iron containing from 15 to 30 per cent of manganese. It has a yellowish white colour, and breaks with a characteristic crystalline fracture, the facets of the crystals having a mirror-like lustre.

Ferro-manganese.—This is an alloy of iron and manganese, often containing 80 per cent or more of manganese. It has a pale bronze colour, breaks with a very granular fracture, and is so brittle that it can be ground in a mortar. It often contains 6 to 7 per cent of carbon.

Silicon Ferro-manganese is ferro-manganese containing a considerable quantity of silicon.

Ferro-chrome.—This is an alloy of iron and chromium often containing 60 per cent of the latter element. The properties of the alloy vary with the amount of chromium it contains. When this is high, it breaks with a very granular fracture; is very brittle, so that it can be powdered in a mortar. The carbon is always high, sometimes reaching 10 per cent.

ANALYSIS OF FERRO ALLOYS.

	1	2	3	4	5
Iron	66·22	12·00	74·54	25·96	86·03
Carbon	1·00	6·71	3·95	10·05	1·75
Silicon	12·25	·84	·53	·40	10·32
Sulphur	·01	trace	·03	·01	·04
Phosphorus	·09	·23	·05	·06	·06
Copper	·02	·06	..	..	..
Manganese	20·41	80·16	·73	·42	1·82
Chromium	..	..	20·17	63·10	..

1. Silico-spiegeleisen.
2. Ferro-manganese.
3. Ferro-chrome (poor).
4. Ferro-chrome (rich).
5. Ferro-silicon.

CHAPTER IV.

PREPARATION OF THE MATERIALS FOR THE SMELTER.

Pig iron is prepared by smelting in the blast furnace. For this purpose the ore is required in pieces of moderate size; finely-divided materials being quite unsuited for use in the blast furnace, as they would impede the current of hot gases which pass upward through the furnace, and, on the other hand, large lumps are unsuitable, as they expose too little surface and therefore take too long to reduce. The elaborate processes of dressing and concentrating, which are used in the case of some metals, are quite unsuited for the preparation of iron ores. They all necessitate the ore being in the condition of powder, which, as remarked above, is not a convenient form for iron smelting. The specific gravity of iron ores again is, as a rule, too low to allow of ready separation from the gangue by running water, and iron is so cheap that costly methods of dressing are out of the question. For these reasons only the simplest and cheapest dressing processes can, as a rule, be applied to iron ores—these are breaking, picking, and calcining.

Ore Breaking.—The ore, as it is raised from the mine, is in large lumps; these are broken into pieces of suitable size, either by hand or by a stone breaker, such as the Blake or other similar machine. Hand breaking has the advantage that pieces of gangue free from ore can be picked out and thrown on one side, whilst, on the other hand, a breaker is cheaper and gives pieces of more uniform size.

The size of the pieces used varies in different localities, and with different ores. The more porous the ore, and the higher the furnace, the larger the pieces that can be used.

In Lancashire and Cumberland, hæmatites are broken to the size of road metal. In Sweden, magnetites are broken into pieces not more than 6 inches in diameter; whilst in Scotland, working calcined clayband and blackband ores, and hæmatites, the material is charged to the furnace in lumps of any size, as received from the kiln.

By hand a man can break four or five tons of hæmatite a day, and a Blake crusher, with 10 in. jaws, driven at 250 revolutions a minute, will crush from ten to twelve tons.

Weathering.—This consists of exposing the ore to the action of the weather, *i.e.*, air and moisture, and is now rarely used. Some clay ironstones contain shale, which exfoliates and breaks up on exposure to the air, and some ores contain pyrites, which, under the same conditions, is oxidised and partially removed in solution. The changes, however, take place very slowly, and, as they are dependent on the influence of moisture, the heaps must be watered in dry weather. Weathering is never resorted to in this country, but is still used in some small Continental works, where the heaps are allowed to weather for many months before smelting. Obviously this is only practicable where the output is very small.

Magnetic Separation.—Since some iron ores are magnetic, whilst the gangue with which they are mixed is non-magnetic, it has been suggested to apply magnetism as a means of separating the ore from the gangue. This magnetic separation has been tried in various districts with more or less success, and is slowly coming into use. For all forms of apparatus the ore must be powdered, and this, as already remarked, renders it unfit for direct smelting in the blast furnace.

Many forms of apparatus have been devised; they vary very much in detail, but in all of them the powdered ore is brought under the influence of powerful electro-magnets, by which the magnetic portion is attracted, whilst the unmagnetic portion is not. With some forms the separator works on the dry powder; with others on the powder suspended in water. As an example of magnetic separator of the former type, the Ball-Norton,* Fig. 13, may be taken, as it is one of the most efficient.

This consists of two drums, A, B, of some non-magnetic material, usually copper, which can be revolved at a rapid rate. Inside each drum, and occupying about one-third of the periphery, is fixed a series of electro-magnets, M, M′, so arranged that the poles alternate. The ore is supplied by the hopper C, and, passing over the chute, is at once brought under the influence of the magnets M. The magnetic portions are attracted and carried round by the drum, whilst the tailings fall into the hopper D, from which they can be removed by the door E. As soon as the drum carries the magnetic portions out of the magnetic field, they fall from it, and are thus brought under the influence of the magnets M′, which are either somewhat less powerful than M, or the speed of rotation of the drum is greater. The non-magnetic "middlings" fall into the hopper F, whence they can be removed by the door G, whilst the magnetic portions are carried round, and when they pass beyond the influence of the magnets they fall into the concentrates hopper H. The whole apparatus is enclosed in a case through which a current of air is drawn by a fan.

When magnetic particles are attracted by a magnet, each becomes magnetic, and they form tufts or brushes standing out from the magnet and retaining much non-magnetic matter entangled among them. The poles of the magnets M and M′ are alternately north

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* See Transactions American Institute of Mining Engineers, vol. xix.

and south so that as the particles are carried round from one pole to the next they become horizontal as they pass between the poles, and then reverse their position, thus allowing the particles of entangled non-magnetic material to fall away. The separation is facilitated by the centrifugal tendency due to the rapid rotation, and by the current of air. The concentrates are free from non-magnetic dust, and the dust is free from magnetic matter. The "middlings" are mainly particles of ore and gangue, which need finer crushing to effect separation. A machine with drums 24 in. diameter and 26 in. long will separate 15 tons to 20 tons an hour of ore which has passed through a 16 mesh or 20 mesh screen. The power required is about 1 to $1\frac{1}{2}$ horse power for electricity, and from $\frac{1}{2}$ to $\frac{3}{4}$ horse power to drive the drums and fan. The following table of examples will show the extent to which the operation can be carried.

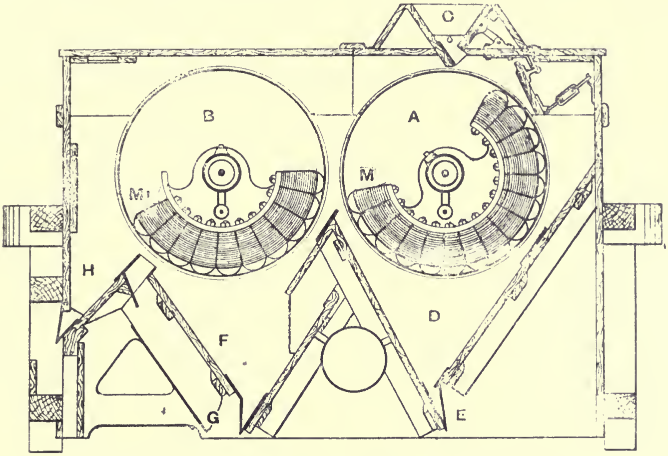

Fig. 13.—The Ball-Norton Magnetic Separator.

It will be seen that in some cases not only is the percentage of the iron increased, but the phosphorus, being in the gangue as non-magnetic calcium phosphate, is to a large extent removed.

The cost of concentrating is considerable. At the Tilly Foster mine it was 7s. 6d. per ton of concentrates, the concentration being in the ratio 2·5 : 1.

Non-magnetic iron ores can usually be rendered magnetic by suitable roasting. If, for instance, red hæmatites be strongly heated without access of air, they lose oxygen

$$3\ Fe_2O_3 = Fe_6O_7 + 2\ O.$$

For this reduction a high temperature is required, and in the presence of silica silicates may be formed.

If the ore be heated in a reducing gas the reduction takes place at a much lower temperature, but many hæmatites are so dense that the gas cannot penetrate readily.

		Crude ore.		Concentrates.				Tailings.	
	Mesh.	Fe.	P.	Fe.	P.	Si O_2.	S.	Fe.	Per cent of original weight.
Benson mines	16	..	..	68·45	·022	4·78	..	..	..
Little River	16	..	..	67·49	·016	5·64	·32	..	..
	20	45·48	..	68·62	·011	4·18	·34	..	..
	20	..	..	67·81	·013	5·19	·27	3·39	..
Chateaujar tailings		11·80	..	68·36	·008	4·31	..	4·33	89·00
Port Henry		47·70	..	70·9	·009	1·48	..	..	38·00
Port Henry		58·70	2·25	71·1	·037	..	..	..	20·00
*Croton, N.Y.		42·99	·153	69·86	·021	1·71	·04	7·95	47·00

* Sulphur ·3 per cent.

Carbonate ores behave very similarly, and are readily converted into magnetic oxides by heating in moderately reducing gas.

At Birmingham, Ala., U.S.A.,* the Clinton hæmatites have been worked by roasting and magnetic separation. The ores contain about 40 per cent of iron, and can be supplied to the kiln at 25 cents per ton. The ore is crushed to about the size of a hen's egg, and is then roasted in a Davis-Colby gas kiln. The ore is first heated in the kiln in the usual way, and then gas unmixed with air is passed through. The carbon monoxide and hydrogen in the gas act on the ore, and convert the iron into magnetic oxide, the magnetisation taking an hour or so, at a temperature of about 1,100 deg. Fah. The magnetised ore is then crushed and passed through the separator, by which it is divided into three portions, concentrates, middlings, and tailings. The first of these containing 58·85 per cent of iron, and the second 51·25, the ore treated having contained 45 per cent.

Magnetic concentration is not likely to be of any importance in this country, because (1) the British ores are not naturally magnetic, (2) it necessitates the ore being in a fine state of division, and (3) because, though the clayband and blackband ores could no doubt be rendered magnetic, the mineral is so intimately mixed

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* See Proceedings of American Institute of Mining Engineers, vol. xxv.

with the gangue that, however finely the ore might be powdered, separation would be impossible.

CALCINATION.

In this country all ores, except hæmatites, brown ores, and magnetites, are subjected to a preliminary calcination either in heaps or kilns. The changes produced by calcination are both chemical and physical.

Chemical Changes.—*Dehydration.*—Any water which is present in the ore, either as moisture or in combination, is expelled.

Organic Matter.—This is decomposed, and as the atmosphere of the heaps or kilns is oxidising, it is completely burnt out.

Carbonates.—These are broken up completely if the temperature be high enough, carbon dioxide being evolved. Iron carbonate yields ferric oxide and carbon dioxide $2\,Fe\,CO_3 + O = Fe_2\,O_3 + 2\,CO_2$. Calcium carbonate (carbonate of lime) yields lime, and carbon dioxide, $CaCO_3 = CaO + CO_2$, manganese carbonate yields manganese oxide $3\,Mn\,CO_3 + O = Mn_3O_4 + 3\,CO_2$.

Sulphides.—These are wholly or partially oxidised. In the case of pyrites, the most important sulphide, if air be insufficient for complete combustion, sulphur may be evolved $Fe\,S_2 = Fe\,S + S$, but if there be a good supply of air ferric oxide is left, and sulphur dioxide is evolved, $2\,Fe\,S_2 + 11\,O = Fe_2\,O_3 + 4\,SO_2$. Ferrous sulphate may be formed $Fe\,S_2 + 6\,O = Fe\,SO_4 + SO_2$, and afterwards decomposed $2\,Fe\,SO_4 = Fe_2\,O_3 + SO_2 + SO_3$. If the supply of air be insufficient, and organic matter be present, the atmosphere may be reducing, and black ferrous silicate may be formed, $Fe_2\,O_3 + CO + Si\,O_2 = 2\,Fe\,O.\,Si\,O_2 + CO_2$, which, being fusible, may cause the mass to clot or frit together.

Oxides.—These undergo little change, except that if the temperature be high the iron oxides may all be converted into the magnetic oxide.

Silicates.—These will not be changed, except ferrous silicate, which, if the atmosphere be strongly oxidising, will be converted into a mixture of ferric oxide and silica—

$$2\,Fe\,O.\,Si\,O_2 + O = Fe_2\,O_3 + Si\,O_2.$$

As a result of these changes the ore may lose considerably in weight, and the iron, in whatever form it existed in the ore, will go to the furnace as oxide.

Physical Changes.—Owing to the expulsion of the volatile constituents ores become more porous and more easily permeable to gases. Care must be taken not to use too high a temperature or the ore may partially fuse and thus become too compact and dense. This is much more likely to occur with blackband ores and those with fusible gangue.

Ores to be Calcined.—*Magnetites* need not be calcined unless they contain pyrites, when calcination may be necessary to remove the sulphur. *Red hæmatites* are only calcined for magnetic separation, never for direct smelting. *Brown hæmatites* lose water only and calcination is unnecessary. *Carbonate ores* lose water, carbon dioxide, organic matter if present, and sulphur, and are always calcined.

Loss of Weight.—The loss of weight on calcination will vary with the nature of the ore. With brown ores it may be 5 to 10 per cent, but with clay and black band ores it may reach 40 per cent or more. Such ores are usually calcined at the mine so as to reduce the cost of carriage.

Calculations.—From the known composition of an ore it is easy to ascertain the changes which will take place on calcination, and to calculate the loss of weight which will take place if the calcination be complete. There are two points on which information is usually required: (1) The percentage of weight which an ore will lose on calcination; and (2) percentage of iron which will be contained in the calcined ore. The chemical changes which take place are simple.

(1) Ferrous carbonate yields ferric oxide

$$\frac{2\,\mathrm{Fe\,CO_3} + \mathrm{O}}{2\,(56 + 12 + 48) = 232} = \frac{\mathrm{Fe_2\,O_3} + 2\,\mathrm{CO_2}}{2 \times 56 + 3 \times 16 = 160}$$

so that as 232 parts of ferrous carbonate give 160 of ferric oxide, 1 part will give $\frac{160}{232} = \cdot 6897$.

In many analyses the ferrous carbonate is stated as ferrous oxide and carbon dioxide. The ferrous oxide will be converted into ferric oxide, the carbon dioxide being expelled

$$\frac{2\,\mathrm{Fe\,O} + \mathrm{O}}{2\,(56 + 16) = 144} = \frac{\mathrm{Fe_2\,O_3}}{160}$$

so that 144 parts of ferrous oxide will give 160 parts of ferric oxide or 1 part $= \frac{160}{144} = 1 \cdot 11$.

(2) Pyrites will be completely oxidised.

$$\frac{2\,\mathrm{Fe\,S_2} + 11\,\mathrm{O}}{2\,(56) + 64) = 240} = \frac{\mathrm{Fe_2\,O_3} + 4\,\mathrm{S\,O_2}}{160}$$

so that 1 part of pyrites will give $\frac{160}{240} = \cdot 666$ of ferric oxide.

(3) Calcium carbonate is decomposed, lime being left

$$\frac{\text{Ca CO}_3}{40 + 12 + 48 = 100} = \frac{\text{Ca O} + \text{CO}_2}{40 + 16 = 56}$$

so that 1 part of carbonate of lime will give $\frac{56}{100}$ = ·56 parts of lime.

(4) Manganese is usually present as carbonate Mn CO_3, which on heating yields the oxide Mn_3O_4.

$$\frac{3\,\text{Mn CO}_3 + \text{O}}{3\,(55 + 12 + 48) = 345} = \frac{\text{Mn}_3\text{O}_4 + 3\,\text{CO}_2}{3 \times 55 + 16 \times 4 = 229}$$

or 1 part will give $\frac{229}{345}$ = ·66 manganic oxide.

Or if it be considered as manganous oxide

$$\frac{3\,\text{Mn O} + \text{O}}{3\,(55 + 16) = 213} = \frac{\text{Mn}_3\text{O}_4}{229}$$

or 1 part Mn O = 1·075 parts Mn_3O_4.

(5) Water and organic matter are expelled, and the various earthy matters remain unchanged.

The following example will probably make the method of calculation clear. Given an ore with the composition in the first column, it is required to find how much it will lose on calcination, and what will be the percentage of iron in the calcined ore.

Before Calcination.			After Calcination.	
Ferros carbonate	70 %	× ·6897	48·28	parts ferric oxide.
Iron pyrites	1 %	× ·67	·67	,, ,,
Calcium carbonate	10 %	× ·56	5·60	,, lime.
Manganese carbonate	1·5%	× ·66	·99	,, manganese oxide.
Organic matter	8·5%	..	..	
Earthy matter	5 %	..	5	
Water	4 %	..	..	
	100		60·54	

100 parts of the raw ore thus yields 60·54 parts of the calcined ore, and the loss would be = 39·46 per cent. The 60·54 parts of the calcined ore, contain 48·95 parts of ferric oxide or in 100 parts $\frac{48\cdot95 \times 100}{60\cdot54}$ = 80·85, and as ferric oxide contains 70 per cent of iron the percentage of iron in the calcined ore will be 80·85 × ·7 = 56·595, and the percentage of manganese will be $\frac{\cdot99 \times 100}{60\cdot54} \times \cdot721 = 1\cdot178$.

As an example of the changes actually produced by calcination, the following analysis of Cleveland ore, before and after calcination, may be of interest. It must be remembered that the figures are percentages in both cases, and that the samples may not have been absolutely identical.

	Raw.	Calcined.
Ferric oxide	2·60	66·25
Ferrous oxide	38·06	..
Manganous oxide	·74	..
Manganic oxide	..	·65
Alumina	5·92	7·72
Lime	7·77	6·46
Magnesia	4·16	4·78
Potash	Trace	·02
Silica	10·36	11·87
Sulphur	·14	..
Sulphuric acid (SO_3)	..	·90
Phosphoric acid (P_2O_5)	1·07	1·13
Carbonic acid (CO_2)	22·06	..
Water	4·45	..
	97·33	99·78
Iron	30·69	46·37

METHODS OF CALCINATION.

Calcination in Heaps (Clamps).—This is the primitive and simplest method of calcination, and is still largely used, though it is gradually being replaced by kiln calcination. It is mainly used where the ore is calcined at the mine or when there is sufficient coaly matter present for the ore to burn without the addition of fuel. It is still used in South Wales, Staffordshire, and other localities.

A level piece of ground is selected, and on this is spread a layer of coal an inch or two in thickness, on this is put a layer of the ore —in large pieces—usually with the planes of bedding vertical, about 12 in. thick, then a thin layer of small coal, then another layer of ore, and so on, till the heap is 5 ft. or 6 ft. high. The bottom layer of coal is then lighted at one end of the heap, and combustion goes on till all the coal is burnt. If the heap burns too rapidly in any direction, or if the fire shows at the surface it must be damped with fine ore or ashes, and screens must be erected to windward, if there is much wind. The burning may take from one to three weeks, varying with the nature of the ore and the size of the heap. The coal consumed with clayband ironstone is about ½ cwt. of large and 2½ cwt. of small for each ton of ore calcined. This method of calcination is apt to give very irregular results, part of the heap being over-burned, or even fused into a mass, while other parts are hardly touched. If the ore contains much combustible matter, or the gangue is fusible, the heaps must be made much smaller.

In the Cleveland district, a space of ground was roughly levelled, channels about 5 ft. apart were formed of the rough stone or ore, and those channels which ran across the heap were filled with rough or splint coals, and these were again covered up with rough stone. A layer of about 15 in. of stone was then laid over the ore, and a small quantity of coal thrown over. Additional layers of ore and coal were then added until the heap was about 8 ft. thick. Fire was then applied to the bottom channels, and after 12 to 18 hours the entire mass became ignited. The operation of burning lasted about 9 to 12 days, depending on the quantity of the stone and the weather.*

Stall Calcination.—In a few districts the heaps are made of small size, and are enclosed on three sides by walls of masonry, the front or fourth side being closed by lumps of ore loosely stacked. Such stalls burn more regularly than open heaps, and the consumption of fuel is a little less.

Calcination in Kilns.—Iron ores are, in this country, usually calcined in kilns. Many forms of kiln have been devised, the object being to ensure uniform and rapid calcination with as small a consumption of fuel as possible.

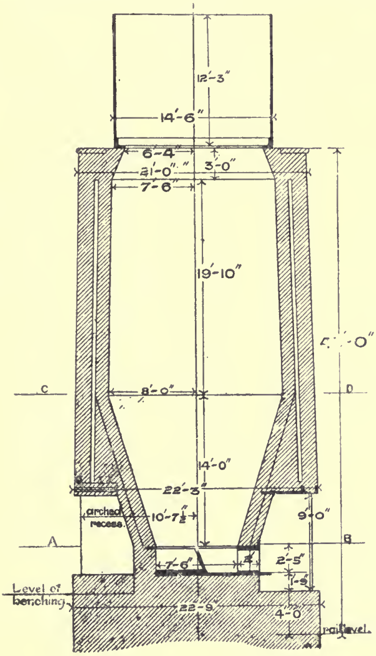

Fig. 14.—Scotch Kiln.

Right-hand side section through discharging door. Left-hand side at right angles to this.

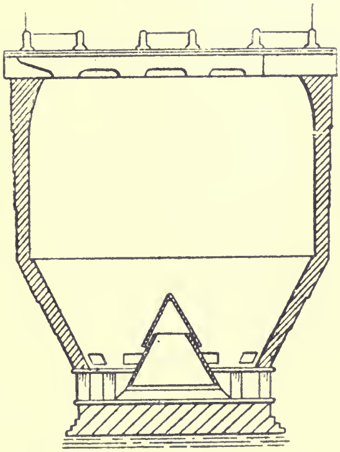

Fig. 15.—Gjers Kiln.

Scotch Kiln.—In Scotland, circular kilns are used. The one shown in Fig. 14 is 45 ft. high, with a diameter of 16 ft. To facilitate drawing, two inclined iron plates are placed across the bottom forming a triangular ridge.

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* C. Wood, Proceedings of C. I. of E., 1896, p. 267.

Gjers Kiln.—This form of kiln (Fig. 15), designed by Mr. Gjers, of Middlesbrough, is largely used in that district and elsewhere. It consists of a shell of fire brick, cased with iron. The upper part is cylindrical, the lower part is in the form of an inverted cone, and is carried on short hollow iron columns between which the calcined charge is drawn, and air enters. In the centre is a cone of iron which serves to throw the descending charge outwards, so that it can be easily drawn, and through which air, from a main, is admitted to the interior of the kiln. Round the kiln is a series of openings closed by iron doors, through which the charge can be poked down if necessary. The charge of ore and fuel is introduced at the top direct from the railway trucks. Large kilns of this type are now built up to 33 ft. high and 24 ft. diameter, with a capacity of about 8,000 cubic feet. Such a kiln will burn about 800 tons of ore per week with a consumption of about ·8 cwt. of coal per ton of ore.

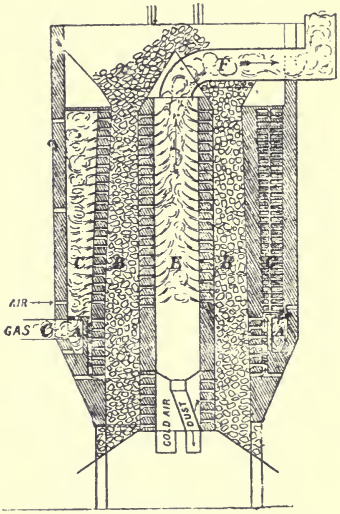

Fig. 16.—Davis-Colby Gas Kiln.

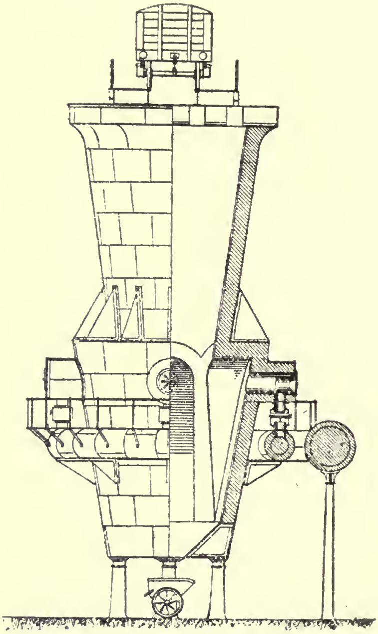

Fig. 17.—Gas Kiln.

Gas Kilns.—Many forms of kilns for burning gas have been suggested, but have never come largely into use, but they have been used in America for calcining magnetites containing pyrites. The most popular form of gas kiln is probably that known as the Davis-Colby, and it may be taken as a type. This kiln (Fig. 16) consists of a circular calcining chamber B, surrounded by an annular combustion chamber C, and surrounding a central flue E, there being a large number of openings in the walls between C and B and B and E, and small openings for observation are made in the outer walls. The ore is charged into the chamber B, and is withdrawn at the bottom into trucks. Air and gas are admitted to the space C, combustion takes place, and the products of combustion pass across the ore to the chimney. The standard kiln is 45 ft. high and 24 ft. in diameter, and will calcine 300 tons of ore (hæmatite) daily, with a consumption of 2 tons of coal for each 100 tons of ore roasted,* this being equivalent to 4 cwt. of coal per ton. The calcination is said to be very perfect, and the removal of sulphur complete. Another form of gas kiln is shown in Fig. 17. Here the gas is supplied into a combustion chamber about one-third the height of the kiln.

Advantages of Kiln Calcination.—Calcination in kilns gives much better results than in heaps, the calcination is much more uniform, and the consumption of fuel is much less.

Briquetting.—In the breaking of ores for use and in transit a considerable quantity of smalls, *i.e.*, material too fine for use in the blast-furnace, is produced. The smalls obtained at the mine in the case of clayband ore were usually thrown aside and accumulated in huge heaps. When magnetic concentration is used finely divided ore in large quantity is produced, which is quite unsuitable for use in the blast-furnace, and a large quantity of purple ore is produced in the "wet" copper works, which would be quite suitable for smelting, except that it is in a fine state of division.

To allow of the use of such materials, methods of briquetting have been introduced by which the ores are made into solid blocks suitable for blast-furnace use.

For blast-furnace use the blocks must be strong. "They must resist a pressure of not less than 2,000 lbs. per square inch, and when dropped from a height of 10 feet on to a cast iron plate, they must not fall into dust, though they may break to pieces."

They must resist a high temperature without crumbling or sintering, and should also resist the action of steam; and they must be sufficiently porous to allow the permeation of the furnace gases. "In order to test the briquettes for porosity, they are, after being dried, placed for about 25 minutes in water, during which time they should absorb not less than 12½ to 16 per cent of water, according to the nature of the ore."

In some cases, especially with ore containing clay, no binding material is needed; but in most cases, under ordinary conditions, the ore will not bind, and either a binding material has to be added, or some other device adopted to secure a strong briquette.

The binding material usually used is clay, of which ten per cent may be required. Lime is sometimes used, 7 or 8 per cent being necessary, and a mixture of lime and sand has been tried.

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* Proceedings of C. I. of E., 1896, p. 277.

Compressing the blocks under high pressure has been suggested, and in the Grôudal process, which is applied to magnetic concentrates, small briquettes are made, and these are heated in an oxidising chamber till the oxide of iron sinters, and thus frits the material into a solid mass.

The material to be briquetted should be in coarse powder, the fragments being of uniform size. It is therefore crushed in a mill, screened, mixed if necessary with the binding material in a pug mill, and compressed into blocks either by hand or in a brick-making machine. The blocks are dried, and then fired at a bright red heat.

Where the briquetting is done at a smelting works, blast-furnace gas is used for the heating.

Blast-furnace flue dust is also briquetted, often with the addition of ferrous sulphate magnesium chloride, and for the briquetting of flue dust, basic blast-furnace slag, which has been decomposed by exposure to the action of high pressure steam, has been used. Flue dust contains a good deal of lime, and must not be exposed for long to moisture before briquetting.

The cost of the process, of course, must vary, that of the Grôudal process is stated to be about 3s. 4d. per ton of briquettes, exclusive of general expenses and royalties, which are estimated at another 1s. 4d.

To avoid the cost of briquetting, it has been suggested to agglomerate the ore by heating to softening temperature in a rotary, the process being accelerated by the addition of some reducing agent, by which the ferric oxide is reduced to the more fusible magnetic oxide or to metallic iron.*

Large quantities of briquetted ore are imported from Sweden.

COAL.

In some localities the coal is used in the blast furnace raw, *i.e.*, uncoked. This is only possible with non-coking coals, either those rich in hydrogen, such as the splints, or poor in hydrogen, such as anthracitic coals or anthracites. In most districts the coal is first converted into coke. For full particulars of the methods of coke-making the reader must refer to a treatise on fuel.

LIMESTONE.

The flux universally used in the blast furnace is limestone. When irons free from phosphorus are required the limestone used must be free from that element, and therefore should be non-fossiliferous. It should be, as far as possible, free from silica, since this will combine with some of the lime, and thus not only reduce the quantity of available lime, but increase the quantity of slag.

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* For further particulars see—J. Wiborg, J. I. S. I., 1899, vol. 2; H. Bumby, J.W. of S. I. S. I., vol. 9, No. 5; L. de Schwaz, J. I. S. I., 1910, vol. 2.

In a few works the limestone is calcined, *i.e.*, burnt to lime, before it is used. The kilns used are either ordinary limekilns, or they are similar to those used for calcining the ironstone, but smaller as a higher temperature is required. Sometimes the limestone and iron ore are calcined together.

EXAMPLES OF LIMESTONES.*

	1	2	3	4	5
Calcium carbonate	97·31	91·30	98·41	99·25	99·89
Magnesium carbonate	1·00	·79	·49	·41	·22
Ferric oxide Alumina	1·89	1·36	·26	·10	·21
Silica	..	6·55	·80	·10	·35
Alkalies	..	..	..	..	·14
Phosphoric acid (P_2O_5)	..	·04	..	trace	trace
Sulphur	..	trace	..	trace	trace
Water	..	..	..	..	·27
Organic matter	..	..	·01	..	..

1. Dudley.
2. Wenlock.
3. Troyhall.
4. Welsh.
5. Derbyshire.

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* Pilkington, S. Staff. Inst., Dec., 1887.

CHAPTER V.

CHEMISTRY OF THE BLAST FURNACE.

Outline of the Process.—In outline the method of iron smelting in the blast furnace is very simple. The furnace itself is a vertical stack of masonry, into the top of which is charged the mixture of ore, fuel, and necessary fluxes, and at the bottom air is blown in by a series of tuyeres. Combustion takes place, producing a very high temperature. The hot gases ascend the stack and escape ; the oxide of iron is reduced, and the metal, combining with carbon and other elements, melts and runs down to the hearth ; the earthy matter of the ore combines with the fluxes added to form a fusible slag, which also melts and runs down to the hearth, from which it and the iron are tapped at suitable intervals.

The income of the furnace is therefore the fuel, ore, flux, and air, and the output is iron, slag, and waste gases. The chemical changes which have to be studied are those by which the one is converted into the other.

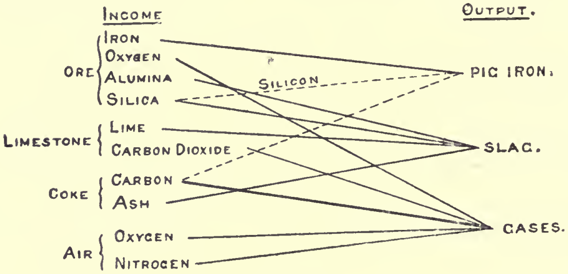

Fig. 18.

This may be represented diagrammatically, as shown in Fig. 18. The dotted lines represent small portions only of the material.

Temperature of the Furnace.—The source of heat in the furnace is the combination of the fuel opposite the tuyeres with the air which is blown in. The hot gases, as they ascend, meet the slowly descending cold charge, and impart to it their heat, becoming themselves cooled in the process. When the furnace is in steady work the two heat streams must balance, so that the temperature of any part of the furnace will remain fairly constant. The temperature at various points of a Cleveland furnace, as given by Sir Lowthian Bell, are shown in Fig. 19*. These temperatures

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* "Manufacture of Iron and Steel," p. 472.

are of very great importance, for it must be remembered that chemical changes depend very largely on temperature, and this, to a large extent, therefore, determines the nature and extent of the chemical changes which take place in any part of the furnace.

Combustion of the Fuel.—The fuel burned is always carbon, in the form of charcoal or coke. Even when raw coal is charged the volatile matter is expelled, and it is converted into coke long before it reaches the zone of combustion. The air coming in contact with the hot carbon at once burns it, carbon monoxide being formed, $C + O = CO$. If any carbon dioxide is formed it will be at once reduced to carbon monoxide by the excess of hot carbon. Any moisture carried in by the air will also be decomposed, and a small quantity of hydrogen thus added to the gas. As carbon monoxide formed by the combustion of carbon occupies twice the volume of the oxygen consumed, 100 volumes of air, containing 79 volumes of nitrogen and 21 volumes of oxygen, will yield 121 volumes of gas containing 42 volumes of carbon monoxide. The ascending gases therefore, if the air were dry, would contain 34·7 per cent of carbon monoxide.

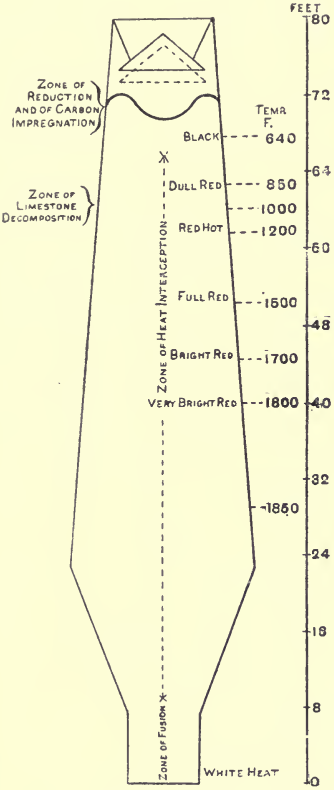

FIG. 19.

A cubic metre of air saturated with moisture at 15 deg. Cen. (59 deg. Fah.) contains 12·8 grammes of water vapour, and this will give 1·4 grammes of hydrogen, which, at 0 deg. Cen. and 760 millimetres, would occupy 15·7 litres. Assuming 1 part air to give 1·2 parts of furnace gas, the gas would contain about 1·3 per cent of hydrogen. The air is rarely saturated with moisture, so that the amount of hydrogen in the gas due to moisture carried in by the air will almost always be less than this.

Reduction of Oxide of Iron.—The iron is always charged into the furnace in the form of oxide, either Fe_2O_3 or Fe_3O_4; other compounds being converted into these by calcination before charging. Immediately the charge is in the furnace it comes in contact with the hot current of ascending gas, which will have a temperature of about 326 deg. Cen. (600 deg. Fah.), and the carbon monoxide at once attacks the oxide of iron and reduces the iron $Fe_2O_3 + 3CO = 2Fe + 3CO_2$, thus replacing some of the carbon monoxide in the gas by carbon dioxide. This reaction begins at about 200 deg. Cen. (392 deg. Fah.), and becomes much more rapid at higher temperatures, so that the temperature at the top of the furnace is quite high enough to ensure the reaction taking place rapidly, though it may be somewhat retarded at first by the presence of the carbon dioxide in the gas. As the charge descends the temperature rises, and the action becomes more vigorous, but, as the ore is in lumps, which cannot be rapidly permeated by the gas, the complete reduction must take some little time. The larger the lumps of ore, and the less porous they are to the gases, the longer will be the time taken for complete reduction. When the

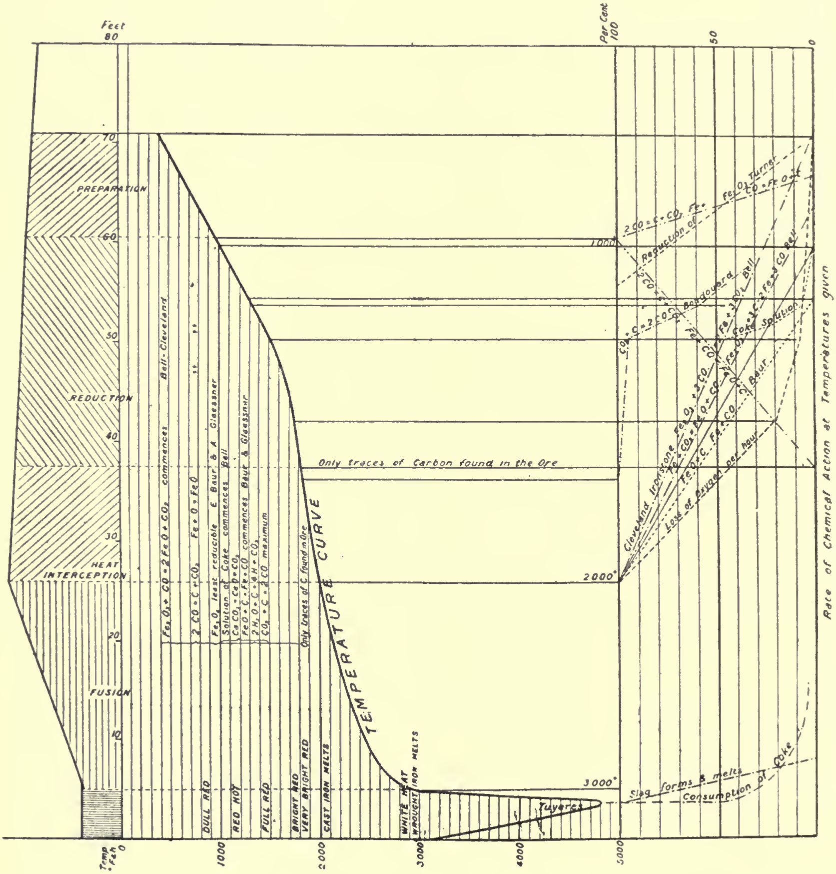

FIG. 20.—Temperature Reactions in the Blast Furnace

charge has reached a bright-red heat any carbon dioxide formed will at once be reduced by the hot carbon—

$$CO_2 + C = 2\,CO;$$

or the solid carbon may act on the oxide of iron, forming carbon monoxide, $Fe_2O_3 + 3\,C = 2\,Fe + 3\,CO$. In either case the result is practically the same, each 56 parts of iron reduced uses up 12 parts of solid carbon. This causes a loss of fuel, since, if this carbon were not thus consumed in this way, it could be burned at the tuyeres, and help to evolve the heat required in the furnace.

It is evident, therefore, that for economical working the oxide of iron should be completely reduced by carbon monoxide before the temperature becomes high enough for the carbon to act on the carbon dioxide liberated. This is, however, rarely practicable, a small quantity of oxide almost always escaping reduction till a higher temperature is attained. The ultimate result of the reduction is, therefore, the separation of iron and the formation of carbon monoxide and carbon dioxide, but the reduction probably takes place in several stages, the exact intermediate steps varying with the nature of the material being treated, hæmatite being much more readily reduced than magnetite. Kosman points out* that the nature of the reactions will also vary with the temperature, no doubt on account of variations in the intermediate products formed. Ferric oxide, for instance, is more readily reduced by hydrogen at the temperature of boiling mercury than at higher temperatures, because at higher temperatures it is first converted into magnetic oxide, which is more difficult to reduce.

The reduction in the blast furnace is, according to Kosman, much as follows: Red hæmatite is attacked in the uppermost zone of the blast furnace thus: $4\,Fe_2O_3 + 6\,CO = Fe_8O_6 + 6\,CO_2$; then at a slightly higher temperature $Fe_8O_6 + 2\,CO = Fe_8O_4 + 2\,CO_2$. Fe_8O_4 may be regarded as being $4\,Fe\,O + 4\,Fe$. Ultimately this Fe_8O_4 loses all its oxygen, and metallic iron results.

Magnetite behaves differently, being more difficult to reduce, it must sink further into the furnace before reduction begins, then, $3\ Fe_3O_4 + 6\,CO = Fe_9O_6 + 6\,CO_2$ the residue, therefore, having the composition $6\,FeO\ 3\,Fe$.

The ore has, however, to pass a zone in which the carbon monoxide that has been burnt to carbon dioxide yields oxygen passing again into carbon monoxide; the liberated oxygen may oxidise the metallic iron into the condition of ferrous oxide or magnetic oxide, which is subsequently re-reduced.

Another reaction of considerable importance takes place and materially assists in the reduction. When carbon monoxide comes in contact with metallic iron or ferric oxide at moderate temperatures it is decomposed into carbon dioxide and carbon, the latter being

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* "Journal of the Iron and Steel Institute," 1888, vol. ii., p. 232.

deposited $2\,CO = CO_2 + C$. This action is very rapid at about 420 deg. Cen., but decreases at higher temperatures.

Sir I. Lowthian Bell expresses the reactions that take place as follows: First the ferric oxide $Fe_2\,O_3$ is reduced to a lower state of oxidation, $Fe_x\ O_{y+1}$, which is then further reduced by carbon monoxide $Fe_x\,O_{y+1} + CO = Fe_x\,O_y + CO_2$. The $Fe_x\,O_y$ is then reduced $Fe_x\,O_y + y\,CO = x\,Fe + y\,CO_2$.

Then the action of the carbon dioxide on the spongy metal commences.

$$x\,Fe + y\,CO_2 = Fe_x\,O_y + y\,CO$$

and then

$$Fe_x\,O_y + CO_2 = Fe_x\,O_{y+1} + CO.$$

When the spongy metal or the oxide is acted on by carbon monoxide carbon is separated thus—

$$Fe\,x\,O_y + C\,O = Fe\,x\,O_{y+1} + C$$

$$x\,Fe + {}_yC\,O = Fe\,x\,O_y + y\,C$$

The carbon thus deposited may then be removed by carbon dioxide $C + C\,O_2 = 2\,C\,O$. The deposited carbon may completely reduce the iron oxide, $Fe\,x\,O_{y+1} + C = Fe x O_y + CO$, $2\,Fe\,x\,O_{y+1} + C = 2\,Fe\,x\,O_y + CO$, $Fe\,x\,O_y + y\,C = x\,Fe + y\,C\,O$.

It will thus be seen that the reduction reactions in the blast furnace are by no means simple, and that, as the result of the complex set of reactions which take place, the iron reduced in the upper zones may be reoxidised lower down. It has, indeed, been stated that probably 10 per cent of the oxygen in the ferric oxide remains in combination till the temperature at which the iron melts.

The changes may be summarised :—

(1) The oxide of iron is reduced to lower oxides, and ultimately to a large extent to metallic iron by the carbon monoxide near the top of the furnace, the reduction being in some cases facilitated by the carbon deposited by the decomposition of carbon monoxide.

(2) Some of the reduced iron may be oxidised lower down in the furnace by carbon dioxide. This action taking place the more readily the smaller the amount of carbon-monoxide present.

(3) The separated iron is impregnated with carbon by the reduction of carbon monoxide.

(4) Any oxygen, either from the ore or from re-oxidised iron not previously separated, is removed by solid carbon when the iron melts.

The way in which the reactions take place will depend on circumstances : the more porous the ore and the more slowly it descends, the more complete will be the action of the carbon monoxide, and the more complete therefore will be the reduction thereby.

The extent to which the reduction is being produced by carbon monoxide can be judged from the composition of the escaping gases. The more carbon dioxide these contain the more perfectly is reduction being effected by the carbon monoxide at a low temperature. When furnace is working satisfactorily under ordinary conditions, the volume of carbon dioxide in the gas should be about half that of the carbon monoxide ; or, to put it in another way, about one-third of the carbon in the gases should be in the form of carbon dioxide, and two-thirds in the form of carbon monoxide.

Suppose a furnace to be consuming one part of carbon for each one part of iron produced, which would be about 22 cwt. of coke for each ton of pig iron. Each 12 grammes of carbon consumed at the tuyeres will yield 22·4 litres of carbon monoxide, and will ultimately reduce 12 grammes of iron. 112 grammes of carbon will, in reducing iron from ferric oxide, convert 67·2 litres of carbon monoxide into the same volume of carbon dioxide.

$$\frac{Fe_2\,O_3}{(2 \times 56) + (16 \times 3)} + \frac{3\ CO}{3 \times 22{\cdot}4 \text{ litres}} = \frac{2\ Fe}{112} + \frac{3\ CO_2}{3 \times 22{\cdot}4 \text{ litres.}}$$

12 grammes of iron will therefore yield $\frac{67{\cdot}2 \times 12}{112} = 7{\cdot}2$ litres of carbon dioxide, and the escaping gas will contain :

Carbon monoxide	22·4 - 7·2 = 15·2 litres
Carbon dioxide..........	7·2 ,,

the gases being thus nearly in the proportion of 2 : 1 given above. Such a proportion under these conditions shows that the whole of the oxide of iron is being reduced by carbon monoxide at a moderate temperature. The proportion will, of course, vary with the actual quantity of coke consumed. The larger this is, the larger will be the proportion of carbon monoxide, and the less iron is reduced by carbon monoxide, the smaller will be the amount of carbon dioxide.

Decomposition of Limestone.—Limestone is always added to the charge as a flux, the proportion used varying with the nature and amount of the gangue to be fluxed away and the conditions of working. For ordinary hæmatite ores with a silicious gangue, the amount used will be about 10 cwt. of limestone for each ton of iron obtained. As the limestone descends into the hot regions of the furnace it is decomposed : $Ca\,CO_3 = Ca\,O + CO_2$. This reaction begins at a dull red heat, but does not become rapid till a bright red heat is reached, and at that temperature carbon dioxide is attacked by carbon, so that the carbon dioxide liberated by the above reaction is reduced to carbon monoxide, and in that condition leaves the furnace. Thus, the amount of carbon monoxide in the gas is increased, and carbon uselessly consumed.

Assuming a furnace to be working as already described, consuming 1 part of carbon for each 1 part of iron reduced, and that

10 cwt. of limestone is added for each ton of iron obtained, and that the ascending gas, as it reaches the zone of limestone decomposition, contains 65 per cent of nitrogen and 35 per cent of carbon monoxide, and to amount to 64 litres for each 12 grammes of carbon consumed.

Each 100 grammes of limestone decomposed will give 22·4 litres of carbon dioxide. The limestone used is half the weight of the carbon consumed, so that 6 grammes, which will correspond to 12 grammes of carbon, will give 1·34 litres of carbon dioxide. If none of this was decomposed, the composition of the gas would be :—

	Litres.	Per cent.
Carbon dioxide from limestone	1·3	13
,, ,, ,, iron reduction	7·2	
Carbon monoxide	15·2	23
Nitrogen	41·6	64
	65·3	100

If the whole of the carbon dioxide were reduced to carbon monoxide, the result would be different.

The 1·3 litres of carbon dioxide would yield its own volume of carbon monoxide, but in so doing it would take up ·7 grammes of carbon, leaving, therefore, only 11·3 grammes of the 12 to be burned at the tuyeres.

The result would be :—

	Litres.	Per cent.
Carbon dioxide from iron reduction	7·2	11·5
Carbon monoxide from reduction of limestone carbon dioxide	2·6	26·2
Carbon monoxide from fuel	13·9	
Nitrogen	39·2	62·3
	62·9	100

The ratio of carbon dioxide to carbon monoxide is in the first case 1 : 1·8, and in the second 1 : 2·3

It is probable that in most cases the reduction of the carbon dioxide, from the limestone, to carbon monoxide is almost, if not quite, complete.

It is obviously impossible to decide in any given case whether the carbon dioxide in the gases comes from the ore reduction or from the limestone, but the amount is always less than that which would be due to the two actions taken together, and is usually less than that which would be produced by the reduction of the ore by carbon monoxide, so that either some of the iron oxide is not reduced by the carbon monoxide, or the carbon dioxide from the limestone is decomposed.

Oxidation by Carbon Dioxide.—When carbon dioxide comes in contact with metallic iron at high temperatures it is reduced to carbon monoxide, the iron being oxidised. Bell made a large number of experiments on this subject, and found that when iron was heated in a mixture of carbon dioxide and carbon monoxide partial oxidation took place unless the carbon monoxide was present in large excess. Hence it follows that, if reduction is to be brought about by carbon monoxide only a small proportion of carbon dioxide must be present.

Carbon-impregnation.—This has already been partially discussed. The iron combines with the carbon in the hot zone of the furnace. It is uncertain whether this carbon is derived from carbon deposited by the decomposition of the carbon monoxide, or direct from the fuel, but probably the former is the case to a considerable extent. The action begins at about 200 deg. Cen. (400 deg. Fah.), and at about 415 deg. Cen. (788 deg. Fah.) becomes very rapid. In an experiment made by Bell at about that temperature pure peroxide of iron was reduced by carbon monoxide for seven hours, and the iron was found to be associated with 144 parts of carbon. At higher temperatures the action is slower, but may be sufficient to impart the small amount of carbon which the iron takes up.

REDUCTION OF OTHER ELEMENTS.

Silicon.—Silica is always present in the charge, in the gangue of the ore, and the ash of the coke. It is not reduced by carbon except at the temperature of the electric arc, but in the presence of metals which can combine with the liberated silicon, the reduction takes place at furnace temperatures—

$$SiO_2 + x\,Fe + 2C = Fe_x\,Si + 2CO.$$

This reaction only takes place at the very highest furnace temperature, and therefore cannot commence till near the fusion point of the charge, and the hotter the furnace the more rapid it will be. The silicon is probably present as silicates, and the more basic these are the more difficult are they to decompose, therefore the more silicious the slag, the more silicon will be reduced. Only a very small portion of the silicon in the charge is reduced, but the amount of silicon which can enter the iron under favourable conditions is very large.

Manganese is present in the ore as oxide, the oxide is difficult to reduce, and in presence of silica very stable silicates may be formed. The manganese, therefore, is always partially reduced, and partially enters the slag as silicate. For the reduction of a large proportion of the manganese present in an ore a high temperature and a very basic slag are required, so as to prevent the formation of fusible manganese silicates which may escape reduction.

Phosphorus.—This element is always present—mainly as tricalcium phosphate, $Ca_3\,P_2O_8$, ($3\,CaO,\ P_2O_5$)—in the ore, and the limestone and the phosphorus is always almost completely reduced, and passes into the iron, so that the only way to obtain an iron nearly free from phosphorus is to use materials containing only the smallest quantities of phosphates.

Phosphorus is not separated from calcium phosphate by carbon or carbon monoxide, but in presence of silica, calcium silicate is formed and phosphoric anhydride is liberated ; this is decomposed by the hot carbon, the separate phosphorus combining with the iron,

$$Ca_3\,P_2O_8 + 3\,SiO_2 + 5\,C + x\,Fe = 3\,Ca\,SiO_3 + 5\,CO + Fe_x\,P_2.$$

This reaction requires a high temperature and the presence of silica, conditions almost always present in the blast furnace, but, under exceptional circumstances, in presence of excess of bases, part of the phosphorus may pass into the slag.

Sulphur is always present in the materials charged into the furnace ; but only a small proportion passes into the metal, the amount varying with the conditions, the temperature of the furnace and the nature of the slag. The higher the temperature and the more basic the slag the less sulphur will pass into the iron. Most of the sulphur enters the slag as calcium or manganese sulphide. The atmosphere of the furnace is so strongly reducing that no, sulphur escapes in the furnace gases.

Other elements, such as chromium, copper, lead, arsenic, &c. if present in the charge, are wholly or partially reduced.

Cyanides.—Cyanides are always produced in the blast furnace. Potassium and sodium cyanides, being volatile, pass up the stack, but are condensed before they reach the top, and are therefore carried down again by the descending charge to be again volatilised and carried up. As fresh quantities are continually being formed, the amount in circulation continually increases as the furnace works. As the cyanide in the liquid condition is very fluid and has great penetrative power, it gets through the masonry, and in very old furnaces often accumulates round the tuyere arches in the form of very simple.

Alkalies are always present in the charge, usually in the form of carbonates. These are reduced by carbon at high temperatures liberating the metal, *e.g.*,

$$Na_2\,CO_3 + 2C = 2\,Na + 3\,CO.$$

The alkali metal in contact with the hot carbon and in an atmosphere of nitrogen at once forms cyanides

$$Na + C + N = Na\,C\,N.$$

Opinions differ very much as to whether the cyanides have any important influence in the reactions of the blast furnace. The general opinion is that they have not. Professor Roberts-Austen, however, says : "The cyanide acts on the last portion of unreduced oxide of iron, converting it into metal and becoming itself changed into cyanate. This is probably decomposed with the formation of an alkaline carbonate, and the elimination of nitrogen. As much as 4 cwt. of alkali metal and 2 cwt. of cyanogen per ton of iron have been repeatedly found near the level of the tuyeres. This concentration of alkali explains the fact that the furnaces reduce more readily after they have been some time in blast."* It is quite possible that these reactions may take place, but up to the present they have not been demonstrated.

Slag Formation.—As the charge becomes hot the earthy constituents combine with the silica, forming a slag. This melts, and runs down into the hearth, where it is tapped out.

Zones in the Blast Furnace.—It must be borne in mind that the reactions described above are not confined to any one part of the furnace, and that several, or all of them, may be going on side by side. The interior of the furnace may be mapped out into zones, according to the nature of the action which predominates.

1. Upper Zone of Reduction.—Here the reducing action of the carbon monoxide is predominant. Reduction takes place, carbon is deposited, and the limestone is decomposed. If coal is used as fuel it is coked.

2. Zone of Heating.—Here there is but little chemical action, the reduction of the iron is completed, and the charge is gradually heated to a high temperature.

3. Zone of Fusion.—Here the temperature is very high, silicon and other elements are reduced and the iron and slag are melted.

Composition of the Iron Produced.—A consideration of the foregoing sketch of the changes which take place in the blast furnace will show that the reductions and therefore the composition of the iron and slag produced will depend on the composition of the charge and on the condition of working, especially on the temperature of the furnace, and irons are now made of a composition required for any special purpose.

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* Introduction to the "Study of Metallurgy," second edition, p. 244.

CHAPTER VI.

THERMAL PHENOMENA OF THE BLAST FURNACE.

The Blast Furnace as a Thermal Agent.—The blast furnace is a machine for the utilisation of the energy, obtained by the combustion of the fuel, for reducing certain compounds containing iron, and melting the resulting products. The changes brought about in the furnace are therefore of two kinds, chemical and physical, and both these involve thermal changes. All chemical changes are attended with the evolution or absorption of heat (or are exothermic or endothermic), and excluding the combustion of the fuel, most of the changes which take place in the blast furnace absorb heat, and therefore require a supply of heat before they can take place. The physical changes which take place also absorb heat.

The heat is supplied by the combustion of the fuel and carried in by the hot blast and it is partly used in producing the necessary changes, and partly lost. The larger the proportion of heat utilised the more efficient will be the furnace, and for economical working the sources of loss must be ascertained, and as far as possible guarded against.

Calorific Power of Coke in the Blast Furnace.—When carbon is completely burned to carbon dioxide, each pound evolves 8,080 C.U. (14,540 B.T.U.), but when it is burned to carbon monoxide only, its calorific power is 2,400 C.U. (4,320 B.T.U.), so that the actual efficiency of a pound of carbon may very between these limits according to the completeness of the combustion.

Owing to the high temperature and excess of carbon at the tuyeres, the carbon is only burnt to carbon monoxide, but the reactions which take place higher up the furnace convert some of this into carbon dioxide, and more heat is thus evolved. Since this heat is evolved near the top of the furnace, it can play but a small part in producing the necessary changes in the furnace, and it might therefore seem that it was of little use. As already pointed out, however, if the reductions were not brought about by carbon monoxide near the top of the furnace, they would be brought about by carbon lower down, and this would lead to waste of fuel, which would otherwise have been burnt at the tuyeres. The larger the quantity of carbon dioxide in the gases near the top of the furnace, the more perfect is the combustion, but at the same time the less is the reducing power of the gas. It is found that a furnace works best when about one-third of the carbon leaves the furnace as carbon dioxide and two-thirds as carbon monoxide ; that is, when 1 lb. of carbon is burnt to carbon dioxide, while 2 lbs. are burnt to carbon monoxide. On this assumption, the heating power of a pound of carbon burnt in the blast furnace will be

$$\frac{1 \times 8080 + 2 \times 2400}{3} = 4293 \text{ C.U.}$$

$$\frac{1 \times 14540 + 2 \times 4300}{3} = 7713 \text{ B.T.U.}$$

and as coke may be taken as containing 90 per cent carbon, the heating power of 1 lb. of coke would be $4293 \times {\cdot}9 = 3863$ C.U., or 6914 B.T.U.

Suppose that the amount of carbon in the gases as carbon dioxide falls to one-fifth of that present as carbon monoxide, as is not unfrequent in small furnaces, the efficiency of the fuel becomes

$$\frac{1 \times 8080 + 5 \times 2400}{6} = 3513 \text{ C.U.}$$

$$\frac{1 \times 14540 + 5 \times 4300}{6} = 6006 \text{ B.T.U.}$$

The composition of the waste gas is therefore a most important factor in determining the efficiency of a furnace.

The Hot Blast.—In addition to the combustion of the fuel in the furnace, heat is carried in by the blast. The blast is now often used very hot, and as the air is heated by combustion of the waste gases there is considerable saving of fuel. Each ton of iron made requires approximately six tons of air, and as this can be heated to 770 deg. Cen. (1,500 deg. Fah.), a large amount of heat is carried in. Assuming 6 lb. of air to each pound of iron, and a temperature of 545 deg. Cen. (1,000 deg. Fah.), the amount of heat carried in by the hot blast for each pound of iron produced will be $6 \times {\cdot}2389 \times 5485 = 787$ C.U. or $6 \times 1000 \times {\cdot}2389 = 1433{\cdot}4$ B.T.U.

Hence considerable variation in the consumption of coke may be produced by varying the temperature of the blast. The amount of coke consumed depends on the amount of air used.

HEAT USEFULLY USED IN A FURNACE.

Reduction of Ferric Oxide.—This is the object for which the furnace is worked. The reaction which takes place is $Fe_2O_3 + 3CO = 2\,Fe + 3\,CO_2$. It is obviously complex, and is made up of two principal parts. The formation of carbon dioxide from carbon monoxide and oxygen, and the decomposition of the ferric oxide. No note need be taken at this stage of the heat evolved by the former reaction, since the heat of oxidation of all the carbon consumed is considered as part of the heat evolution of the fuel.

The calorific power of iron burning to ferric oxide is 1,780 C.U. (3,204 B.T.U.), and therefore that amount of heat will be absorbed when 1 lb. of iron is separated from the oxide. Pig iron may be taken as containing 94 per cent of iron, so that the heat absorbed by this decomposition will be 1,673 C.U. (3,011 B.T.U.) for each pound of pig iron produced.

Carbon Impregnation.—Here again the reaction is complex, $x\ \mathrm{Fe} + 2\ \mathrm{CO} = \mathrm{CO_2} + (\mathrm{Fe}_x\mathrm{C})$; but for the purpose of thermal calculation it may be considered as the decomposition of carbon monoxide, for the carbon dioxide formed will be at once reduced by the action of the hot carbon, and as before the total heat evolution is calculated from the composition of the gases. Assuming the iron to take up 4 per cent, *i.e.*, ·04 of a pound of carbon for each pound of iron, this will be for each pound of iron produced $2400 \times {\cdot}04 = 96{\cdot}0$ C.U. ($4300 \times {\cdot}04 = 172{\cdot}0$ B.T.U.).

Decomposition of Limestone.—The limestone has to be decomposed. The heat evolved by the union of 1 lb. of lime with carbon dioxide to form carbonate is 370 C.U. (666 B.T.U.), and this amount of heat will therefore be absorbed when the limestone is broken up. The carbon dioxide liberated is, to a large extent, reduced by the hot carbon, and leaves the furnace as carbon monoxide.

It has often been suggested to calcine the limestone, outside the furnace, and to charge the lime into the furnace, thus saving the heat absorbed in decomposing it. Heat would, of course, be required in the kiln, and would need the consumption of fuel, though perhaps the heat could be obtained more economically in the kiln than in the furnace. Whether the use of lime in the furnace in place of limestone would be advantageous from a purely thermochemical standpoint is uncertain. Even the best calcined limestone would contain some carbonate, and if it were exposed to the air for any length of time moisture would be absorbed, and would require heat for its expulsion. A good deal of carbon dioxide might also be taken up from the air, and at the temperature at the top of the furnace the carbon dioxide in the escaping gases might combine with the lime and convert it into carbonate, which would then have to be decomposed.

Other Reductions.—Silicon, sulphur, and phosphorus are all reduced, but the heat absorption thus produced is small, the amount of the elements reduced being usually small. The calorific power of silicon burning to silica is about 7,800 C.U. (14,000 B.T.U.), so that if a large amount of silicon were reduced the heat absorption would be considerable.

Manganese is partially reduced, so are phosphorus and some other elements, and these reductions absorb a certain amount of heat.

Sources of Loss of Heat.

Decomposition of Water.—The blast always carries in with it a certain amount of water, which is decomposed by the hot carbon, hydrogen being liberated and carbon monoxide produced. Each pound of hydrogen liberated in the gas represents 9 lb. of water, and a heat absorption of 34,000 C.U. (63,600 B.T.U.).

Heat Carried off in Gases.—This is always a very large item. Assuming the gas to have the following composition by weight—

Carbon dioxide	12·80
Carbon monoxide	25·53
Hydrogen	·07
Nitrogen	61·60

and to escape at a temperature of 222 deg. Cen. (432 deg. Fah.), the heat carried away will be—

$$\begin{array}{rcrcrcr} & & & & & & \text{C.U.} \\ 12{\cdot}80 & \times & {\cdot}2169 & \times & 222 & = & 616{\cdot}50 \\ 22{\cdot}53 & \times & {\cdot}2450 & \times & 222 & = & 1226{\cdot}00 \\ {\cdot}07 & \times & 3{\cdot}4090 & \times & 222 & = & 52{\cdot}98 \\ 61{\cdot}60 & \times & {\cdot}2438 & \times & 222 & = & 3334{\cdot}00 \\ \hline & & & & & & 5229{\cdot}48 \end{array}$$

5229·48 C.U. (9413·06 B.T.U.) for each 100 lbs. of gas. It will be seen, therefore, how important it is to keep the temperature of the escaping gas low. Each pound of iron reduced is accompanied by 5 to 8 times its own weight of gas, and if this escapes at a high temperature a large quantity of heat may be carried away.

Heat Carried out by Liquid Products.—The pig iron formed has to be melted. Its latent heat may be taken as 320, so that each pound of iron will carry out that amount of heat quite irrespective of its sensible heat. The latent heat of slag may be taken as 550, which will therefore be the amount of heat carried out as latent heat by each pound of slag.

Other Sources of Loss.—Heat is lost by radiation through the walls of the furnace, by absorption into the foundations, and in other ways. Heat is also carried out by the tuyere water, and is absorbed in numerous other ways, the amount of which cannot be accurately estimated.

Example.—As an example, the following case from Gruner's " Blast Furnace Phenomena "* may be taken.

The furnace was at Consett, working a mixture of Cleveland and hæmatite ores, and yielded 60 tons of iron in 24 hours.

		Carbon.
Coke consumed per pound of iron	·910 lb. =	·819 lb.
Ore	2·085 lb.	
Limestone	·406 lb.	
Slag produced	·950 lb.	
Temperature of blast	710 deg. Cen.	
,, ,, waste gases	248 deg. Cen.	

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* English edition.

Hence for each pound of iron produced there was—

		Lb.
Carbon in coke		·8190
,, ,, limestone	·406 × ·12=	·0485
		·8675
Carbon absorbed by iron		·0300
,, in gases		·8375

The ratios $\frac{CO_2}{CO}$ by weight was found to be ·625.

The gases contained by weight—

			Lb.	
Carbon dioxide	·8715	containing	·2375	carbon
,, monoxide	1·400	,,	·6000	,,
Nitrogen	2·867		·8375	
Weight of gases	5·1385			
Water from coke	·0225			
	5·1610			

Weight of air, blown in, obtained from nitrogen in blast—

	Lb.
Oxygen in dry air	·856
Nitrogen	2·867
Weight of air	3·723
Moisture in air	·023
	3·746

Heat carried in by blast :—

3·746 × 710 × ·239 = 636 C.U.

Heat produced in furnace—

Due to carbon dioxide :—

(·2375 – ·0487 ×) 8080 = 1525 C.U.

Due to carbon monoxide :—

·6000 × 2400 = 1440 C.U.

Heat due to combustion of carbon, 3965 C.U.

Hence the heat evolved by the combustion of the carbon is about 49 per cent of that which it would evolve if completely burned to carbon-dioxide.

The amount of carbon burnt in the zone of combustion can be readily obtained. The ·94 lb. of iron in 1 lb. of pig iron is united with ·403 lb. of oxygen, and this requires for its reduction a quantity of carbon monoxide containing the same amount of oxygen and ·302 of carbon. If this carbon dioxide were not re-converted into carbon monoxide, it, with the carbon dioxide of the limestone, would escape as such; but the gases only contained ·8715 lb. of carbon dioxide, therefore some of the carbon dioxide was reduced to carbon monoxide, and the amount of carbon thus oxidised is the same as that in the carbon dioxide reduced, viz.: ·302 + ·0485 – ·2375 = ·113 lb. and ·113 × 2400 = 271 C.U.

The conversion of carbon monoxide into carbon dioxide also evolves heat. This is: ·2375 – ·0485 = ·1890, which × 2·3 will give the amount of carbon monoxide, so that ·1890 × 2·3 × 2400 = 1043 is the amount of heat evolved in C.U.

And the total amount of heat evolved in the zone of reduction is 271 + 1043 = 1314 C.U.

The heat evolved at the tuyeres will be—

·819 × 2400 = 1965 C.U.

The total heat in the furnace is therefore—

Heat evolved in zone of reduction ..	1043
Heat evolved at tuyeres	1965
Heat in blast	636
	3644 C.U.

The heat absorbed in the furnace is—

		C.U.
Reduction of ores and fusion of iron		2314
Fusion of slags	·950 × 550=	522
Decomposition of limestone	·406 × 373=	152
Evaporation of water in coke ...	·0225 × 666=	14
Decomposition of vapour in blast .	·023 × 322=	74
Heat of gases	5·161 × 248 × ·237=	303
		3379
Loss by radiation, &c., difference		265
		3644 C.U.

Sir Lowthian Bell's Estimate.—Bell gives an estimate of the heat distribution from a Cleveland furnace in a somewhat different form. He works out the sources of loss, and then deduces the amount of fuel which should be required. The figures are given in centigrade units for each 20 lbs. of iron produced.

	Lb.			C.U.
Evaporation of water in coke	·58	× 540 =		313
Reduction of 18·6 lbs. of iron from Fe_2O_3	18·6	× 1780 =		33108
Carbon impregnation	·6	× 2240 =		1440
Expulsion of CO_2 from limestone	11	× 370 =		4070
Decomposition of carbon dioxide from limestone	1·32	× 3200 =		4224
Decomposition of water in blast	·05	× 34000 =		1700
Reduction of phosphoric acid, silica, &c.		=		3500
Fusion of pig	20	× 330 =		6600
Fusion of slag				15356
Heat usefully used				70311
Transmission through walls of furnace			3600	
Carried off in tuyere water			1800	
Expansions of blast and escape into foundations			3389	
				8789
Carried off in gases				7900
				87000

Heat evolved by one unit of coke so burned as to give one volume of carbon dioxide to two volumes of carbon monoxide

$$\frac{1 \times 8000 + 2 \times 2400}{3} = 4266. \text{ C.U.}$$

Coke may be taken as containing 90 per cent of C., so that each pound of coke will give $4266 \times \cdot 9 = 3840$ units of heat.

The heat carried in by the blast at 540 deg. C. is about 12000 units for each 20 lbs. of iron, so that $87000 - 12000 = 75000$ units has to be supplied by the combustion of the fuel, and

$\frac{75000}{3840} = 19\cdot 53$ are the pounds of coke that will be required.

CHAPTER VII.

THE BLAST FURNACE.

The Blast Furnace.—The external form of the blast furnace is familiar to all. Externally it is a cylindrical, or sometimes slightly conical, stack of masonry either bound with iron bands or more usually cased completely with iron plates. The lower portion is in the form of an inverted frustrum of a cone, and the upper portion is, therefore, carried on a series of iron or masonry columns.

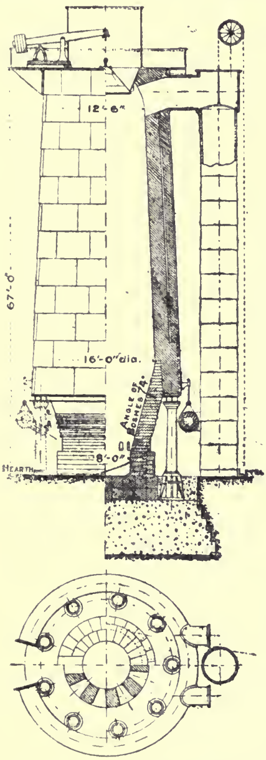

Fig. 21.—Blast Furnace at Wishaw.

Internally the furnace widens out from the top downwards for about two-thirds the distance down; then it narrows more rapidly and terminates in a cylindrical portion at the bottom. The upper conical portion is called the stack, the lower inverted cone the bosh; this name being also often applied to the widest portion where the two meet, and the lowest portion is the hearth. Sometimes the lines of demarcation between the portions are sharp, but, as a rule, they are curved one into the other.

Fig. 21 is a modern Scotch furnace, half in section, half in elevation, and the various parts are well shown.

The iron columns carry an iron lintel plate on which the upper part of the masonry rests, this being so built as to be quite independent of the lower part. The body of the furnace is a shell of masonry—brick or stone—about 30 in. thick, and outside this is the casing of $\frac{3}{8}$ in. to $\frac{3}{4}$ in. iron plate. The columns may be from 10 ft. to 20 ft. high, the tendency in modern furnace construction being to make them as high as possible. Inside the shell is built the lining of refractory, not too silicious firebrick, about 30 in. thick, which is continued downwards to form the boshes and the hearth. The shell is built and lined before the hearth and boshes are put on. The hearth and boshes being subjected to the highest temperature and the greatest wear, it is essential that they should be relieved of all pressure except their own weight, and that they should be so constructed that they can be removed and replaced without interfering with the rest of the masonry.

The older furnaces were much lower than those now in use; they were built much more solidly, were conical instead of cylindrical, and the shell was carried on a heavy mass of masonry, through which arches were left to allow access to the hearth. The lower part was usually rectangular externally, and in some cases they were rectangular all the way up. In the interior the various portions were sharply separated. Fig. 22 is an old Scotch furnace, erected in 1832.

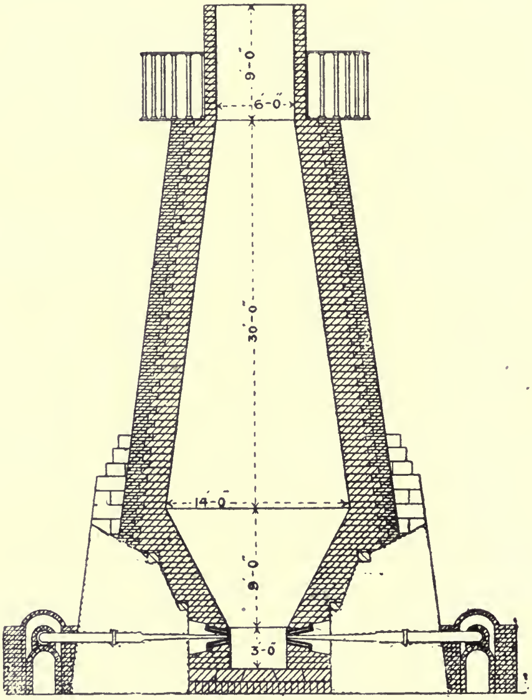

Fig. 22.—Old Furnace at the Clyde Ironworks.

Size and Form of the Furnace.—No absolute rules can be laid down as to the best size and form of the furnace, for these obviously depend much on the nature of the materials to be used and the conditions of working.

As a rule—within limits—the higher the furnace the more economically will it work. The advantages of a high furnace are that the gases are more perfectly cooled, and therefore escape at a lower temperature, and that the zone in which reduction can take place by carbon monoxide is longer, so that the temperature of the descending charge falls more gradually.

A height is soon reached, in any case, beyond which increased height ceases to exert any additional cooling effect on the gases, for the reactions by which the iron is reduced evolve heat, and as these reactions commence immediately the ore comes in contact with the carbon monoxide, the temperature of the gases cannot fall much below 300 deg. Cen. (570 deg. Fah.), and when the height of the furnace is so great that reduction is practically complete in the upper zone of reduction, increased time of contact with carbon monoxide can be no use.

What is the most advantageous height for a furnace will depend on many conditions, the strength of the materials, the temperature of the blast, and the rate of driving being the principal. It must be remembered that increased height means additional cost not only of erection, but of hoisting the materials, and it will therefore never be economical to make the furnace so high that the saving of fuel by increased height is more than counterbalanced by these increased costs.

A limit is frequently fixed for the height of the furnace by conditions other than those of economy. The height must not be so great that the weight of the column of materials will crush the fuel, as this would seriously interfere with the ascent of the gases. With hard Durham coke, furnaces 80 ft. to 100 ft. high can be used without crushing taking place, but with the soft splint coals used in Scotland, 60 ft. is about the greatest satisfactory working height.

Diameter of Furnace.—The ratio of the diameter of the furnace at its widest part to its height varies very much, but it is usually between one-fourth and one-third. If the diameter be less than one-fourth the height, the furnace may be called a tall furnace, whilst if it be more than one-third the height, it may be called a low or squat furnace. In most modern furnaces the ratio is about 1 to 3·5.

The diameter should be as large as possible, but not so large as to prevent a uniform distribution of the ascending gas. The amount of gas depends on the amount of air sent in, and therefore the greater the diameter of the furnace the slower will be the ascending current of gas. The effect of increased diameter is therefore, within limits, much the same as that of increased height, and very tall furnaces are often built proportionately narrower than those of less height.

Size of Hearth.—The hearth is to contain the molten metal and slag which accumulates between the tappings, and it must be large enough to hold all this. It must not be so wide that the air from the tuyeres, which enters just above it, cannot penetrate to the centre of the charge, or a pillar of coke, &c., may accumulate in the middle of the furnace. The diameter of the hearth will therefore depend somewhat on the blast pressure which is used, and the porosity of that portion of the charge which is solid at the tuyere level. With a blast pressure 3½ lbs. to 4 lbs. on the square inch, a hearth 8 ft. or 9 ft. in diameter is the largest that can be satisfactorily used, but with the more powerful blast used in modern practice the diameter may be increased to 11 ft. or 12 ft. The diameter of the hearth should be about half that of the furnace at its widest part, unless this would be too great for the blast to penetrate. The hearth must be deep enough to hold the metal, and, as the furnace is usually tapped once in 12 hours, this will be 12 hours' production, or from 15 to 100 tons, according to circumstances. It must be borne in mind that the hearth will also contain a large quantity of solid coke pressed into it by the weight of the superincumbent charge in addition to the molten iron.

Scotch furnaces tapping about 50 or 60 tons of iron in the 24 hours have hearths about 8 ft. in diameter and 6 ft. deep. Such a hearth would have a capacity of about 300 cubic feet, and would hold about 60 tons of iron.

Stock Line.—The level to which the furnace is charged is called the stock line. In furnaces using the bell and cone-charging apparatus this must be from 6 ft. to 10 ft. below the top of the furnace. The diameter at the stock line is usually about two-thirds of that at the bosh.

The Throat.—When open-topped furnaces were in use the top of the furnace was contracted to form a throat 10 ft. or 12 ft. in diameter for charging, this being surrounded by the brick tunnel head. With the bell and cone this is not necessary, at least not to the same extent, the bottom of the bell fixing the charging diameter. The bell is usually from 10 ft. to 15 ft. in diameter, but its size bears no relation to that of the furnace. The edge of the bell, however, should be about 2 ft. from the furnace wall.

The charge never descends with perfect regularity, the portions at the centre always going down more rapidly than those at the side. The ascending current of gas is also irregular, the gas tending to creep up the wall of the furnace or to find its way through the coarsest materials. The coarser portions of the charge should therefore be thrown towards the centre of the furnace, so as to encourage the ascent of the gas there rather than at the sides. For this reason the bell should be as large as possible, so as to throw the charge near the furnace wall and allow the larger fragments to roll towards the centre. With a small bell there will always be a tendency for the coarse materials to roll, to some extent, towards the wall.

Angle of Bosh.—The diameter of the various portions of the furnace and the depth of the hearth being fixed, there is only one point more to be determined to give the outline, and that is the angle of the bosh. A flat bosh is very objectionable, as the ascending current of gas may not reach the corners, and unacted on materials may accumulate. Too steep a bosh is also objectionable, as it is apt to cause the charge to jam as it comes down. The angle of the bosh, that is, the angle of slope with the horizontal, is now almost invariably made about 75 deg.

Contour of Furnace.—As a rule, all sharp angles are avoided, the parts being rounded off one into the other.

Blast Furnace Shell.—The outer shell of the furnace is cylindrical or slightly conical, and is built of ordinary brick or stone, usually the former. It is either bound with strong iron bands, or, preferably, is cased entirely with sheet iron. Holes are left through the masonry to allow of the escape of moisture from inside. The shell rests on a series of lintel plates carried on supports, rolled steel girders bent to the form of the furnace being now usually used, these being carried on iron columns 12 ft. or 20 ft. high. The higher columns are now coming into general use, as they allow readier access to the hearth, and also promote the cooling of the bosh.

The outer shell should be as thin as possible, consistent with strength. It is usually about 30 in. thick, but in cased furnaces may be made considerably less. In a banded furnace the lining has to bear the whole weight of the structure, but in a cased furnace the weight is largely borne by the casing, and this is a very great advantage, as there is much less chance of distortion taking place. The charging gallery is carried on the top of the shell, and is supported on brackets bolted to the casing. In many modern German furnaces the charging platform is carried on an iron scaffolding quite independent of the furnace, so as to relieve the latter entirely of the stress. Under these circumstances the walls can be built much thinner.

Furnace Lining.—The furnace is lined with refractory bricks. The lining is built inside the shell, but quite independent of it, and is usually separated from it by a layer of ashes or similar material about 2 in. thick. It is built up from the lintel plate. In order to secure tight joints the bricks are moulded to the curve of the furnace, so that their sides are radii. The bricks for each layer will thus be different in form, and drawings are made for each set.

Fire-clay bricks are usually used. They should be refractory, but not too silicious. The same bricks may be used all the way up, or cheaper and less refractory bricks may be used near the top where the temperature is much lower.

The Hearth.—This is the cylindrical bottom portion of the furnace in which the molten slag and metal collects. It must be large enough to contain the molten charge. This is one of the most important parts of the furnace, and requires to be built with great care, as it is necessarily subjected to very high temperatures and to the corrosive action of the slag.

The floor of the hearth is first made. It must be of very refractory material, and must be so built that should molten metal find its way through it, the bottom cannot be lifted up. It is therefore made so as to be practically in one piece, and is extended as far as the outside of the hearth walls, so that the weight of the furnace may be upon it, and help to keep it down. Several methods of making the hearth bottom are in use.

(1) The bottom is made of solid blocks of refractory sandstone, carefully worked together, and 6 ft. to 9 ft. thick. Such a hearth is very durable, but is very costly to make.

(2) The bottom is built in the form of an inverted dome, Fig. 23, the bricks being moulded to the required form. Such a hearth will be from 3 ft. to 6 ft. thick.

(3) The hearth is made of blocks or "lumps" of fire brick, about 12 in. to 18 in. thick, each made with a projection on one side and a recess on the other, so that each block fits a little beneath its neighbour, and, therefore, one cannot be raised without raising the whole. Two layers of such blocks are usually used, Fig. 24.

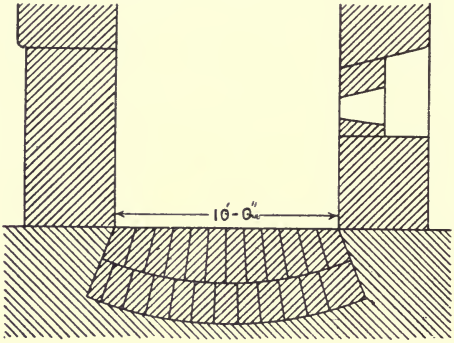

Fig. 23.

(4) The bottom is made of a concrete made of fire clay, burnt clay and coke, rammed in in thin layers to a depth of about 6 ft., Fig. 25.

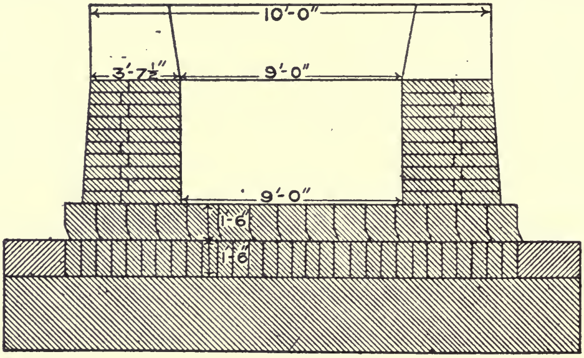

Fig. 24.

All these forms of bottom are in use, and have given satisfaction.

The hearth wall is built up on the bottom to a height of 6 ft. or so, the side walls are about 3 ft. thick, and are usually built of large fire-clay blocks moulded to the required form, and set so as to break joint. The circular form of the hearth is ensured by the use of a frame pivoted at the centre, which acts as a template.

To strengthen the hearth, it is usually completely cased in cast-iron plates bolted together by suitable flanges, openings being left for the metal and slag tap holes.

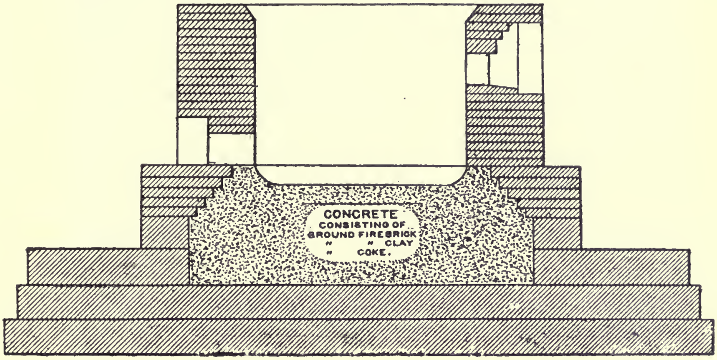

Fig. 25.

The Front of the Furnace.—Through the masonry of the hearth two openings are left about 12 in. high and 6 in. wide. The one is at the bottom of the hearth, the other at the top, and they are not vertically one above the other. The bottom hole is for tapping out the metal. Before the furnace is started it is built up with bricks, leaving a tap-hole about 6 in. in diameter, and it is usually protected by an iron plate.

The upper hole is for tapping out the slag. Before the furnace is started it is partially bricked up, an opening being left for the escape of the slag, this being sometimes protected by a water tuyere.

Whilst the furnace is at work these holes are stopped with fire-clay, and when the furnace is to be tapped the clay is driven in by means of a long iron bar and a sledge hammer. The metal is usually tapped once in twelve hours, the slag once in six hours, or oftener.

Open Furnaces.—This type of hearth is entirely closed except for its tap holes, such closed hearths are now almost universal, but the earlier furnaces were somewhat differently arranged.

The hearth was not circular, but was extended a little in front. The bosh being carried over the projecting portion by a masonry arch or an iron girder (sometimes kept cool by water) called the tymp-arch. The front of the hearth was partially closed by a masonry dam, which was protected by an iron dam plate. The tap hole passed through the dam and dam plate, and the slag flowed

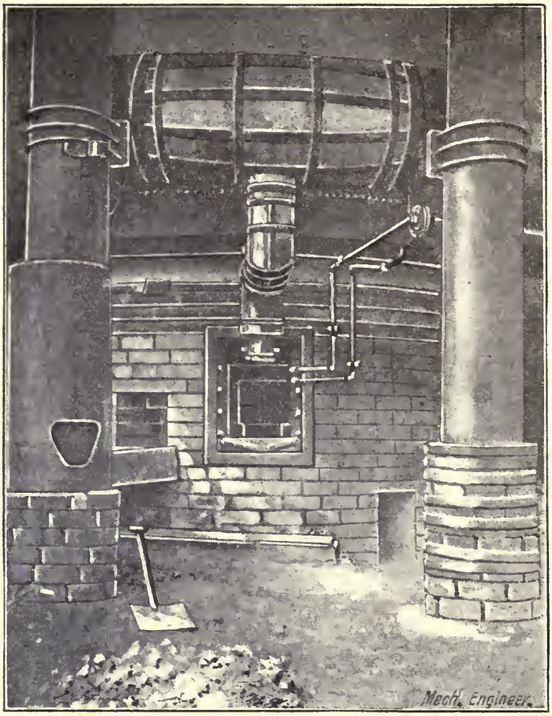

FIG. 26.—Front of a New Furnace showing Tap Hole, Slag Hole, and Tuyere Arch.

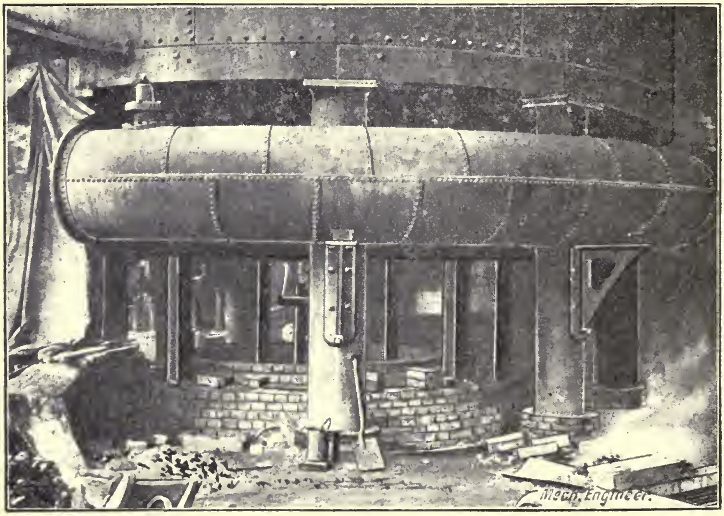

FIG 27.—Furnace Hearth in Course of Construction.

away over the top of the dam through a groove, the slag notch, cut in the top, and then away by an inclined plane called the cinder fall. When the furnace was at work, the space between the top of the dam and the tymp-arch was closed with clay, an opening being made at the notch for the escape of the slag.

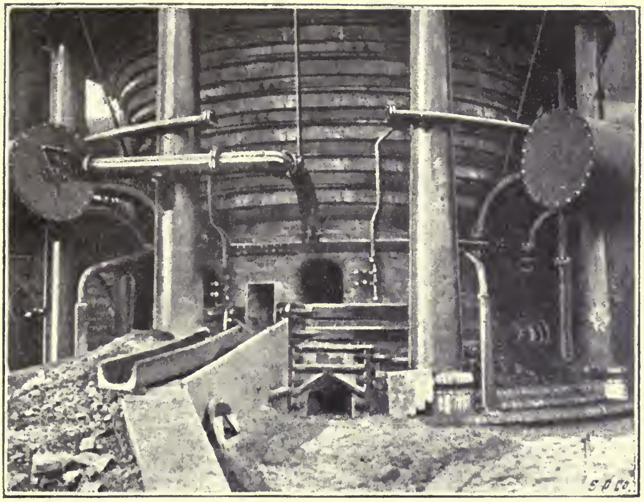

Fig. 28.—Front of Furnace showing Tuyere Arch (the Tuyere not yet in Position), and Openings for the Metal and Slag Tap Holes.

The Boshes.—At the top of the hearth the boshes commence, and just where the furnace begins to widen are placed a series of arched openings, round or ∩ shaped, eight or more in number, for the insertion of the tuyeres. These are now usually evenly spaced round the furnace, but in the older furnaces in which access

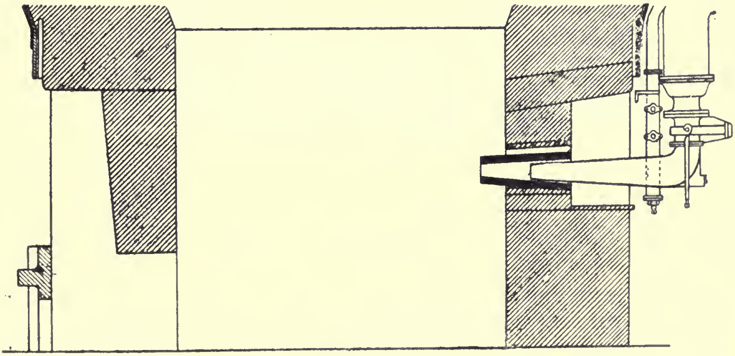

Fig. 29.—Hearth of Cleveland Furnace, showing Tuyere Tube, Water Tuyere, and Open Front.

could only be allowed to the hearth by arched spaces at four sides, three tuyeres were used, or if more were needed, six, two in each arch, the fourth arch being occupied by the slag and tap-holes, but having no tuyeres. In modern furnaces a tuyere is placed over the tap hole. In some cases the bosh begins to widen at the bottom, at others at the top of these tuyere openings.

The bosh is built of masonry 24 in. to 36 in. thick, it is carried out in a series of steps, either, alternate steps being banded with iron bands, or more rarely the whole bosh being cased with iron. The masonry is built up till it meets the lining, where the two are built firmly together.

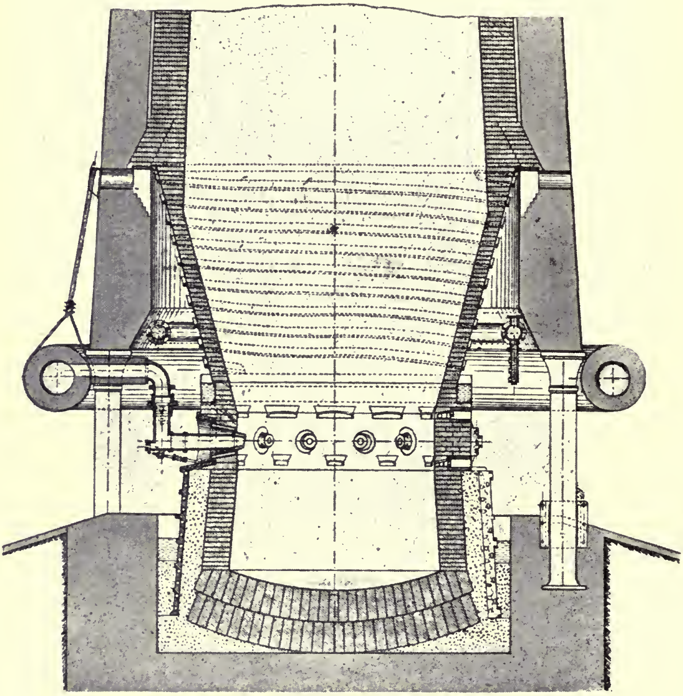

Fig. 30.—Sahlin's Blast Furnace Bosh and Bosh Jacket.

The bosh must be built of refractory fire bricks. Basic bricks and also carbon bricks (made by grinding hard coke with tar, moulding into blocks under great pressure and firing in a muffle at a low temperature) have been suggested, but neither of them have come into use.

Protecting the Bosh.—In small furnaces, and those used with a blast only moderately heated, the cooling through the walls of the bosh is so rapid that the masonry becomes coated with a layer of slag, which protects it from corrosion. With large furnaces driven very rapidly, and with a very hot blast, the bosh would be rapidly destroyed. To avoid this, various methods of cooling the bosh are in use, and have become quite general, except in the case of small furnaces.

The usual method is by the use of water blocks. These are iron or gun-metal blocks with a pipe cast into them through which water can be made to circulate, so as to keep the blocks cool. These blocks produce cool spots on the inside of the bosh, round which slag accumulates, and thus protects the masonry. A large number of blocks are used, usually built in in tiers, the water being allowed to run out into an open channel so that the foreman can see that it is flowing freely.

Mr. Sahlin has described an arrangement* which is said to be very effective. The bosh is cased with iron, and round the outside are two open iron troughs arranged spirally and terminating in a circular discharge trough. The troughs are made of 1½ in. by 1½ in. steel bar, 8 in. by ¼ in. steel plate, joining respectively the bottom and sides of the trough. The vertical distance from the bottom of the trough to the one above or below is 14 inches. Such apparatus is far less costly than blocks.

When external cooling is used, the bosh is built as thin as is consistent with strength, and is always plated, *i.e.*, cased with iron.

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* Journal of Iron and Steel Institute, 1901, vol. 1, p. 236.

CHAPTER VIII.

BLAST FURNACE ACCESSORIES.

Furnace Top.—The top of the furnace is always paved with iron plates, and is made sufficiently wide to furnish a charging gallery, from which the workmen can charge the furnace. In the older furnaces the thickness of the masonry was quite sufficient, but in modern furnaces an overhanging gallery carried on brackets is necessary. The gallery should be at least 6 ft. wide.

In the older furnaces the throat or top opening was surrounded by a brickwork chimney—the tunnel head—through which openings were left for charging, and the gases from the furnace were allowed to escape and burn to waste in the air. The value of the waste gases is now understood, and practically all furnaces are provided with closed tops, so that the gases can be drawn off and burned usefully. Obviously the top must be so arranged that the charge can be readily and rapidly introduced with but little escape of gas.

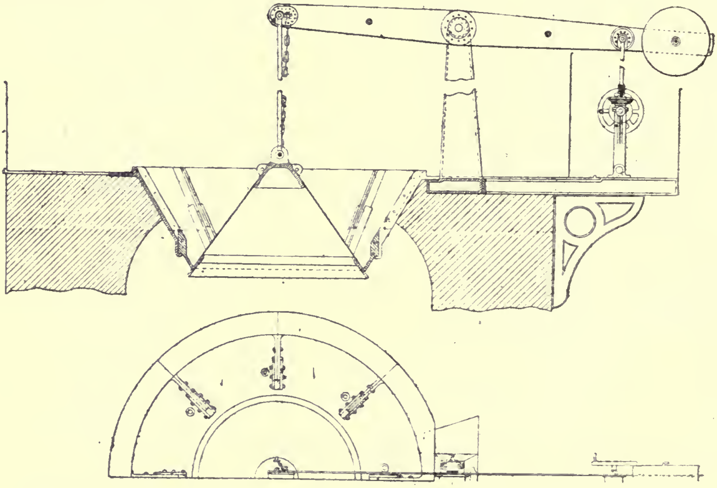

FIG. 31.—Bell and Cone Charging Arrangement (Composite Bell).

Bell and Cone.—This is the form of charging arrangement which has now become almost universal. An inverted cone (Fig. 31), made of several pieces of cast iron bolted together, is placed in the throat of the furnace and securely bolted to the charging floor. This is the cone. Very frequently a lower ring of cast iron is bolted to the bottom of this so that it can be readily removed to allow of the bell being raised if necessary.

The bell is an iron cone hung within the cone, and of such size that when drawn up it fits closely against the bottom of the cone, and when lowered leaves an annular space by which the charge can drop into the furnace. The bell is sometimes made in one casting, but, as these cast-iron bells are very heavy, composite bells are generally used.

A composite bell consists of a cast-iron headpiece, into which a malleable iron hook is cast, and on which are two lugs, to which the safety chains are attached, to prevent loss of the bell in case of fracture of the main hook or chain. The bottom of the bell is an iron ring, cast in segments and bolted together. The head and the bottom ring are checked to receive plates of malleable iron. The body of the bell consists of plates, usually six in number, of malleable iron riveted firmly to the head and bottom pieces, the joints being covered and the whole stiffened by a series of T-pieces riveted by the head to the plates, and at one end to the head-piece, and at the other to the bottom ring.

The bell is attached to a counter-balanced lever, supported on a cast-iron column, the balance weight being sufficient to bring up the bell, when there is no charge on it. Above the bell is hung a brazier of burning coal, so as to ignite, at once, any gas which escapes from the furnace when the bell is lowered, and thus prevent the formation of an explosive mixture of air and gas.

Various means of operating the bell have been devised, such as a winch and chain, a steep threaded screw, a toothed wheel working in rack, &c. The most simple and satisfactory arrangement is an hydraulic one. A cylinder of cast iron is fitted with a piston, the rod of which is attached to the weighted end of the bell lever, and this rod is provided with a catch by which it can be held in place when the bell is up. The cylinder is full of water, and the parts above and below the piston are connected by a tube fitted with a stopcock. The balance weight is so adjusted that its weight is greater than that of the bell, but less than that of the bell and charge. When the bell is to be lowered the catch is released, and the stopcock opened, the bell slowly descends, forcing the water from the upper to the lower side of the piston. As soon as the charge is off, the weight of the balance brings the bell back, the water being forced now from the lower to the upper side. As soon as the bell is fully up, the stopcock is turned and the catch is secured. It will be seen that the rising and lowering of the bell is automatic, the water cylinder serving to regulate and steady the motion. As the end of the beam moves in an arc of a circle, the water cylinder is pivoted at the bottom to avoid the need for a parallel motion. The time required for opening and closing the furnace by this arrangement is about twenty seconds. In the figure shown, the bell is operated by a steep screw working in a nut which can be rotated, but cannot move up or down.

Other Charging Appliances.—One disadvantage of the bell and cone is that it takes up a portion of the height of its furnace, about 6 ft. to 10 ft. being required, according to circumstances. With a tall furnace this is of little moment, but with a short furnace this space cannot be spared. The simplest arrangement for overcoming this difficulty is to roof over the furnace mouth with a dome or a flat roof, provide a gas-pipe in the centre, and arrange around it four trap doors with suitable balance weights, which can be opened to let in the charge.

Many engineers think that the gas should be drawn off from the centre of the furnace rather than from the side, as this, they contend, ensures a more uniform distribution of the gas. Many German furnaces are fitted with a bell so modified as to allow of this. The bell is provided with a central opening, through which the gas-pipe enters. Round the top of the bell is a strong ring by which it is carried, and on which is a watertrough into which a flange attached to the gas-pipe drops, thus making an efficient water seal when the bell is up.

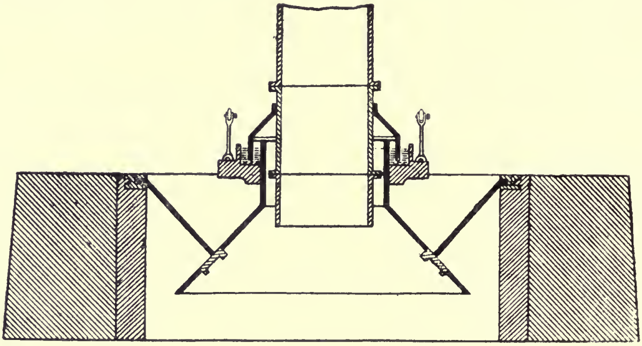

FIG. 32.—Bell and Cone Charging Arrangement (with Central Gas Outlet).

Arrangements have also been suggested to allow charging without opening the furnace to the air, so as to avoid the possibility of explosion in case of reduced pressure in the furnace. The simplest plan is to increase the height of the furnace by six or seven feet, and fit a second bell above the first. The lower bell is carried on an iron rod, which passes through a stuffing box in the centre of the upper one. The charge is put on to the upper bell. This is then lowered, and the charge falls on to the lower bell. As soon as the upper bell is in position again, the lower one is let down, and the charge drops into the furnace.

In the early days of gas recovery, many plans were suggested for drawing off the gas below the stock-line without closing the top of the furnace, but the recovery of gas was never satisfactory, and the working of the furnace was always more or less interfered with.

Test-holes.—The top of the furnace is always provided with a series of holes, which can be closed by plugs, through which rods can be put down so as to ascertain the actual height of the charge. In the case of bell and cone these are usually placed in the upper part of the bell.

Drawing off the Gas.—The gas passes out of the furnace by a pipe at the side which leads to the downcomer pipe. At the top of the downcomer is a stand pipe opening into the air, valves being provided by which the gas can be cut off from the main and directed into the stand pipe. In many furnaces where the gases are not treated for the recovery of the by-products, and gas is in excess of what is needed for the boilers, the stand pipe is left permanently open, so that gas is always burning at the top of it, but in most furnaces the whole of the gas is carried away, there being no flame at the stand pipe except when the gas is cut off from the main. It was at one time usual to close the downcomer valves and open those to the stand pipe before lowering the bell. This is unnecessary, as there is always an excess of pressure in the furnace, and it is now very rarely done.

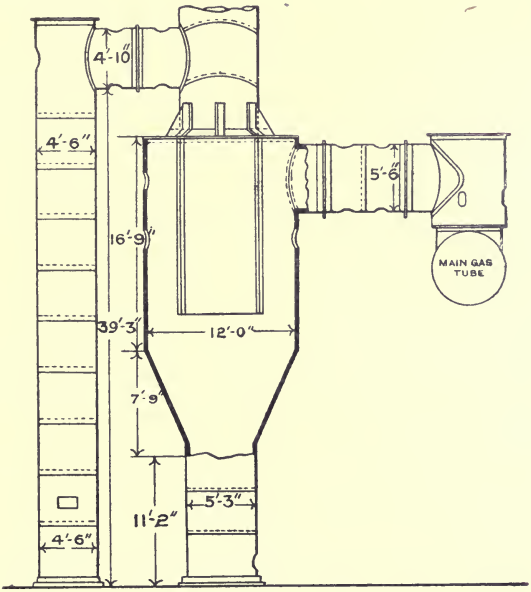

FIG. 33.—Dust Catcher (Glengarnock).

Dust Catcher.—The gas always carries out with it a considerable quantity of dust. To remove this it is passed through a dust catcher (Fig. 33), which is simply a chamber so arranged that the rate of flow of the gases is diminished, and the direction of current altered so that the dust may subside.

Horse-shoe Main.—Round the furnace, at a convenient height, either inside or outside the iron columns, and carried on iron brackets attached to the columns, or suspended by rods from the lintel plate, runs the horseshoe main, by which the air is supplied to the furnace. It is usually circular, about 18 in. in diameter, thickly lined with fire-brick or coated with non-conducting material, and, except in the case of cold-blast furnaces, externally covered with some non-conducting compositions. It may be inside or outside the columns, the latter position being the better, and it must be high enough above the ground not to interfere with the working of the furnace. Opposite each tuyere opening is a downcomer pipe, by which the air is conducted to the tuyere. Each downcomer should be provided with its own valve, so that the blast through any particular tuyere can be regulated, or a tuyere removed for repairs.

Tuyeres.—The tuyeres are iron—or, more rarely, bronze—tubes, with a diameter at the narrow end, by which the air leaves, of 3 or 4 in. The large end of the tuyere is attached to a horizontal pipe, which can be attached to the downcomer. At the end is a valve, in the centre of which is an opening covered with mica or blue glass, by which the furnaceman can see into the furnace and thus form an idea as to how it is working. The spot of light thus seen is called the eye of the furnace.

An opening on the upper side of this tuyere pipe is widened out so as to receive the lower end of the downcomer, which is cast either spherical or conical, so as to fit it. An iron loop hangs from two projecting pins cast on the downcomer and passes under the tuyere tube, which is then wedged up securely; the tuyere is thus held very firmly, but in such a way that it can be very readily removed.

In the old blast furnaces the downcomer was connected to the tuyere by a leather tube, called the goose neck, and this name is often still used for the connecting pipes.

Water Tuyeres.—When the air was sent cold into the furnace its cooling action was sufficient to prevent the destruction of the tuyeres. Now that air is used at a very high temperature this is not the case, and the tuyere has to be surrounded by a cooling apparatus, or "water tuyere." The form of water tuyere most used is that known as the Scotch tuyere, which was invented by Mr. Condie, of Calder, immediately after the invention of the hot blast, and it is hardly too much to say that without the water tuyere the hot blast could not have been a success.

Scotch Tuyere.—This consists of a slightly conical spiral of wrought-iron tube, about 1 in. in diameter, embedded in cast iron. The tube is coiled up, placed in a mould with a suitable core, and the mould is filled up with molten cast iron. The tuyere tube rests in the central space, and is thus surrounded by the mass of cast iron, through the pipe in which water is kept circulating.

Staffordshire Tuyere.—This, which is often called the box tuyere, consists of a slightly conical cast-iron box, in which is a tube through which the tuyere nozzle passes. Cold water is kept circulating through the annular space, and thus keeps the tuyere cool.

Open Tuyere.—This is something like the Staffordshire tuyere in form, but the back is so low that it holds very little water. The cooling water is supplied in the form of a spray.

Many other forms have been suggested, but these are the only ones which have come largely into use.

Vacuum Tuyere.—In all the types of tuyere described the water is supplied under pressure. Should a tuyere break, water will rush into the furnace, and even if it does not produce an explosion, may seriously cool the charge. To overcome this difficulty, the Foster vacuum tuyere has been introduced.* The water is drawn through the tuyere by suction, so that should a leak occur, water does not flow into the furnace, but the gases are drawn into the water pipes, and the accident is at once noticed.

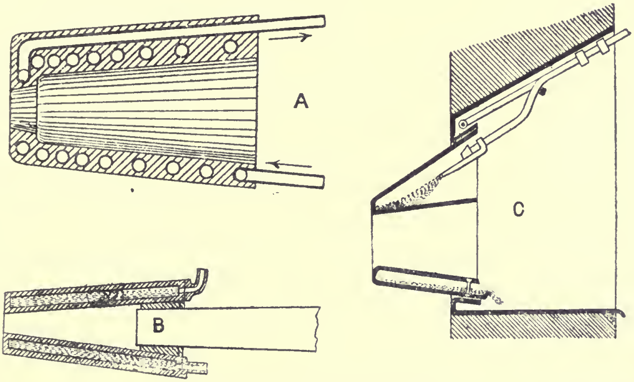

Fig. 34.—Water Tuyeres.—A. Scotch Tuyere. B. Staffordshire Tuyere. C. Open Tuyere.

Coolers.—With the use of very hot blast the ordinary water tuyeres have been found to be insufficient, and additional cooling, therefore, to be necessary. This is provided by an additional external cooler or tuyere, usually of the Scotch type. It is a circular or D-shaped casting, in which is cast a wrought-iron pipe, through which the water can circulate. It fits into the tuyere opening, and the ordinary water tuyere fits inside it.†

The coolers and water tuyeres must be firmly luted in their places. The water tuyeres may end flush with the inner wall of the furnace, or they may be made to project—or overhang—into the furnace. The latter arrangement is said to give more even distribution of the air,

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* Journal of Iron and Steel Institute, 1902, vol. i.

† For other forms of double tuyeres, see Pilkington, Proceedings of South Staffordshire Iron and Steel Works Managers, 1891-92.

but it practically decreases the diameter of hearth. By carrying the zone of combustion inward it may protect the masonry somewhat, but the ends of the tuyeres are liable to damage, and therefore any large overhang is very objectionable, and the need for it indicates faulty furnace design. The tuyeres are usually directed radially, so that they point to the centre of the furnace, but they may be inclined from this direction.

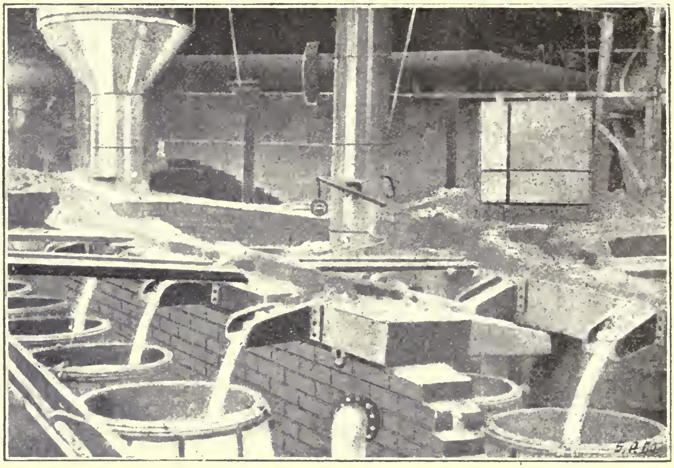

Fig. 35.—Slag Runners and Bogies.

Slag.—The slag is tapped from the furnace periodically every three or six hours, and flows away by an inclined plane to slag moulds made in the sand, or is distributed by a series of metal shoots to the slag trucks or bogies.

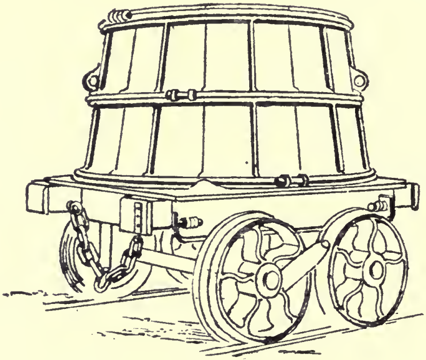

Fig. 36.—Scotch Slag Bogie.

The slag bogie often consists of a truck on which rests an iron tub, slightly conical in form, and made in three pieces, which are held together by an iron band. The slag is run into the tub. When full the truck is hauled away, and when the slag has solidified the tub is lifted off by a crane, either as a whole or in pieces, and the solid mass of slag is thrown over on to the slag tip, and the bogie made ready for use again. Slag bogies of many other forms are used—some are square, built of separate plates; some are large basins cast in one piece, from which the slag can be turned out.

To facilitate cooling the slag is usually sprayed with water as it runs into the bogies.

Tipping Ladles.—Slag ladles of large capacity from which the slag can be tipped are rapidly coming into use. The illustration shows a Dewhurst 10-ton ladle. The ladle is of such a shape that the solidified mass of slag will easily slip out. It is carried on a suitable car, hauled by a locomotive, and is tipped by means of a chain attached to the locomotive. The tipping may be either end or side, as may be most convenient. Such ladles are built of 20 tons capacity. Conveyors similar to the pig casting machine are sometimes used for the continuous removal of slag.

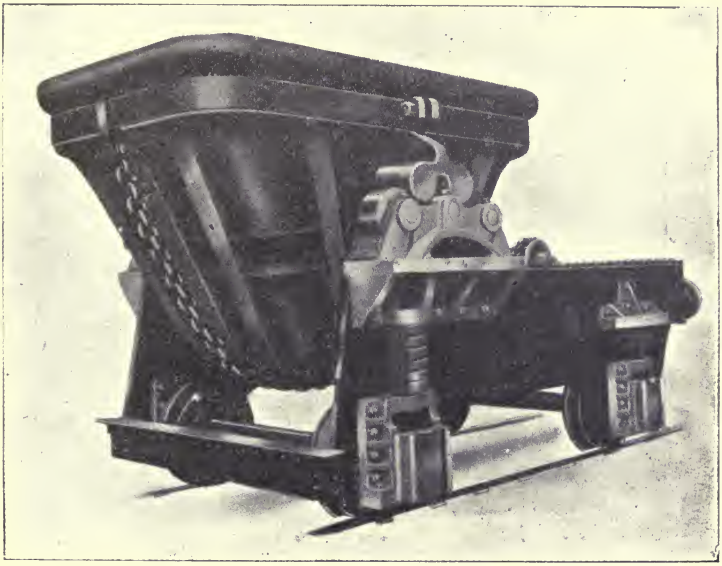

Fig. 37.—"Dewhurst" Patent End-Tipping Slag Ladle and Car, Ten Tons Capacity.

The Pig Bed.—The metal is usually tapped out into sand moulds. In front of the furnace is a bed of sand about 8 in. deep, with sufficient inclination from the furnace to determine the flow of the metal. The sand is not pure silicious sand, but must contain enough clay to have sufficient binding power to retain the form of the moulds. The sand is levelled, and a set of wooden patterns, in the form the pigs are to be, are pressed into it, sand is filled in between them and is rammed tight. The patterns are then carefully lifted out, leaving the moulds for the metal. Each set of 20 or 25 moulds is connected with a trench in the sand running at right angles to them, and these trenches are connected with the channel leading to the tap hole of the furnace.

The pig bed is prepared to hold rather more metal than is expected to be tapped at one cast, and may consist of 300 to 800 moulds, according to the size of the furnace. When the furnace is tapped the entrances to all the cross-channels leading to the moulds, except the bottom one, are closed by iron plugs, so that the metal has to fill the moulds furthest away from the furnace while it is hottest. When the first row of moulds is filled the metal is admitted to the second, and so on. As soon as the metal has partially solidified, sand is sprinkled over it, and as soon as it is cold enough, each pig is broken away from the metal in the channel, to which it is connected by a neck. The metal in the channel—called the sow—is broken up into pieces of convenient size for use or sale, and the bed is prepared for the next charge.

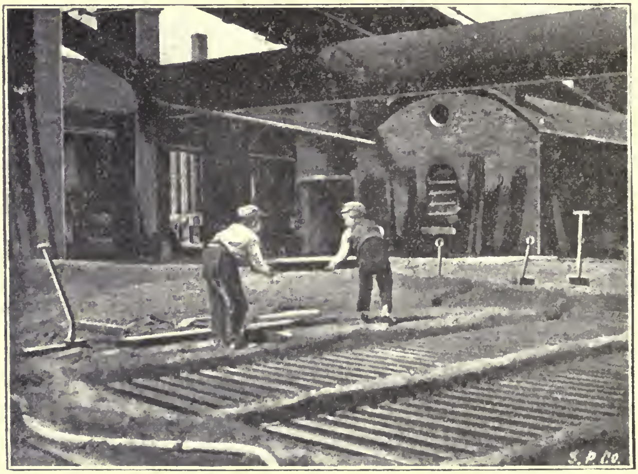

FIG. 38.—Boys Making Moulds in Pig Bed.

In America the pig bed is always under cover ; in this country it is always open.

Handling the Pigs.—In the ordinary way the pigs are removed by hand. As soon as they are cool enough, but while still warm, the workmen, provided with leather gloves, commence the removal, the "grid" of pigs is lifted with an iron rod, the pigs are broken off by means of a sledge hammer, and are lifted away to trucks put to receive them. This is very laborious and slow work, and in the case of furnaces with a large output, it is very difficult to get the bed ready for another tap in time.

To facilitate the work, the "grid" is now very often lifted away by a crane as a whole, allowed to cool, and then when required the "grid" is lifted to a "pig breaker," and the pigs are broken off.

At some works the crane runs on rails along the edge of the pig bed, but at others, and this, where possible, is the best arrangement, an overhead crane runs along the whole length of the furnaces over the pig bed, so that a "grid" can be lifted at any required place and carried to the stack, whence it can be carried by another crane to the breaker.

Metal Mixers.—For some purposes, especially for steel making, and in other cases where uniformity is required, the metal is run into a metal mixer, where it can be kept liquid till it is required for use. The metal from the blast furnace is apt to vary tap by tap, but obviously if the metal from various furnaces and from several taps be mixed, these inequalities will, to some extent at any rate, balance one another.

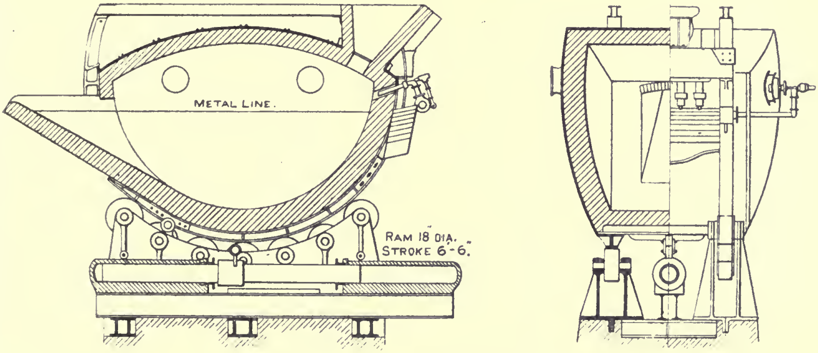

FIG. 39.—Metal Mixer.

Metal mixers are made in various forms. The illustrations, Fig. 39, show one capable of holding 200 tons, used by the Carnegie Steel Company. It is made of 1 in. steel plates, and is lined with firebrick 18 in. thick. The shell is riveted to two cast-steel segments, which rest on a number of flanged steel rollers 27 in. diameter. The mixer is moved by a horizontal double-acting ram 18 in. in diameter, and having a stroke of 6 ft. 6 in. There are two small cleaning doors on each side, and an arrangement by which gas and air can be led in above the surface of the metal so as to maintain its temperature. There is a weight to balance the weight of the projecting spout.

Casting Machines.—To allow of very rapid casting, casting machines of various kinds have been introduced, the best known

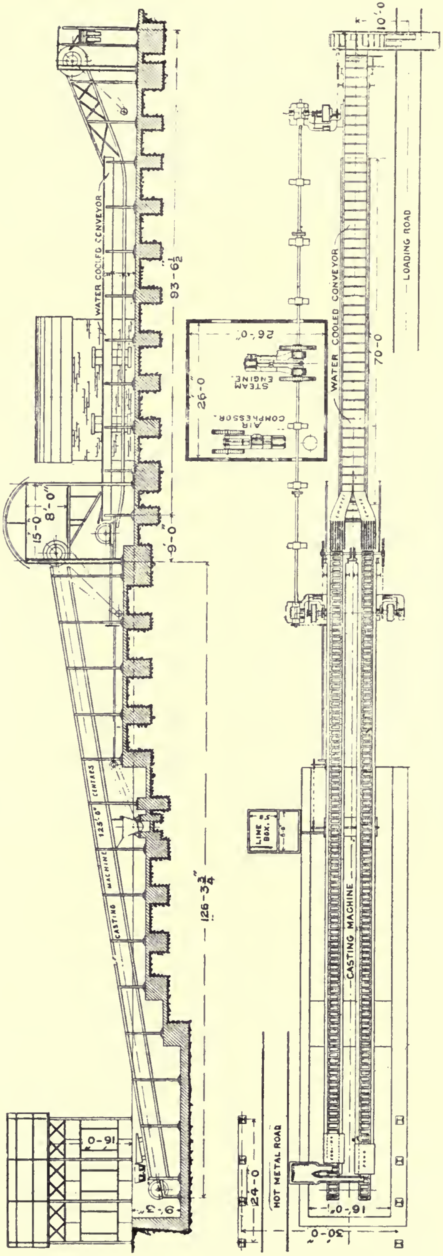

FIG. 40.—Uehling Casting Machine.

being the Uehling casting machine, Fig. 40, of which many are in satisfactory use in America, and several, at least, have been erected in this country.

The metal is tapped from the blast furnace into a large metal mixer capable of holding 100 or 200 tons of iron, and thence it is distributed to the moulds on the machine.

The principle of the machine is very simple. Two series of iron moulds are carried on endless chains, and pass under the spout of the mixer—from which the metal runs in a continuous stream—at the rate of 15 ft. per minute, the flow of metal being regulated so as to just fill the moulds in the time they are under the spout. The surface of the iron is sprinkled with water to facilitate cooling, and by the time a mould reaches the end of the run the metal has solidified. As the moulds pass over the end pulley the pig falls out and slides down a slope into a water tank, where cooling is completed. The pig is carried along this tank by an endless belt conveyor, and is delivered to the store or a truck as required. As the moulds return they are cooled and prepared for the next charge by being sprayed with milk of lime by means of a sprayer worked with compressed air.

The belt is from 90 ft. to 125 ft. from centre to centre of the pulleys over which it runs. The moulds are 22 in. long, 10 in. wide, 6 in. deep, and the metal is about $\frac{3}{4}$ in. thick; they are made of grey pig iron.

Such a machine will handle one ton of iron per minute. At the Duquesne furnaces 1,600 tons a day are cast over the machine. At the Lucy furnaces a machine erected in 1897 had in 1898 dealt with 435,750 tons without missing a cast, or any mishaps. The moulds wear about six months and are easily replaced. "Three men work the machine on each 12-hour turn." The average cost of handling a ton of pig iron by this method was 6 cents per ton, equal to, say, 3d. or $3\frac{1}{2}$d. The saving effected was about 11 cents, or $5\frac{1}{2}$d. per ton.*

An advantage of the machine, apart from economy, is that the pigs are perfectly clean and free from sand, but owing to the sudden cooling the grade cannot be determined from the fracture, and therefore it is not likely to come into use for the casting of foundry pig until grading by analysis becomes more general.

Hoists.—The material which has to be charged has to be raised to the top of the furnace, and for this purpose a hoist of some kind is necessary. Usually several furnaces are connected by galleries, so that one hoist may serve two or three furnaces.

Inclined Plane.—In many of the older furnaces an inclined plane was used, and there are still many such in existence. The trucks are so made that the platform remains horizontal, and they are drawn up by means of wire ropes. Fig. 41 shows an inclined

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* Miller, Journal of the West of Scotland Iron and Steel Institute, vol. vi., page 35.

plane in use at a Scotch works. The bank at the back of the furnace is high, so that the lift is only about 30 ft. Steps are provided by which the furnace top can be reached without using this hoist.

Direct Hoist.—The direct-acting vertical hoist is now nearly universal. This consists of a cage usually about six feet square, working in vertical guides, and raised and lowered by means of a wire rope which passes over a large pulley wheel, and is coiled on to a drum driven by an engine. Usually these hoists are worked in pairs, one ascending and the other descending.

Each hoist will lift 3 to 6 tons, and, as a furnace may require 500 tons of material a day, considerable power is required.

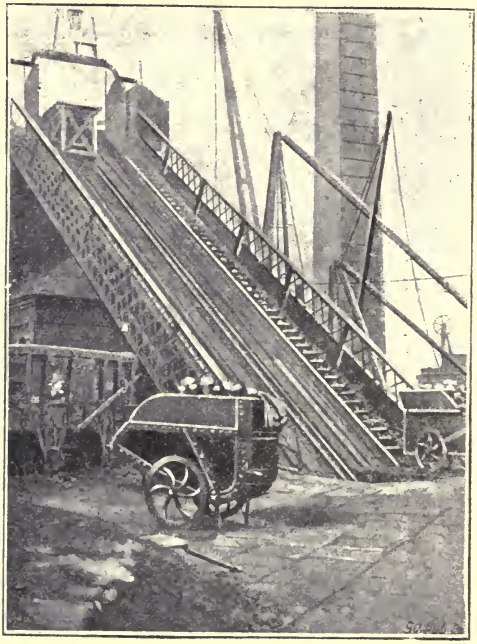

Fig. 41.—Inclined Plane at Shotts.

The direct hoist may be worked by hydraulic power, the motion of the ram being multiplied by suitable gearing. The cage guides may be an open framework, or they may be enclosed in a masonry tower.

Gjers Hoist.—This is the best form of pneumatic hoist which has been designed. The framework is a vertical iron tube about 3 ft. in diameter, and as tall as the furnace to be served. The interior is quite smooth, and the exterior carries four vertical guides. The table is about 15 ft. square. It has a hole in the centre, through which the iron tube passes, and is provided with guide wheels which run on the vertical guides. The platform is carried by four wire ropes, one at each corner, which pass over four large pulleys at the top of the supporting tube, the other ends being attached to a piston, which works air-tight in the cylinder. The bottom of the cylinder is connected with an air pump, which can give either pressure or exhaust. The table being at the top, the piston will be at

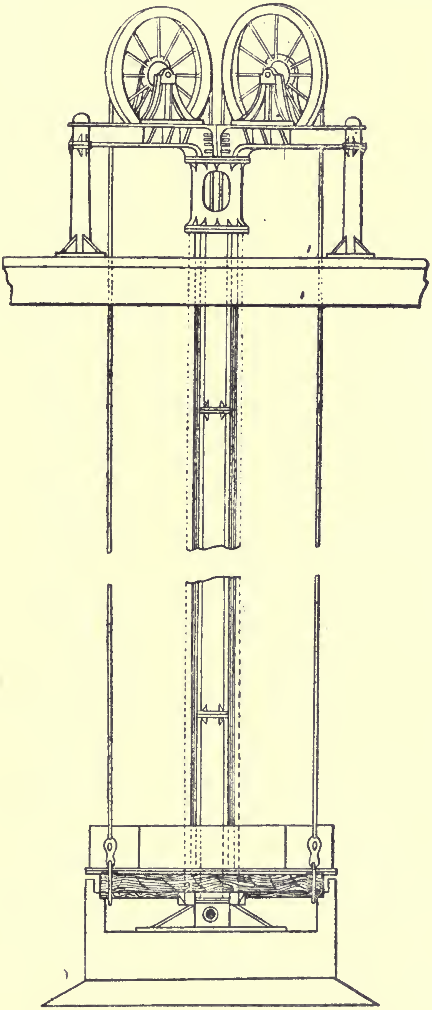

FIG. 42.—Gjers Pneumatic Hoist.

the bottom, the empty barrows are run on, air is forced under the piston at a pressure of about 2 lbs., the piston rises and the table descends. At the bottom the empty barrows are run off, and full ones take their place, the air beneath the piston is exhausted so as to give a vacuum of about 4 lb. when the piston descends and the table rises.

This hoist is said to be perfectly safe and very satisfactory.

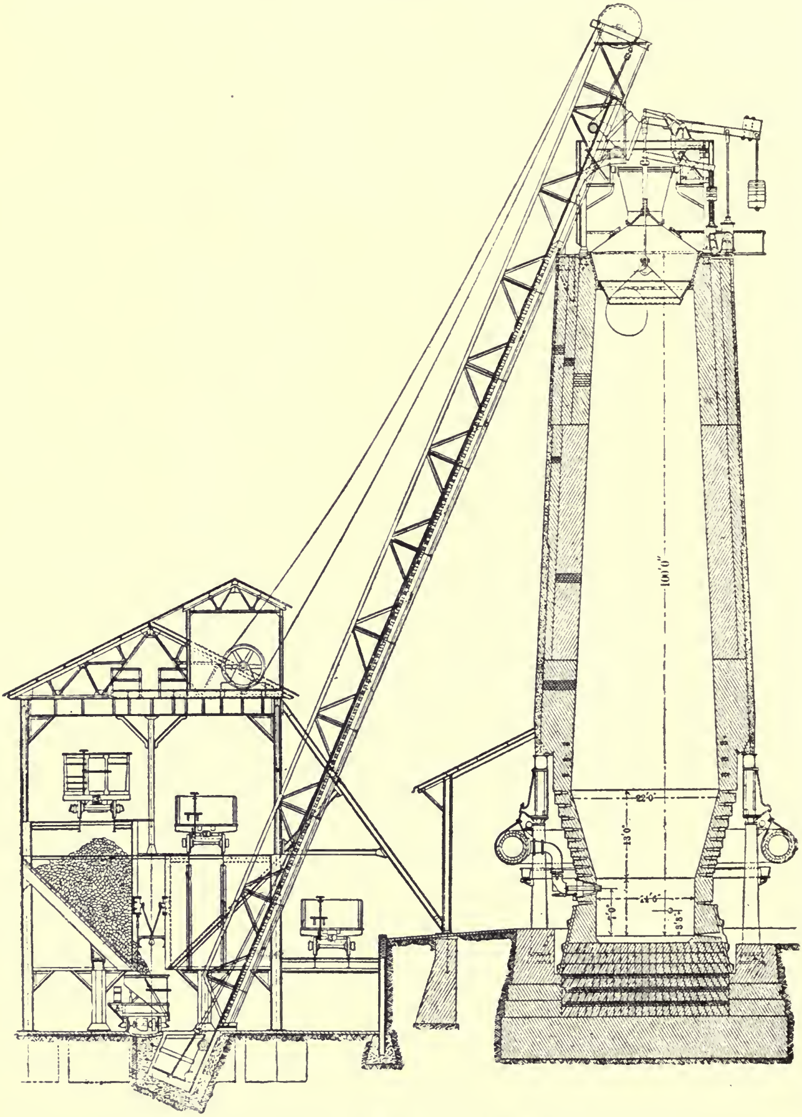

FIG. 43.—Blast Furnace with Brown Automatic Hoist.

Double hoists of this type, large enough to lift a loaded railway truck, are used for lifting the material to be calcined in the Gjers kilns, at Middlesbrough.

Other Forms of Hoist.—Many other forms of hoist have been used. In the direct hydraulic hoist a pit has to be sunk as deep as the furnace is high to receive the ram, and the same is the case with some forms of pneumatic hoist. In the water balance hoist the cage is fitted with a water tank. When it is to come down, water is pumped into this tank, the cage then descends, and raises a loaded cage. When the cage reaches the bottom its tank is emptied, and that of the cage at the top is filled with water, and so on.

Barrows.—The material is moved in large iron barrows of such form that the contents can be easily emptied into the furnace. One is shown in Fig. 41.

Mechanical Charging.—With the ordinary methods of charging the barrows are filled by hand from the trucks, ore bins, or heaps, wheeled to the hoist, lifted, then wheeled to the bell, tipped, and the empty barrows are returned to the hoist. All this necessitates a large amount of labour, both at the bottom and at the top of the furnace. To avoid this various methods of mechanical charging have been devised, the best known being that of the Brown Conveyer Co., which has been largely adopted in the United States, and to some extent in this country.

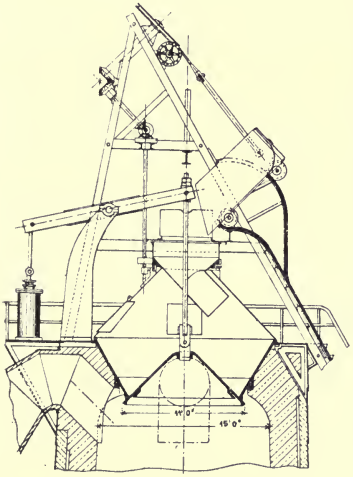

Fig. 44.—Brown's Automatic Furnace Hoist and Stock Distributor.

The arrangement is shown in the illustrations, Fig. 43, showing the general arrangement, and Fig. 44, details of the arrangement at the furnace top.

An inclined track, at a steep angle, runs from the bottom to the top of the furnace, reaching some little distance above, so that the skips may be emptied into the furnace, and some little distance below, so that it may come beneath the shoots of the ore bin. The skip is made of iron, and is capable of holding from 2,000 lbs. to 6,000 lbs., it has four wheels which run on a track, as shown, the hind wheels being double, the inner wheels which run on the usual track, and an outer wheel rigidly fixed to it of somewhat smaller diameter. At the top of the furnace an additional pair of curved rails of slightly wider gauge than those on which the car runs are arranged. As the car reaches the top, the outer hind wheels run on to the track, the back end of the skip is thus elevated, and the charge is shot into the bell. As soon as the skip is empty it is run to the bottom, and is charged automatically or by hand from the bin. If the charge were sent directly into the bell it would always fall on the same spot, and therefore would not be properly distributed. To prevent this a hopper is fixed over the bell, and is turned a little as each skip goes up, so that the charge is distributed all round the bell. Usually the rotation of the hopper is once for each 4½ or 6½ trips, so that in time every part of the bell is utilised.

No labour is required at the top of the furnace, the charging goes on perfectly regularly day and night, and automatic arrangements can be attached so as to stop the charging should the stock not fall regularly.

Efficiency of a Furnace.

In estimating the efficiency of a furnace several things have to be taken into account.

(1) The amount of fuel consumed for each ton of iron produced.

(2) The amount of iron produced by the furnace per week.

Increase of size of the furnace up to a certain point, which varies with circumstances, is attended with a diminution of fuel consumption, but beyond that limit there is no further saving of fuel by increase of size.

Increase in the size of the furnace is also in general attended with increased output, but the output depends so much on blast pressure and other conditions that no definite relation can be given between size and output.

Cost and Durability of Furnaces.—A blast furnace is a very expensive structure. Sir B. Samuelson estimated the cost of three furnaces, each 80 ft. high, erected in Middlesbrough, in 1887, as being, including engines, &c., £73,506 or £24,502 each. Full details of the costs are given in the paper.

The life of a blast furnace varies very much. In this country, with slow driving, the lining may last from 10 to 20 years. The shell will last a long time ; indeed, up to the present, shells have generally been removed, not because they were worn out, but because they were out of date.

No. 1 Gartsherrie furnace was erected in 1838, and was pulled down in 1896. In the United States, where furnaces are driven harder, the life is proportionately shorter.

Plan of Works.—The arrangement of a works will vary very much, according to the nature of the ground available. The furnaces are usually built in a row, with the stoves immediately in the rear, the blowing engines being placed at one end of the row. The ore bins should be near the back of the furnaces, and should, of course, be in direct connection with a railway. The pig beds should be immediately in front of the furnace, and should be at a higher level than the rails, to facilitate removal of the pigs.

CHAPTER IX.

THE AIR SUPPLY.

The Air Supply.—As there is no natural draught in the blast furnace, the air for combustion must be forced in by blowing engines of some kind. The amount of air required is very large, amounting to about six pounds for each pound of iron produced. As a cubic foot of air at ordinary temperatures weighs about ·07639 lb., the volume will be about 77 cubic feet for each pound, or about 172,000 cubic feet for each ton of iron made.

The actual amount of air required depends on the amount of fuel consumed and can be readily calculated. All volatile matter is expelled from the fuel before combustion begins, so that it is only the fixed carbon of the fuel that burns, and that only to carbon-monoxide.

One pound of carbon burning to carbon-monoxide requires 1·3 lb. of oxygen, or 1·3 × 4·35 = 5·655 lb. of air, assuming a cubic foot of dry air at 0 deg. C. and 760 mm. bar) to weigh ·0809 lb., the volume of air required will be 69·9 cubic feet for each pound of carbon, or about 157,000 cubic feet for each ton of carbon consumed.

If c be the quantity of fixed carbon in one pound of the fuel, the weight of air required to burn it to carbon-monoxide will be

$$W = c \times 1{\cdot}3333 \times 4{\cdot}35 = c \times 5{\cdot}655$$

and the volume in cubic feet (at 0 deg. C. and 760 mm. bar) will be

$$V = \frac{W}{{\cdot}0809} = W \times 12{\cdot}361.$$

If the air be at any other temperature, the volume can be calculated by making the necessary corrections for temperature and pressure.

Pressure of the Blast.—The pressure at which the blast is supplied varies very much. It must be such as to supply the air in the required quantity, and to force it up through the furnace in a continuous stream. The taller the furnace, and the denser the material charged, the greater will be the pressure required.

The average pressures used are about

For charcoal furnaces	½ lb. to 1 lb.	per square inch.
,, coal ,,	2½ lb. to 5 lb.	,,
,, coke ,,	3 lb. to 7 lb.	,,
,, ,, ,, (American)	5 lb. to 10 lb.	,,
,, anthracite ,,	5 lb. to 9 lb.	,,

The fluctuations of pressure during working are very considerable.

Power Required.—The power required to force in the air varies with the pressure, the conditions of working, and the variety of engine used. Roughly speaking one horse power hour of energy expended in blowing will supply enough air, at a pressure of 5 lb. or so, to consume about 1·5 tons of coke, so that engines of about one actual horse power will be required for each 36 tons of coke consumed in 24 hours. The greater the pressure at which the blast is supplied the more power will be required to force it through.

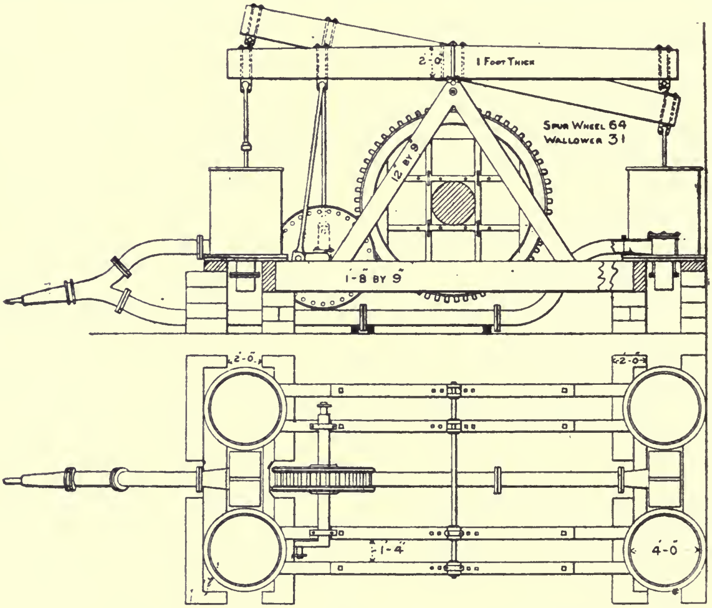

Fig. 45.—Carron Water-power Blowing Engine.

British and American Working.—There are two methods of working which require very different types of engine. In this country several furnaces are usually worked from the same blast main, the air being supplied by one powerful engine. In America each furnace usually has its air supply, and therefore the engines required are smaller, but are larger in number. In this country one engine may blow two or more furnaces ; in America each furnace has usually three engines, two of which work together. The use of separate engines for each furnace has many advantages, and is gradually becoming general in this country.

Carron Engines.—The first blowing engines erected at the Carron Iron Works (1760) were driven by water power. There were two beams, each having a cylinder at each end, the cylinders being single-acting only. (See Fig. 45.)

Blowing Cylinder.—The air is always forced from a blowing cylinder, which is usually of large size, that at Dowlais, which is one of the largest, is 12 ft. in diameter, and has a stroke of 12 ft. It will therefore deliver $12 \times 6^2 \times 3{\cdot}1416 = 1357$ cubic feet of air each stroke, and as it is run at the rate of 20 double strokes a minute the delivery would be $1{\cdot}357 \times 20 \times 2 = 54{,}280$ cubic feet per minute.

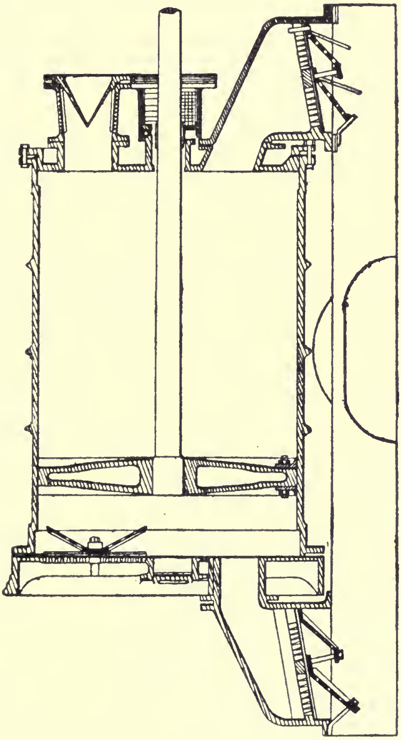

Fig. 46.—Section of a Blowing Cylinder.

The blowing cylinder is provided at each end with intake valves for the admission of air, and outlet valves by which the air passes to the blast main. The inlet valves must have a large area, so as to allow free ingress of the air, the area allowed being usually about one half that of the piston. In the Dowlais cylinder the area of the piston is 113 sq. ft., so that the area of the intake valves would be about 86 sq. ft. Single valves of such large size would be impracticable for various reasons, so a large number of smaller valves are always used. The valves are usually rectangular metal plates, hinged at the longer side, faced with leather or indiarubber, and working on seats of the same material. The bottom valves lie flat in the cylinder bottom, and when shut are horizontal ; the top valves are placed in rectangular valve boxes on the cylinder cover, and when closed they hang nearly vertically against a grating on the valve box. The outlet valves have about one-quarter the area of the intake valves; they are similar in structure, and swing against gratings at the entrance to the blast main. (See Fig. 46.)

Owing to the compression, the air, as it leaves the cylinder, is sensibly warm.

Other Forms of Valve.—Many other forms of valve have been suggested, such as ball valves, in which a ball rests on a seat and is lifted to allow the air to pass, falling into place again by its own weight when the pressure ceases to act. Rotating valves, in which a series of openings either in the end or side of the cylinder, are opened and closed by the rotation of a disc or cylinder with corresponding holes, or flap valves, opened and closed mechanically instead of by the pressure of the air. In horizontal engines the valves are sometimes closed by a spring, so as to ensure a rapid action. Slide valves have been used, but the bearing surfaces wear very rapidly, owing to the action of the gritty particles drawn in with the air.

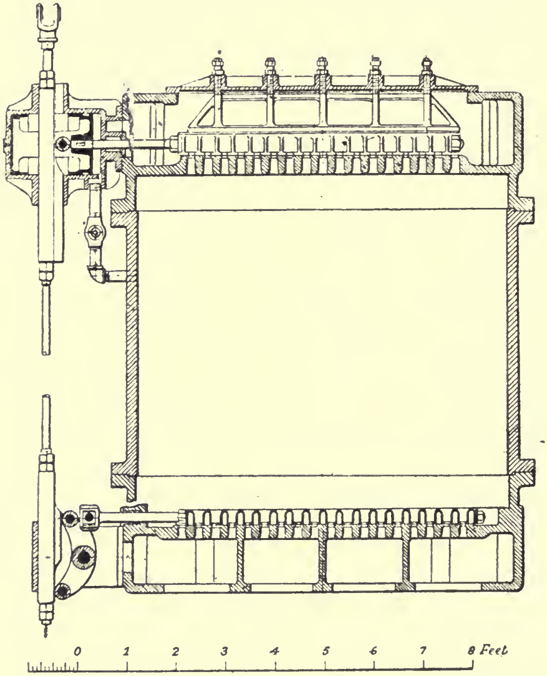

Fig. 47.—Blowing Cylinder with Southwark Valve.

Southwark Valve.—This is a slide valve, the slide and the cover being made in the form of a gridiron. There is little rubbing friction, as the valve is slightly lifted from its seat at the instant of moving, and the valve gives a very large opening with a very small movement.

Beam Engine.—In this country the blowing cylinder is still usually worked by a beam engine (Fig. 48). In this type of engine a heavy beam, supported on suitable bearings at or near the centre, has the steam cylinder at one end and the blowing cylinder at the other, the piston rods being attached to the beam by means of a suitable parallel motion. If the beam is centred in the middle the two cylinders will have the same stroke. Such a beam must necessarily be very massive, and in the case of one engine it was about 40 ft. long and weighed 33 tons. A flywheel is almost an essential for such engines, though many of the early beam engines were not provided with one. It is either attached to a projecting nose on the beam at the steam cylinder end, or between the steam cylinder and the support; in either case by means of a long connecting rod. The flywheel must be of large size; in one case it weighs 35 tons. Owing to the great weight of the beam engine the supports must be very solid, and owing to the great weight of the moving parts the engine is very difficult to start and can only be driven slowly. The pressure of the air supplied by beam engines is usually small, not more than 5 to 7 lbs.

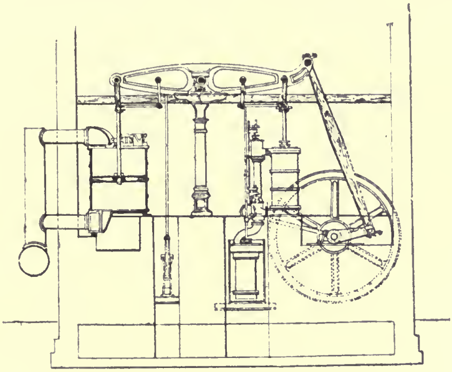

Fig. 48.—Beam Blowing Engine. Air Cylinder, 96 in. diameter; Steam Cylinder, 44 in. diameter by 8 ft. stroke.

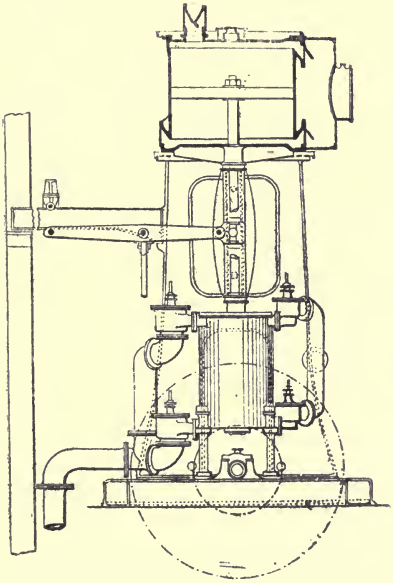

Fig. 49.—Bull Blowing Engine.

Among the first beam blowing engines worked by steam were those at Carron and at the Clyde works, both of which were erected by Watt.

Direct-acting Engine.—Direct-acting vertical engines are now coming rapidly into use, and in time will no doubt displace the older and heavier form. The steam cylinder and the blowing cylinder are placed one above the other, the two pistons being at attached to the same piston rod. The details of the arrangements vary very much, sometimes the steam cylinder is at the top, sometimes the air cylinder; sometimes the flywheel is carried from a crosshead between the cylinders, at others the cylinders are placed so high that the flywheel can be below them. Fig. 49 shows a modern blowing engine of this type. The blowing cylinder is 78 in. in diameter, and the steam cylinder is 32 in., the stroke being 4 ft. Two engines are coupled together, the flywheel being between them.

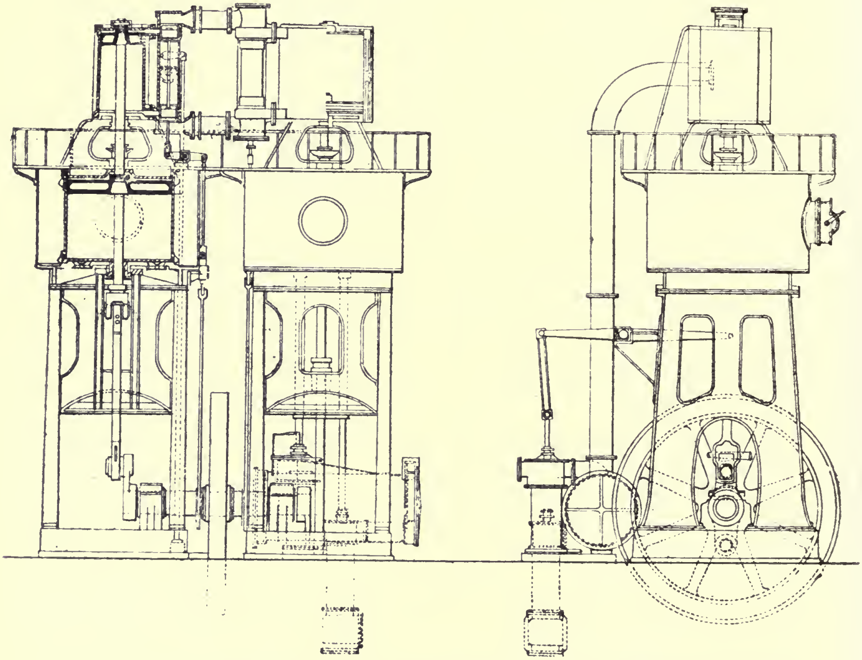

Fig. 50.—Double-expansion Blowing Engines at Dowlais. Blowing Cylinders. 88 in. diameter; High-pressure Cylinder, 36 in. diameter; Low-pressure, 61 in. diameter by 5 ft. stroke.

Compound Engines.—Double-expansion blowing engines (Fig. 50) have been erected at the Dowlais works. "The blowing cylinders are 88 in. diameter, the high-pressure steam cylinder 30 in. in diameter, and the low-pressure steam cylinder 64 in. in diameter, with a stroke of 5 ft. Each engine, with a boiler pressure of 100 lb.

to the square inch, develops about 1,200 horse power, and can deliver 25,000 cubic feet of air per minute, at a pressure of from 4½ lb. to 10 lb. per square inch as desired. There is no doubt that this, or an engine designed on the same principle, is the best blowing engine that can be produced. It has been adopted on the Continent and in America."*

American Blowing Engines.—These are always direct-acting. Those at the Lucy furnaces have blowing cylinders 84 in. and steam cylinders 42 in. in diameter, with a stroke of 5 ft. They are driven at from 20 to 28 revolutions (*i.e.*, double strokes) per minute, and three are provided for each furnace.

Turbo-Blowing Engines.—With the great success of the Parsons' turbine for marine propulsion and other purposes, it was only reasonable that the same principle should be applied to blowing engines. That has been done with considerable success, and several such engines have been erected and are working quite successfully.

The engine consists essentially of two parts, a smaller cylinder containing a turbine driven by steam power, and a large cylinder containing a series of blades by which the air is carried forward. These are attached to the same axis, so that the air is driven forward continuously in one direction, and there is no fluctuation of pressure as in all reciprocating engines.

The turbine is driven by high-pressure steam at about 3,000 revolutions per minute, and, of course, the air blades are driven at the same speed. The air entering the air cylinder is directed by set of guide blades by which it is guided on to the rotating blades; from there it passes to another set of guide blades and on to another set of rotators, and so on till the full velocity is attained. The blades are quite clear of the case, and the pressure is due to the velocity of the air. The quantity and pressure of the air delivered will, of course, depend on the size and construction of the engines. At one works 18,000 cubic feet of air per minute is delivered at a pressure of 8 or 9 lbs.

Turbine blowers have the great advantage of occupying little space, delivering the air steadily and at uniform pressure, and of not requiring costly foundations. The makers also claim that fuel cost, cost of attendance, and upkeep are less than with reciprocating steam blowers.

Gas Engines.—Blast furnace gas is quite suitable for use in properly constructed internal combustion engines. The gas must be thoroughly cleansed, so as to be free from dust and tar, and that is not easy in the case of gas from coal feed furnaces which is always laden with finely divided tar. These engines are now constructed up to 1,500 H.P. A mixture of one half air and one half gas is used. At one works the explosion cylinders are 50 inches in diameter, and have a stroke of five feet, and are driven at 60 strokes

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* T. M. Grant, "Notes on Blowing Engines," Journal of the West of Scotland Iron and Steel Institute, vol. v., p. 128.

per minute, the air cylinders being 66 inches in diameter. The amount of gas derived from the furnaces is far more than is needed to drive the blowing engines and heat the blast, and the balance can be used for supplying electricity or power for any other required purpose.

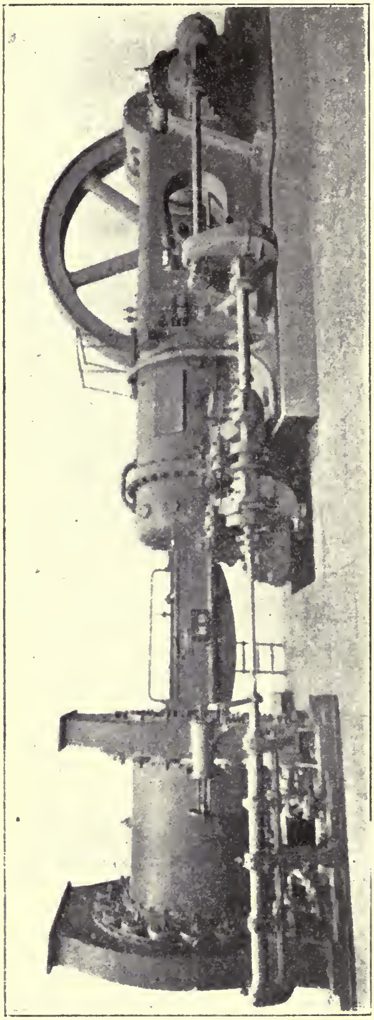


Fig. 51.—800 H.P. Blowing Engine driven by Blast Furnace Gas.

Boilers.—Steam is always raised in boilers fired with the waste gas from the blast furnaces. The loss of energy in this method of working is very great, non-luminous gas not being in any sense an ideal fuel for boiler firing, but gas being plentiful no attempt at economy is made. The boilers in this country are usually of the Lancashire type, but in America water-tube boilers are largely used.

Blast Regulators.—The air leaves the cylinder in puffs, and it should enter the furnace in a steady stream. To ensure this blast regulators were at one time used. The common form was a large balloon-shaped vessel of sheet iron, having a capacity of 30 to 40 times the blast delivered per second, attached to the main usually near the engines. The elasticity of the mass of air takes up the variations in pressure, so that the air leaves the mains in a steady stream. In modern plant the capacious hot blast stoves and large mains have the same effect, so that a separate blast regulator is no longer needed.

Blast Pressure.—The pressure of the blast may be measured by a simple mercury manometer, or by a pressure gauge. The pressure should be taken near the blowing cylinder, and also near the furnace; in the latter case the mercury must be separated from the main by a sufficiently long column of cold air. The blast pressure varies considerably from time to time. Fig. 52 shows the variations in pressure recorded by a self-recording instrument over 20 hours.

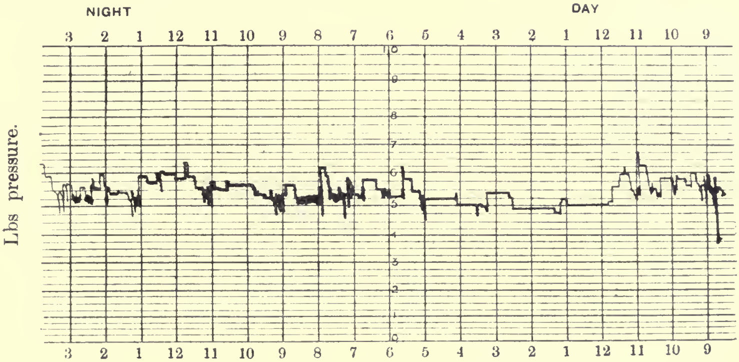


FIG. 52.—Diagram from Blast Furnace taken with Bailey's Patent Recorder.

The blast pressure may either be stated in pounds on the square inch, or in inches of mercury; roughly speaking, two inches of mercury is equal to one pound per square inch.

CHAPTER X.

THE HOT BLAST.

In the early days of iron smelting the air was sent into the furnace at the atmospheric temperature. It is now always heated in stoves, and is supplied at a temperature varying from 300 deg. C. (570 deg. Fah.) to 800 deg. C. (1,472 deg. Fah.).

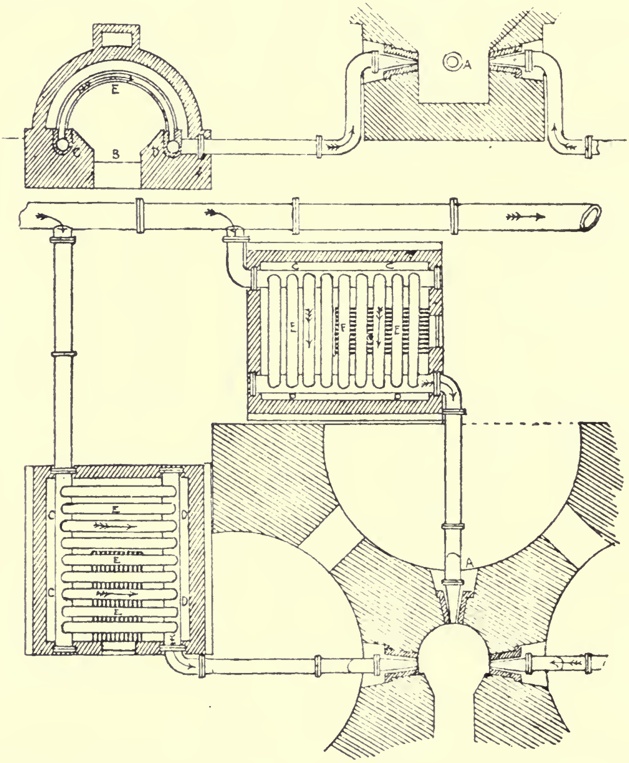


Fig. 53.—Neilson's U Pipe Stove at the Clyde Iron Works.

Pipe Stoves.—The use of hot air was first suggested by J. Beaumont Neilson in 1828. His first hot blast stove was simply an iron box, heated by a fire, through which the air was passed; then longitudinal pipes were substituted for the box; and lastly, a practicable stove with U pipes was designed. This was subsequently slightly modified, and under the name of the Staffordshire U pipe stove it came into general use.

This stove, Fig. 53, consisted of a fireplace enclosed in an arched brick chamber. The blast main from the engine ran along one side of the fireplace, and the main leading to the furnace on the other; these being connected by U pipes, elliptical in section (often with internal corrugations to increase the heating surface), passing over the fire, so that the air on its way to the furnace had to pass over the fire. Later, as a higher temperature was required, stops were introduced into the mains, so arranged as to make the air travel two or three times over the fire.

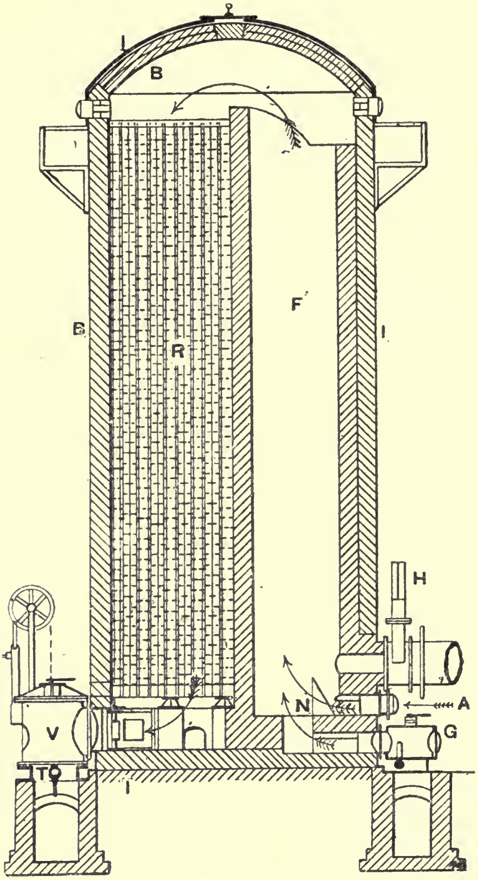
In the early stoves the heat was supplied by coal fires, but about 1845 the use of blast-furnace gas for the purpose was successfully introduced in Staffordshire.

Other Forms of Pipe Stove.—The pipes in the U pipe stove often broke at the crown, and to obviate this many other forms of stove were suggested. In the pistol pipe stove the air main was divided in two by a diaphragm, the heating tube was bent over at the top (whence the name), and was also divided to near the top. The air coming along the outer half of the main passed up the outer half of the heating pipe down by the inner half and away by the inner half of the main to the furnaces. These pipes were arranged in pairs, one on each side of the fire. In Scotland similar pipes were used without the bend, and they were placed in an inclined position over the fire. Horizontal pipes were sometimes used passing over the fire and connected by bends outside.

With pipe stoves of any kind the air could not be heated much above 300 deg. C. (570 deg. Fah.)

The Cowper Stove.—Mr. Cowper, of Middlesbrough, was the first to apply the regenerative system, with firebrick regenerators to the heating of the air for blast furnaces. The first Cowper stove was heated by a separate fire. Mr. Cowper, however, modified it so as to use blast-furnace gas.

An early form of the Cowper stove may be taken as a type. It consists of a vertical chamber of firebrick, 30 ft. or 40 ft. high, cased completely with iron. Inside this outer cylinder is a smaller cylinder or combustion chamber, the space between the outside of this and the inside of the outer chamber being filled with a chequerwork of firebricks carried on a series of brick arches, so that the openings all communicate with the space at the bottom. The gas from the furnace and the air are led into the combustion chamber and there burn, the products of combustion pass over the top of the combustion chamber, down through the chequerwork of bricks, and away to the chimney. When the brickwork is sufficiently hot, the air and gas are sent into another stove, the chimney valve is closed, and the cold air is sent into the bottom of the stove—rising up through the chequerwork it becomes strongly heated, and passes down through the combustion chamber to the hot blast main. The stoves are worked in pairs, one being heated whilst the other is heating the blast.



Cowper Stove—Vertical Section.

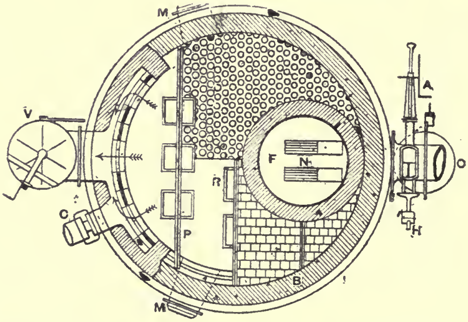


FIG. 54.—Cowper Stove—Horizontal Section.

All modern hot-blast stoves are based on the same principle, but differ in detail, chiefly in the arrangement of the heating brickwork.

Modern Cowper Stove.—The more modern form of Cowper stove, Fig. 54, differs from that described in being of larger size, and the plain bricks are replaced by bricks made of a special form so as to leave a series of circular or hexagonal tubes, down which the products of combustion pass. By this arrangement the accumulation of dust in the stove is prevented, and cleaning is facilitated.

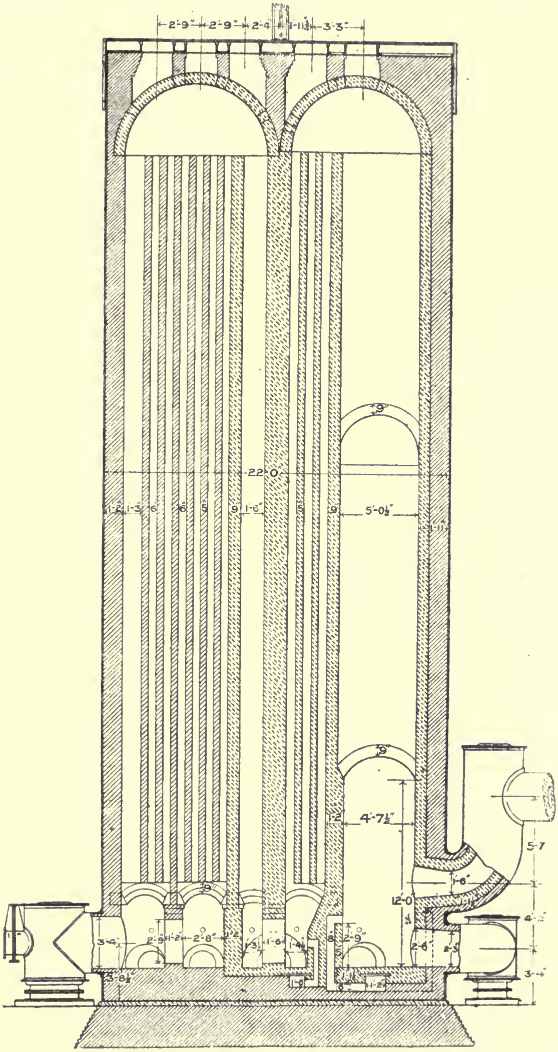


Fig. 55.—Section of Whitwell Stove.

Whitwell Stove.—In this stove, Fig. 55, the heating chamber is divided by fire-brick walls, about 5 in. thick, into a series of rectangular spaces or heating tubes. In the earlier types, the walls were so arranged that the gas had to pass down some of the tubes, up others, and down a third set, thus traversing the height of the stove three times, but in the more modern form the gas passes down the whole of the tubes once. This form of stove is very largely used.

Massick and Crookes Stove.—The arrangement of this stove is the same in principle as that of the Whitwell stove, but the combustion chamber is in the centre, and the heating chamber is divided into annular passages by radial and concentric walls. The products of combustion pass down one set of tubes, up a second, and down a third outer set, and thence to the chimney.

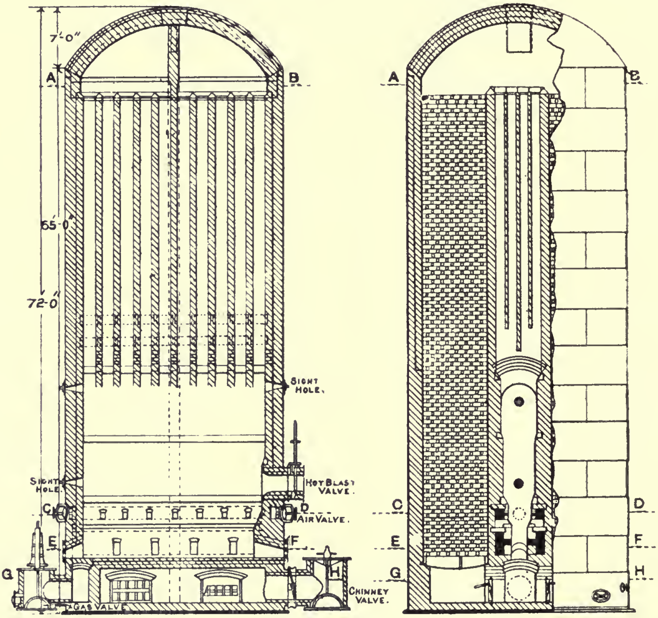


FIG. 56.—The Ford and Moncur Stove.

Section through Combustion Chamber. Section across Combustion Chamber.

Ford and Moncur Stove.—This is one of the latest forms of hot blast stove. The combustion chamber walls, Fig. 56, extend across the middle of the stove, thus dividing it into three parts, a combustion chamber in the centre and two heating chambers, one on each side. The upper part of the combustion chamber is divided into a series of narrow passages by brick divisions carried on arches, and the two heating chambers are each divided into two equal parts by brick walls at right angles to the combustion chamber. The heating chambers are divided up into a series of narrow passages by brick walls at right angles to the combustion chamber, these walls being "finished at the top with knife-edged bricks." Across these passages are placed a large number of lozenge-shaped bricks, with the sharp edges upwards and arranged in a zig-zag form, so that spaces and bricks alternate. Thus the chequerwork is very strong, offers a very large heating surface, and does not accumulate dust.

The gas enters the bottom of the combustion chamber, the air being admitted a little higher by a series of ports, so that the air and gas mix thoroughly and combustion is complete, and owing to the combustion chamber running right across the stove, the gas is very evenly distributed to the heating chambers. The capacity of the stove is also considerably larger than that of any other type. The heating surface of a stove 72 ft. high is about 64,000 square feet.

These stoves are coming largely into use. They were first used in Cumberland, but there are now many in Scotland, Middlesbrough, and other districts.

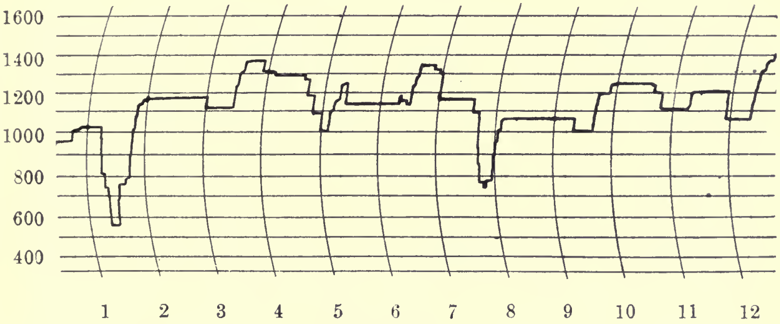


FIG. 57.

Size of Stoves.—The stoves are now built of large size up to about 70 ft. in height, and 25 ft. in diameter, so that they are almost as large as—in some cases, indeed, larger than—the blast furnaces themselves. Such stoves will heat the blast to 700 deg or 800 deg. Cen. (1,292 deg. to 1,472 deg. Fah.), and the fall of temperature between the reversals will not be much more than 50 deg. Cen. (90 deg. Fah.)

The number of stoves used varies very much. In America there are usually two or sometimes three for each furnace, but in this country one pair is usually made to suffice for two furnaces, or even more, the air from all the stoves passing into the same main. The use of separate stoves for each furnace is very advantageous.

Variations of Temperature.—The stove is of course at its hottest when the air is put on, and gradually cools till the blast is reversed; the temperature of the blast therefore gradually falls. Fig. 57 shows the temperature of the blast passing to one set of furnaces over 12 hours, registered by a self-recording pyrometer.

Equalisation of the Temperature.—To equalise the temperature of the air supplied, Messrs. L. F. Gjer and J. H. Harrison*suggested the use of an additional chamber filled with a chequerwork of brick placed between the furnace and the heating stoves, this chamber being divided so that the hot air passes through it twice, once up and once down. The bricks in this chamber tend to become heated when the gas is hotter than the average, and to be cooled when it is lower, so that the temperature of the blast is rendered much more uniform, and there is hardly an appreciable fall of temperature between the changes.

Cleaning the Stoves.—When gas is passed direct from the blast furnace to the stoves, a large quantity of dust is always carried over, and as the air current is much slower through the stoves than through the mains, the dust tends to deposit, and its removal is often very troublesome. This was especially the case with the older types of stove. Ordinary stoves require thorough cleaning at least once every three months, and this, of course, necessitates stopping. Many stoves are provided with cleaning openings in the dome, above the heating passages, by which cleaning rods can be passed down.

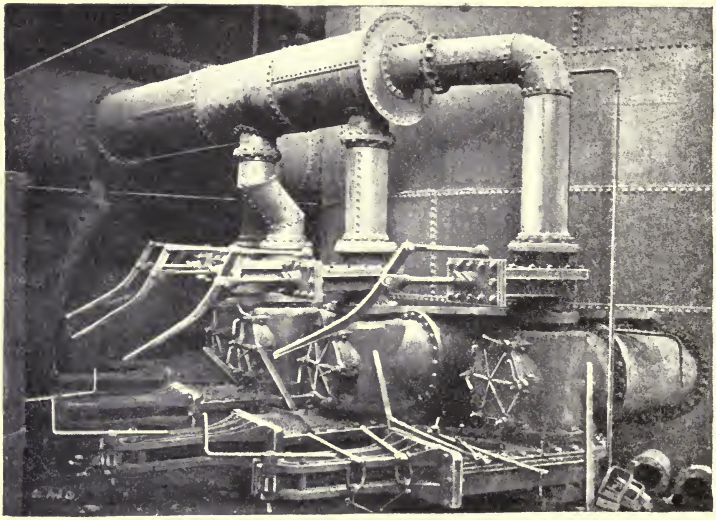


Fig. 58.—Stove Valves, Carron.

A great deal of dust can be blown out by simply blowing air from the engines through the stoves, and more by blowing out suddenly; indeed, with the Ford and Moncur stoves this is all the cleaning that is necessary. All the valves are closed except the

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* J. I. and S. I., 1900, Vol. i., p. 154.

cold blast valve, so that the stove is filled with air at the blast pressure, a relief valve, arranged so as to give an instantaneous opening, is then opened, and the rush of air carries out most of the dust. Sometimes gunpowder is exploded in the stove to disturb the dust, which is then blown out by the air.

A method of stove construction has recently been introduced to facilitate cleaning. The stove is built on columns, arranged so that access can be had beneath it, and cleaning doors are provided at the bottom. The stove can be cleaned "at any casting time, as the heat after the stove has been on blast is at the upper part, whilst the bottom is comparatively cool."*

Valves.—The valves are of great importance, as leakage is most objectionable, and may lead to great damage to the stove.

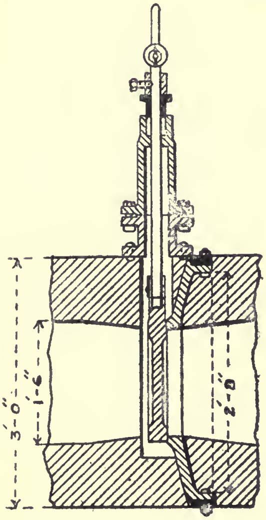

Fig. 59.—Blast Valve.

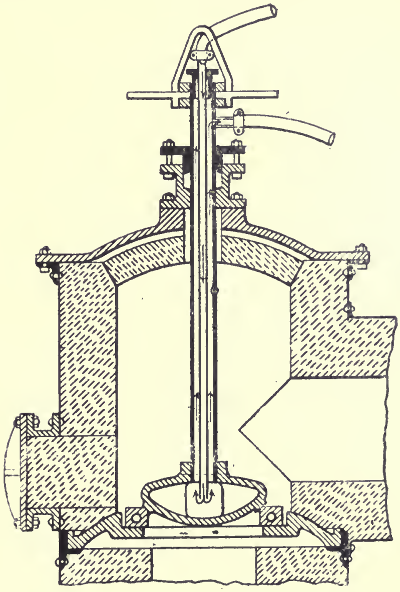

Fig. 60.—Hot Blast Valve (Water cooled).

The *air valve* may be a valve of any kind, as it opens directly to the air. The cold blast valve is fitted in the cold blast main. It is usually a sliding valve (Fig. 59), and a similar valve may be used for the chimney valve.

The *hot-blast valves* are the most important, and the most troublesome, owing to the high temperature to which they are exposed. When the blast was used at a moderate temperature, any ordinary valve could be used for the hot blast, but with the

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* Pilkington, Proceedings of South Staffordshire Institute of Iron and Steel Works Managers, 1891-92.

introduction of the brick stoves and consequent high temperatures water-cooled valves became essential. Fig. 60 shows a type of valve which is very largely used for the purpose, the direction in which the water circulates being shown by the arrows. Fig. 61 shows a form of water-cooled valve designed by Mr. James Robinson, which is probably one of the best in use. The valve seat is a cast-iron ring with a tube cast in it, through which water can circulate. The valve itself is made of a steel ring, to which steel plates are riveted, so as to leave a space between, in which water is kept circulating.*

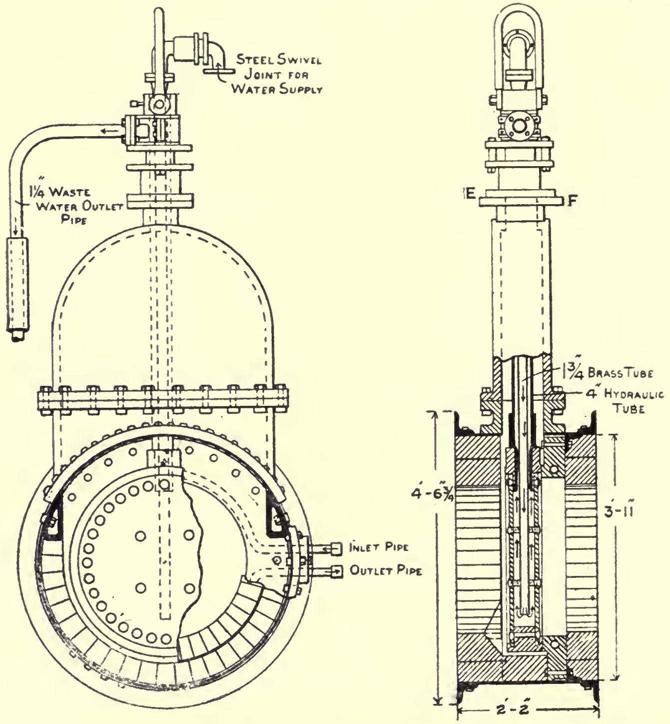

Fig. 61.—Robinson's Hot Blast Valve (Water cooled).

Many other types of valves have been designed. The higher the temperature of the blast the more difficult it is to keep the valve cool and tight.

Drying the Blast.—Air under ordinary conditions contains a considerable quantity of water vapour, the amount depending on the temperature and humidity of the air. This water is decomposed in the blast furnace in contact with carbon, hydrogen and carbon-monoxide being produced, this reaction causing the absorption of a considerable amount of heat. Mr. Gayley estimates that in sum-

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* See Journal of the West of Scotland Iron and Steel Institute, April, 1899.

mer time furnaces using 40,000 cubic feet of air per minute take in with the air from 150 to 230 gallons of water. The decomposition of the water, by the absorption of heat, lowers the temperature at the point where the highest temperature is needed, and thus reduces the efficiency of the furnace.

Mr. Gayley fitted up plant for drying the air. A large chamber is erected, across which a large number of iron pipes are fixed, through which brine, cooled below 0 deg.C. by means of the evaporation of ammonia, is made to circulate. The air on its way to the hot blast stoves is passed through the chambers, and most of the water is precipitated in the form of snow. The air thus dried is passed to the blowing engines in the usual way.

With the dried air, Mr. Gayley found that the burden of the furnaces could be increased, and a larger output was obtained, and that even when all cost of the cooling were taken into account the gain was considerable. He also contends that the silicon in the iron can thus be kept low without fear of increasing the sulphur, and also that the phosphorus is reduced.

Other suggestions have been made, the most important being that of Messrs. Daubine and Roy (Iron and Steel Institute, May, 1911). They dry the air by passing it over calcium chloride, which is kept cool by circulating water, so as to avoid liquefaction of the hydrated chloride. The calcium chloride is then regenerated by passing the waste gases from the furnace at regulated temperatures over it, so that it is dehydrated and rendered again fit for use, and it is cooled by circulating water coils before use. Three towers are thus required, one for desiccating the air, one for regenerating the chloride, and a third for cooling the chloride for use. It is stated that only one man is needed to look after the plant, which is capable of drying 300,000 cubic feet of air per minute to two grams of water per cubic foot, and that the cost of the plant is about one-fourth of that of a refrigerating plant to do the same work.

ADVANTAGES OF THE HOT BLAST.

When the hot blast was introduced by J. B. Neilson in 1828, it at once led to great saving in fuel. The saving varied very much in different localities, depending on local conditions and how wastefully the fuel had previously been consumed. At the Clyde Iron Works, where the process was first introduced, the saving was greater than in any other locality.

The following figures will give an idea of the saving produced at that works :—

	Weekly Make per Furnace.		Coal used per Ton.		
	Tons.	cwt.	Tons.	cwt.	qr.
1829, Jan. to Aug., coke and cold air	36	18	8	1	1
1830, ,, ,, ,, hot air (300 deg. F.)	54	1	5	3	1
1833, ,, ,, ,, ,, (600 deg. F.)	61	1	2	5	1

The coal consumed in the two last cases included that used to heat the blast.

The economy of fuel produced by the hot blast seems to be due to two causes :—

(1) When cold air is blown into the furnace it becomes heated and expands, and this expansion of the air absorbs a considerable quantity of heat, thus cooling the charge. When the air is blown in hot, this expansion is very much less.

(2) When hot air is used less heat is required to be produced by the combustion of the fuel, less fuel is burned, and less air is sent in. The current of ascending gas is therefore slower, and it is more perfectly cooled. The result obtained is, to a certain extent, the same as that obtained by increasing the size of the furnace, and, as might have been expected, the saving effected by using the hot blast was greatest when it was applied to small furnaces.

In the early days the blast was heated by separate fires, for which coal had to be used. In modern furnaces there is a still greater saving of fuel by the use of the waste gas for heating the blast.

Each increase in the temperature of the blast produces some saving in fuel, but the saving for each increment of temperature is less as the temperature rises, and a limit is soon reached beyond which further increase of temperature is undesirable. Sufficient fuel must always be present to keep the carbon well in excess, so that carbon-monoxide may be produced, and the atmosphere of the furnace may be kept reducing.

CHAPTER XI.

BLAST-FURNACE SLAG—CALCULATING FURNACE CHARGES.

Blast-furnace Slag.—The nature of the slag which is being produced by a furnace is of the very utmost importance. It varies with the character of the iron and the condition of the furnace to such an extent that very often the first indication of a change in the working of the furnace is given by a change in the appearance and composition of the slag. The melting point of the slag has a great influence on the working of the furnace, for obviously this is the lowest temperature at which the charge can be perfectly fused, and this in its turn modifies the quality of the iron.

Blast-furnace slags are always silicates, and almost invariably silicates of lime and alumina.

Silicates.—The silicates are a very complex series of salts, silica having the power of combining with very varying quantities of bases, producing a large number of silicates. The classification of the silicates usually adopted in metallurgy is based on the ratio which the oxygen contained in the base (lime, &c.) bears to that in the silica. This is called the oxygen ratio. For example, the silicate Ca Si O_2 may be written Ca O, Si O_2. It is then seen that to each atom of oxygen in the base there are two atoms in the silica, and the oxygen ratio is therefore 1 : 2 or $\frac{1}{2}$.

The following are types of silicates which may occur as slags :—

		Atoms of O. in acid in base.	Oxygen Ratio.	
(1)	Subsilicates, x RO, Si O_2, $x > 2$ (Basic silicates.)	$x . 2$	$x : 2$	, $\frac{x}{2}$
(2)	Monosilicates, 2 RO, Si O_2 (Ortho-silicates.)	2 . 2	1 : 1	$\frac{1}{1}$
(3)	Sesquisilicates, 4 RO, 3 Si O_2	4 . 6	2 : 3	$\frac{2}{3}$
(4)	Bisilicates RO, Si O_2 (Meta silicates.)	1 . 2	1 : 2	$\frac{1}{2}$
(5)	Acid silicates RO, y Si O_2, $y > 1$	$1 . 2y$	$1 : 2y$	$\frac{1}{2}y$.

Silicates of most of these types occur in nature as minerals

The formulæ of the silicates of lime and alumina of each type are :—

(1)	Subsilicate x = 4.	$4\,CaO, SiO_2 . 4\,Al_2O_3, 3\,SiO_2$.
(2)	Monosilicate	$2\,CaO, SiO_2 . 2\,Al_2O_3, 3\,SiO_2$.
(3)	Sesquisilicate	$4\,CaO, 3\,SiO_2 . 4\,Al_2O_3, 9\,SiO_2$.
(4)	Bisilicate	$CaO, SiO_2 . Al_2O_3, 3\,SiO_2$.
(5)	Acid silicate	$2\,CaO, 3\,SiO_2 . 2\,Al_2O_3, 9\,SiO_2$.

A silicate such as CaO, SiO_2, containing only one base, is called a simple or monobasic silicate, whilst one which contains two bases, such as the emerald, $3\,BeO, Al_2O_3, 6\,SiO_2$, is called a double or di-basic silicate. Any number of silicates of the same type may be mixed, or may be in molecular combination, without alteration of type, *i.e.*, the oxygen ratio will not be changed. Silicates, therefore, are frequently of very indeterminate composition, though the type may be quite definite.

There are several methods of calculating the oxygen ratio or type of a complex silicate from its analysis.

For example, a silicate gave on analysis—

Lime (CaO)	31·68	per cent.
Magnesia (MgO)	4·53	,,
Alumina (Al_2O_3)	23·01	,,
Silica (SiO_2)	40·78	,,

To find the oxygen ratio.

First Method.—Divide the percentage of each constituent by its molecular weight, and reduce the numbers thus obtained to a simple form :—

$$\begin{array}{llcl} CaO & 31{\cdot}68 \div 56 & = & {\cdot}5657 = 5 \\ MgO & 4{\cdot}53 \div 40 & = & {\cdot}1132 = 1 \\ Al_2O_3 & 23{\cdot}01 \div 102 & = & {\cdot}2256 = 2 \\ SiO_2 & 40{\cdot}78 \div 60 & = & {\cdot}6796 = 6 \end{array}$$

so that the formula is $MgO, 5\,CaO, 2\,Al_2O_3, 6\,SiO_2$. There are 12 atoms of oxygen in the bases and 12 in the silica, and therefore the oxygen ratio is 12 :12 = 1 : 1.

Second Method.—Reduce all the bases to their lime equivalent. The figures will then be—

$$\begin{array}{lrl} \text{Lime } (CaO) \ldots\ldots\ldots\ldots & 31{\cdot}68 & \text{parts.} \\ \text{Magnesia } (MgO)\ 4{\cdot}53 \times \dfrac{56}{40} \ldots\ldots & 6{\cdot}34 & ,, \\ \text{Alumina } (Al_2O_3)\ 23{\cdot}01 \times \dfrac{56 \times 3}{102} \ldots & 37{\cdot}80 & ,, \\ \hline & 75{\cdot}82 & ,, \end{array}$$

So that if lime were the only base the silicate would contain—

Lime	75·82	parts.
Silica	40·78	,,
	116·60	,,

Dividing each of these quantities by its molecular weight—

Lime ..... $75{\cdot}82 \div 56 = 1{\cdot}354 = 2$

Silica .... $40{\cdot}78 \div 60 = {\cdot}679 = 1$

The formula of the corresponding silicate is $2\,CaO, SiO_2$, and the oxygen ratio is 1 : 1 as before.

If only the oxygen ratio is required it may be obtained directly from the lime equivalent.

Since lime contains $\frac{16}{56}$ and silica $\frac{32}{60}$ of oxygen.

Lime .... $75{\cdot}82 \times \frac{16}{56} = 21{\cdot}51 = 1$

Silica .... $40{\cdot}78 \times \frac{32}{60} \quad 21{\cdot}75 = 1$

The ratio is 1 : 1.

The fusibility of silicates depends both on their type and on the bases which they contain.

For silicates of the same type, those of the alkalies and lead are the most fusible, then those of iron and manganese, and afterwards those of lime, magnesia, and alumina.

For silicates containing the same bases, as a rule the basic silicates are the most, and the acid the least, fusible, the fusibility decreasing as the silica increases. This is the general order, but it is not universal. In the case of the silicates of alumina the fusibility seems to increase with the quantity of silica, till when the composition is $Al_2O_3, 16\,SiO_2$, with an oxygen ratio of 3 to 32, the most fusible compound is obtained, the fusibility then decreasing as more silica is added, probably from intermixture of uncombined silica. The melting point of any of the silicates is lower than that of either silica or alumina alone.*

Basic silicates are usually very fusible and melt to very fluid liquids, solidifying rapidly without passing through an intermediate pasty condition. When they contain even a small proportion of ferrous oxide they are dark coloured or black, and they are often very dense.

The more acid silicates form more or less viscous liquids, the viscosity increasing with the percentage of silica which they contain. As a rule they solidify slowly, and pass through an intermediate pasty condition. Basic silicates, therefore, usually flow freely, whilst those containing more silica are more or less sluggish.

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* Seger. Quoted in American Institution Mining Engineers, xxiv, p. 43.

Mixed silicates, *i.e.*, those which contain two or more bases, are usually much more fusible than silicates of the same type containing only one base, and a mixture of two silicates of different types is often more fusible than either of the two separately.

Clay ($Al_2 O_3 2 Si O_2$) has an oxygen ratio of 3 : 4, and is infusible, but the addition of small quantities of other bases, by producing mixed silicates of a lower type, renders it fusible.

The following table of fusibilities of silicates may be of interest, but the figures can only be taken as being the very roughest approximations :—

	Degree Centigrade.
Silicate of aluminia	2400
,, magnesia	2200
,, baryta	2100
,, lime	2100
,, iron	1789
,, manganese	1789
,, baryta and lime	2100
,, ,, and alumina	2050
,, lime and magnesia	2000
,, ,, and alumina	1920

Blast-furnace Slags.—Blast-furnace slags are almost always silicates of lime and alumina, containing invariably small quantities of other bases, but in exceptional cases lime or alumina may be present only in small quantity. The proportion in which the silicates are present varies very much. Bodeman gives 4 ($Ca O Si O_2$) + ($3 Al_2 O_3$, $3 Si O_2$) as being the composition of the best slag from a charcoal furnace. The slags from coke furnaces are usually monosilicates or admixtures of these with more basic silicates and a typical slag may be taken as having the composition $3 (2 Ca O, Si O_2) + 2 Al_2 O_3 3 Si O_2$, that is as being a monosilicate in which the bases are present in equivalent proportions. Such a slag would contain :—

Lime	37·3	per cent.
Alumina	22·7	,,
Silica	40·0	,,

Blast-furnace slags cannot be regarded as being definite chemical compounds, but rather as being mixtures of various silicates and perhaps other compounds in different proportions, with a monosilicate of lime and alumina. Chemical analysis can only indicate an average composition, as it is impossible to isolate the various constituent silicates.

The behaviour of alumina is somewhat uncertain, its properties being balanced between those of an acid and a basic oxide, so that its influence may be variable. In slag calculations it is always assumed to be present in the basic form, in combination with silica to form a silicate.

The following analyses of blast-furnace slags will indicate their general character :—

	1	2	3	4	5	6
Silica	35·0	29·00	36·30	43·59	50·70	43·8
Alumina	17·0	19·00	18·43	14·78	15·30	9·5
Ferrous oxide	..	..	·69	1·06	3·15	4·5
Lime	40·0	38·50	44·20	31·40	25·70	35·9
Magnesia	6·0	8·5	·11	4·66	·71	..
Manganese	1·5	..	..	1·41	4·76	6·5
Alkalies	·5	..	..	1·91	..	..
Calcium sulphide	..	5·5	..	1·93	..	..
	100·0	100·0	99·73	100·74	100·32	100·2
Lime equivalent of RO bases	49·4	49·7	44·9	39·85	32·9	44·5
Lime equivalent of all bases	77·4	81·0	91·7	64·19	58·1	60·1
Oxygen ratio	1 : ·85	1 : 1·67	1 : ·73	1 : 1·26	1 : 1·63	1 : 1·36
Molecular ratio, RO, R_2O_3	1 : ·11	1 : 1·16	1 : ·35	1 : 8·21	1 : 24	1 : ·11

1. Scotch works' average.
2. Scotch.
3. Furnace making basic iron.
4. Dowlais.
5. Furnace making silicon iron.
6. Scouring cinder.

Relation between the Slag and the Iron.—The composition of a slag being made in a furnace is very closely related to the iron produced, since both depend on the same changes and furnace conditions, but the connection is not always easy to make out.

Dark coloured slags, containing iron (scouring cinder), are often fairly high in silica, but are fusible owing to the presence of fusible ferrous silicate. They are produced (1) when the furnace is working cold with a heavy burden, the temperature not being high enough, or the reducing action powerful enough, to ensure complete reduction of the iron, and, as these furnace conditions are also favourable to the production of a white iron, black slag and white iron often go together. (2) When the quantity of lime is deficient very acid slags are formed, which often carry ferrous oxide, the ferrous oxide in a slag being the more difficult to reduce the more acid the slag.

In the presence of a sufficiency of lime at a high enough temperature the slags will be grey or white, unless coloured by the presence of small quantities of foreign elements. At very high temperatures highly silicious slags may be produced which nevertheless carry very little iron.

It will be seen, therefore, that the composition of the slag depends not only on the materials present, but also on the furnace conditions, the condition of equilibrium largely depending on the temperature. With a heavy burden and low temperature, as in the manufacture of basic iron, the tendency will be to the production of white iron and slags containing ferrous silicate, whilst at higher temperatures and with lighter burdens the slags will probably be free from iron, though much more silicious.

The amount of sulphur in an iron depends mainly on the nature of the slag and on the furnace temperature. When a furnace is working at a low temperature with slags not too heavy in lime, much of the sulphur may pass into the iron, whilst in the presence of a larger quantity of lime it may be retained in the slag. At high furnace temperatures, even with less basic slags, very little sulphur passes into the iron. An explanation suggested by E. L. Rhead is that the reduced silicon acts on the lime, liberating calcium, which at once removes the sulphur from the iron as calcium sulphide.

Manganese combines readily with sulphur to form a sulphide, which passes into the slag, thus helping to keep the metal free from that very objectionable element.

Colour and Appearance of Slags.—Slags are usually grey in colour. If black, silicate of iron is present, manganese sulphide gives a yellowish colour, and manganese oxide often gives a violet colour.

The appearance of the slag depends somewhat on the rate of cooling, the quicker this is the greater being the tendency of the slag to be glassy. Slags rich in alumina are often porcelain-like in appearance, whilst those that contain much lime are stony. When a very large quantity of lime is present, some seems to separate on cooling, so that such slags are apt to disintegrate and fall to pieces on exposure to moisture, owing to the slaking and consequent expansion of the lime. Molten slags often dissolve gases which are given out on cooling, the slags being then very porous.

Sulphur in Slags.—The sulphur is usually present in the slag as manganese sulphide or calcium sulphide. The latter is readily decomposed by water, hydrogen sulphide being formed, $CaS + 2H_2O = Ca(OH)_2 + H_2S$. The odour of hydrogen sulphide can be distinctly perceived when such a slag is watered.

CALCULATION OF BLAST-FURNACE CHARGES.

The charge for a blast-furnace depends on the materials to be used and the nature of the slag to be produced, the latter, of course, depending on the character of the iron, and the furnace conditions. The blast-furnace manager, before starting to calculate a charge, must always carefully consider the type of slag which he desires to produce, for on that very much depends. The higher the temperature of the furnace and the greyer the iron, as a rule, the more acid can the slag be.

For making grey iron the slag to be aimed at should be a monosilicate, or it may be a little more basic. For basic iron the slag may be somewhat more basic, and for silicon iron considerably more acid, and may approach to the bisilicate type.

The problem to be solved usually is: Given an ore of known composition, to find the amount of limestone which must be used, the slag-forming constituents of both the ore and coke ash being taken into account.

Assume the following materials have to be dealt with:—

	Ore.	Coke.	Limestone.
Ferric oxide	71·43	..	..
Manganous oxide	1·00	..	..
Alumina	7·50	4·5	..
Lime	1·00	·1	54·88
Magnesia	..	·2	..
Silica	15·50	5·0	2·0
Sulphur	·50	1·67	..
Phosphoric anhydride	1·00	..	..
Water, &c.	2·07	..	..
	100·00		

Assume that for each 100 lbs. of ore used the amount of coke consumed is 60 lbs., which will be about 22 cwt. for each ton of iron obtained. The amount of material to be fluxed away for 100 lbs. of ore will be:—

	Ore.	Coke.	Total.
Manganous oxide	·5*	..	·5
Alumina	7·5	2·7	10·2
Lime	1·0	·06	1·06
Magnesia	..	·12	·12
Silica	15·5	3·0	18·5

Each of the bases must now be reduced to its lime equivalent:—

Manganous oxide .... $\cdot 5 \times \frac{56}{71} = \cdot 40$

Alumina .... $10{\cdot}2 \times \frac{56}{34} = 16{\cdot}80$

Magnesia .... $\cdot 12 \times \frac{56}{40} \quad \cdot 17$

Lime .... 1·06

18·43

Thus there are bases equivalent to 18·43 lbs. of lime to pass into the slag, and there is 18·5 lbs. of silica to be disposed of. The 100 lbs. of ore will yield about 54 lbs. of iron, which will contain, say,

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* About one-half of the manganous oxide will be reduced.

2·5 per cent of silicon, or 1·35 lbs. for 100 lbs. of ore. This would require to supply it 2·9 lbs. of silica. The amount of silica to be fluxed away is therefore 18·5 − 2·9 = 15·6 lbs.

The slag formed is to be a monosilicate, $2\,RO, Si\,O_2$, for which 60 parts of silica will require 112 parts of lime. The 15·6 lbs. of silica will therefore require $15\cdot6 \times \frac{112}{60} = 29\cdot12$ lbs. of lime, of which the equivalent of 18·43 lbs. is supplied by the charge itself, leaving 29·12 — 18·43 = 10·69 lbs. to be added to the form of limestone.

There is also 1·5 lb. of sulphur to be taken into account. The amount of lime required to convert this into calcium sulphide will be $\frac{56 \times 1\cdot5}{32} = 2\cdot6$ lbs., so that the total amount of lime to be added to the charge will be 10·69 + 2·6 = 13·29 lbs. for each 100 lbs. of ore.

The limestone contains 2 per cent of silica, which, to form a monosilicate, will require $\frac{2 \times 112}{60} = 3\cdot73$ lbs. of lime for each 100 lbs. of limestone, leaving therefore 54·88 − 3·73 = 51·15 per cent of available lime in the limestone. To supply the necessary 13·29 lbs. of lime therefore $13\cdot29 \times \frac{100}{51\cdot15} = 25\cdot98$ lbs. of limestone will be necessary.

The charge will be :—

Ore	100 lbs. or 20 cwt.
Fuel	60 lbs. or 12 cwt.
Limestone	25·98 lbs. or 5 cwt.

The slag will be, as decided, a monosilicate, and the ratio of the R O to the $R_2\,O_3$ bases will be $\frac{13\cdot37}{56} = \cdot24$ to $\frac{10\cdot2}{112} = \cdot091$, or about 1 : ·38.

The amount of slag for each 100 lbs. of ore will be :—

From the ore :—

Manganous oxide	·5	
Alumina	7·5	
Lime	1·0	
Silica	15·5	
Sulphur	·5	
		25 lbs.

From the coke :—

Alumina	2·7	
Lime	·06	
Magnesia	·12	
Silica	3·0	
Sulphur	1·0	
		6·88

From the limestone :—		
Silica	·52	
Lime	14·26	
		14·78
		46·66
Less oxygen replaced by sulphur		·75
		45·91 lbs.

The percentage composition of the slag will be :—

Lime	12·72*	$\times \frac{100}{45{\cdot}91}$	$= 27{\cdot}70$
Magnesia	·12	$\times \frac{100}{45{\cdot}91}$	$= {\cdot}26$
Manganous oxide	·5	$\times \frac{100}{45{\cdot}91}$	$= 1{\cdot}08$
Alumina	10·2	$\times \frac{100}{45{\cdot}91}$	$= 22{\cdot}20$
Silica	19·02	$\times \frac{100}{45{\cdot}91}$	$= 41{\cdot}42$
Calcium sulphide	3·37	$\times \frac{100}{45{\cdot}91}$	$= 7{\cdot}34$

Very frequently, instead of making the slag conform to any definite type, it is calculated on the basis of a silicate of calcium containing a fixed percentage of silica, and for practical purposes this is probably as convenient.

Suppose in running for grey iron it is decided to make a slag containing 30 per cent of silica, or rather one of such a composition that if it were a calcium silicate it would contain 30 per cent of silica and 70 per cent lime (or bases equivalent to that amount).

The lime equivalent of the bases in the example already taken is 18·43 and the available silica is 15·6. The amount of lime required for the slag will be $\frac{70 \times 15{\cdot}6}{30} = 36{\cdot}4$ lbs., and as 18·43 is contained in the charge the amount to be added will be 17·97. The limestone contains 54·88 per cent of lime and 2 per cent of silica. The 2 per cent of silica will use up $\frac{2 \times 70}{30} = 4{\cdot}7$ lbs. of lime, leaving 50·18 per cent available. The amount of limestone required will therefore be $\frac{17{\cdot}97 \times 100}{50{\cdot}18} = 35{\cdot}81$ lbs.

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* Total lime = 15·32 – 2·6 required to form calcium sulphide with sulphur.

The charge will be :—

	lbs.	cwt.
Ore	100	20
Coke	60	12
Limestone	35·81	8

and the composition of the slag will be :—

			per cent.
Lime	28·11	× $\frac{100}{58{\cdot}42}$	= 48·11
Magnesia	·12	× ,,	= ·21
Manganous oxide	·5	× ,,	= ·86
Alumina	10·2	× ,,	= 17·46
Silica	19·49	× ,,	= 33·36

Much of the labour of calculation, and the reducing of the bases to lime equivalent may be saved by the use of factors which can be easily calculated. This is usually done in works.

For instance, assuming the slag aimed at to be a monosilicate, $2\,RO, SiO_2$, it is obvious that the quantity of silica required to combine with one part of each of the bases will be :—

(1) $Ca\,O = \frac{60}{112} = {\cdot}536$, so that $Si\,O_2$ required for 100 lbs. $= \%$ of $Ca\,O \times {\cdot}536$.

(2) $Mg\,O = \frac{60}{80} = {\cdot}750$, so that $Si\,O_2$ required for 100 lbs. $= \%$ of $Mg\,O \times {\cdot}750$.

(3) $Al_2\,O_3 = \frac{180}{204} = {\cdot}882$, so that $Si\,O_2$ required for 100 lbs. $= \%$ of $Al_2\,O_3 \times {\cdot}882$.

(4) $Fe\,O = \frac{60}{144} = {\cdot}416$, so that $Si\,O_2$ required for 100 lbs. $= \%$ of $Fe\,O \times {\cdot}416$.

(5) $Mn\,O = \frac{60}{142} = {\cdot}422$, so that $Si\,O_2$ required for 100 lbs. $= \%$ of $Mn\,O \times {\cdot}422$.

The amount of silica required by the bases present is thus found, and this being subtracted from the silica present leaves that which must be fluxed away. The amount of base required to flux 1 part of silica can be calculated thus :—

(1) $Al_2\,O_3 = \frac{180}{160} = 1{\cdot}13$.

(2) $Ca\,O = \frac{112}{60} = 1{\cdot}86$.

(3) $Ca\,C\,O_3 = \frac{200}{60} = 3{\cdot}33$.

A table could be calculated so that the figures could be obtained by inspection.

An example will make the method of using the factors clear. Taking the charge of ore and coke already given, the amount of silica required by the bases present to form a monosilicate will be :—

Manganous oxide	·5 × ·422 = ·211
Alumina	10·2 × ·882 = 8·996
Magnesia	·12 × ·750 = ·090
Lime	1·06 × ·536 = ·568
Total silica required	9·865 lbs.

and as there is 18·5 of silica in the ore, the amount to be fluxed away will be 18·5 − (9·865 + 2·90) = 5·735, and this will require, 5·735 × 1·86 = 10·657 of lime, 2·6 lbs. is required to flux off the sulphur, so that the total lime required is 10·657 + 2·6 = 13·257, and since the limestone contains 51·15 per cent of available lime, this will be,

$$\text{Total limestone} = \frac{13{\cdot}257 \times 100}{51{\cdot}15} = 25{\cdot}9 \text{ lbs.}$$

or 5·18 cwt. for each ton of ore.

Prof. Balling has also suggested a simple graphic method for determining furnace charges, based on similarity of triangles, by which the calculations can be avoided, and a slide rule for the same purpose has been designed by Mr. H. C. Jenkins,* and another by Mr. Wingham.†

In practice a far less elaborate method of estimation is often used, based only on the percentage of silica which the slag is to contain, irrespective of the nature of the bases. No special type of silicate is aimed at, but for grey iron the slag is usually a little more basic than a monosilicate.

Take again the ore and fuel already considered, and assume that it has been decided that the slag is to contain 35 per cent of silica. The amount of available silica in 100 lbs., as before, is 15·6, so that the amount of bases required will be

$$\frac{15{\cdot}6 \times 65}{35} = 28{\cdot}97 \text{ lbs.}$$

The amount of bases present is ·5 + 10·2 + 1·06 + ·12 = 11·88 ; 28·97 − 11·88 = 17·09 lbs. of which lime must be added, in addition to the 2·6 parts required for the sulphur, so that the total lime required will be 19·69 lbs. This will require

$$\frac{100 \times 19{\cdot}69}{51{\cdot}17} = 38{\cdot}47 \text{ lbs.}$$

of the limestone already considered, which will be just about 8 cwt. to the ton of ore charged.

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* Journal of the Iron and Steel Institute, 1892, vol. i., page 233.

† Journal of the Iron and Steel Institute, 1891, vol. i., page 151.

Amsden's Calculations.—Mr. Amsden has recently given in *The Iron Age*[*] some calculations which are of interest in this connection. The slag is to be made to contain 46 per cent of silica: that is, the ratio of bases to silica is to be 1 : ·85.

The ore used contains :—

	Per cent.	Mol. wt.	Equiv.	Bases.	Acid.
Silica	20·68 ÷	60 ×	4 . .	. .	1·3787
Manganese oxide (½)[†] . .	·29 ÷	70 ×	2 . .	·0083	. .
Alumina	4·80 ÷	102 ×	6 . .	·2824	. .
Lime	5·38 ÷	56 ×	2 . .	·1921	. .
Magnesia	2·35 ÷	40 ×	2 . .	·1175	. .
				·6003	1·3787

The ratio of bases to silica is therefore ·6003 to 1·3787. The ore contains 48·5 per cent of iron, and 1·96 tons of it would yield 1 ton of pig iron containing 95 per cent iron.

Limestone to be used :—

	Per cent.	Mol. wt.	Equiv.	Bases.	Acid.
Silica	3·85 ÷	60 ×	4 . .	. .	·257
Alumina Iron oxide . .	2·15 ÷	102 ×	6 . .	·126	. .
Lime	28·95 ÷	56 ×	2 . .	1·034	. .
Magnesia	20·02 ÷	40 ×	2 . .	1·001	. .
				2·161	·257

The excess of bases is here 1·904.

The amount of limestone required to form a slag with 100 parts of ore, represented by x, may be calculated from the proportion.

$$\text{Amount of base} : \text{Amount of silica} : : 1 : \cdot85$$

$$\cdot6003 + \cdot02161\,x : 1\cdot3787 + 00257\,x : : 1 : \cdot85$$

$$\text{Therefore} \quad \frac{1\cdot3787 + \cdot00257\,x}{\cdot6003 + \cdot20161\,x} = \cdot85$$

whence $x = 54{\cdot}9$ lbs., and that amount of limestone will be required for each 100 lbs. of ore.

The fuel ash contains—

	Per cent.	Mol. wt.	Equiv.	Bases.	Acid.
Silica	50 ÷	60 ×	4	. .	3·333
Alumina Ferric oxide	45 ÷	102 ×	6	2·647	. .
Lime	1·50 ÷	56 ×	2	·0536	. .
Magnesia . .	2·25 ÷	40 ×	2	·1125	. .
				2·8131	3·333

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[*] Vol. xlvii.

[†] The other half is assumed to be reduced.

Let y be the amount of limestone in pounds to be added to 100 lbs. of ash to form a slag in which the ratio of bases to silica is in the proportion of 1 : ·85, then

$$\frac{3{\cdot}33 + {\cdot}00257\,y}{2{\cdot}8131 + {\cdot}02161\,y} = {\cdot}85,$$

whence 100 lbs. of fuel containing 8·5 lbs. of ash will require $8{\cdot}5 \times {\cdot}590 = 5$ lbs. of limestone. The total amount of limestone is thus easily obtained.

This method can be applied to any ore, and is quite accurate enough for all ordinary purposes.

Calculation of Amount and Composition of the Iron.

For ordinary purposes pig iron may be taken as containing 95 per cent of iron unless the phosphorus or manganese be high, in which case it is best to consider the 95 per cent as being iron + manganese + phosphorus.

The ore, the analysis of which has been given above, contains 71·43 per cent of ferric oxide, or 50·8 per cent of iron. Assuming the pig yielded to contain 95 per cent of iron, 100 lbs. of ore will give $\frac{100 \times 50{\cdot}8}{95} = 52{\cdot}6$ lbs. of pig iron, or 1 ton will give 10·52 cwts.

This is only a rough approximation, as the composition of the iron varies considerably.

Manganese in the Iron.—It may be assumed, under ordinary conditions, that one-half of the manganese in the ore enters the iron, the other half passing into the slag.

Suppose that the ore contains ·9 per cent of manganous oxide ($Mn\,O$) and 70 per cent of ferric oxide, the amount of iron yielded will be $70 \times {\cdot}7 \times 1{\cdot}05 = 51{\cdot}45$ lbs. for each 100 lbs. of ore.

The manganese will be $\cdot 45 \times {\cdot}774 = {\cdot}348$, and as this will be in 51·45 lbs. of pig iron, the percentage will be $\frac{{\cdot}348 \times 100}{51{\cdot}45} = {\cdot}67$.

Amount of Phosphorus in the Iron.—The whole of the phosphorus in the charge is reduced, and passes into the iron.

Suppose an ore contains 70 per cent of ferric oxide and 1 per cent of phosphoric anhydride, what will be the percentage of phosphorus in the iron?

The 100 lbs. of ore as above will yield 51·45 lbs. of pig iron.

The 1 lb. of phosphoric anhydride contains $1 \times {\cdot}4366 = {\cdot}4366$ lbs. of phosphorus. This is concentrated in the 51·45 lbs. of pig iron, so that the percentage will be $\frac{{\cdot}4366 \times 100}{51{\cdot}45} = {\cdot}84$.

A more accurate method, and one which must always be used when the quantity of phosphorus is large, as in basic pig, is as follows: Taking the same figures as before, 100 lbs. of the ore yields 49 lbs. of iron and ·4366 lbs of phosphorus, and the two together make up 95 per cent of the pig iron, so that the amount of pig iron made will be $\frac{49{\cdot}4366 \times 100}{95} = 52{\cdot}03$ lbs. for each 100 lbs. of ore. This will contain $\frac{49 \times 100}{52{\cdot}03} = 94{\cdot}17$ per cent of iron and $\frac{{\cdot}4366 \times 100}{52{\cdot}03} = {\cdot}82$ per cent of phosphorus.

ORE MIXING.

In the previous calculations it has been assumed that a definite ore was being smelted, and that it was only necessary to calculate the composition, &c., of the resulting pig iron. This is rarely the case, the charges used usually consisting of mixtures of ores of various kinds, partly because no single ore in stock will give pig iron of the required composition, and more often because ores of various kinds have to be used.

The mixing is largely done by guess-work. When uniform working is required, and still more when it is desired to produce iron of uniform quality, the charges must be calculated.

If silicious and calcareous or aluminous ores are in stock, it is always well to use a mixture, so as to diminish the quantity of limestone to be added; but ores of very different physical characters, *e.g.*, hard and soft ores, should not be mixed. Once the mixture has been decided upon, the amount of limestone to be added can be calculated by the methods already described.

Example.—Ores of the following composition being in stock, it is required to make a foundry pig containing about 1 per cent of phosphorus.

A—Brown Hæmatite :—

	Per cent.
Ferric oxide	70 = 49 per cent iron.
Silica	10
Alumina	2
Manganous oxide	2
Phosphoric anhydride	·6 = ·26 per cent phosphorus.
Water	15·4

B—Calcined Clayland :—

	Per cent.
Ferric oxide	60 = 42 per cent iron.
Silica	18·6
Alumina	12
Lime	5
Magnesia	1
Phosphoric anhydride	3·4 = 1·49 per cent phosphorus.

Assuming that the pig iron is to contain 94 per cent of iron and 1 per cent of phosphorus.

In A the proportion of iron to phosphorus is 94 : ·5, and in B it is 94 : 3·33; these ores are to be mixed in such proportions that the ratio shall be 94 : 1.

If a quantity of A be taken which will contain 94 parts of iron, it will contain only ·5 of phosphorus, while a quantity of B containing 94 parts of iron will contain 3·33 parts of phosphorus.

To a quantity of the ore B containing 94 parts of iron and 3·33 parts of phosphorus it will be necessary to add x portions of the ore A, each containing 94 parts of iron and ·5 parts of phosphorus. Thus

$$(x \times \cdot 5) + (1 \times 3{\cdot}33) = (x + 1) \times 1$$

$$\cdot 5\,x + 3{\cdot}33 = x + 1 \;\therefore\; \cdot 5\,x = 2{\cdot}33,\ x = 4{\cdot}66.$$

So that the ores must be mixed in such proportion that 4·66 times as much iron must be yielded by A as by B.

The amount of phosphorus in a quantity of ore B containing 94 parts iron = 3·33

Amount of phosphorus in a quantity of ore A containing 4·66 × 94 parts of iron = ·5 × 4·66 .... 2·33

Amount of phosphorus in a quantity of the mixture containing 5·66 × 94 parts of iron = 5.66

Amount of phosphorus in a quantity of the mixture containing 94 parts of iron $= \dfrac{5{\cdot}66}{5{\cdot}66} =$ 1·00

Therefore to 100 parts of the ore B, containing 42 parts of iron, it will be necessary to add 399·4 parts of the ore A, containing 195·7 parts of iron; or, in round numbers, 400 parts of A to 100 parts of B.

As a rule, it is only necessary to go to whole numbers in the proportions, and these can be judged by inspection.

Suppose, for instance, the proportions are judged to be such that A should yield four times as much iron as B. Then

1 part B containing 94 parts iron will give .... 3·33 parts P.
4 parts A containing 94 × 4 parts iron will give .... } ·5 × 4 = 2·00 parts P.

The five parts will give .... 5·33

and a quantity of the mixture containing 94 parts of iron will give $\dfrac{5{\cdot}33}{5} = 1{\cdot}06$ parts of phosphorus, which is very near the required percentage. If the proportions be assumed to be 1 : 5, then

1 part B (94 parts iron) = 3·33 P.
5 parts A (94 × 5 parts iron) = 2·50 P.

6 parts of the mixture .... 5·83

One part of the mixture containing 94 parts iron $= \dfrac{5{\cdot}86}{6} = \cdot 97.$

It is obvious therefore that small variations in the quantity of the ore A used are of very little moment, and it will be quite near enough to assume that 4 parts of iron must be yielded by A for each part given by B.

That is, if 100 parts of the ore B be taken, yielding 42 parts of iron, then the amount of A must be taken so as to yield 168 parts of iron. Therefore $\frac{168}{49} \times 100 = 342{\cdot}8$, or say, 343 lbs.

The charge used therefore will be

A—343 lbs., containing

Ferric oxide	240·10 lbs.	= 168·07 lbs. Fe.
Silica	34·30 ,,	
Alumina	6·86 ,,	
Manganous oxide	6·86 ,,	
Phosphoric anhydride	2·05 ,,	= ·898 lb. P.
Water	52·83 ,,	
	343 lbs.	

B—100 lbs., containing

Ferric oxide	60·0 lbs.	= 42 lbs. Fe.
Silica	18·6 ,,	
Alumina	12·0 ,,	
Lime	5·0 ,,	
Magnesia	1·0 ,,	
Phosphoric anhydride	3·4 ,,	1·49 lb. P.
	100 lbs.	

And the mixture :—

Ferric oxide	240·10 +	60·0 =	300·10
Silica	34·30 +	18·6 =	52·90
Alumina	6·86 +	12·0 =	18·86
Manganous oxide	6·86		6·86
Lime		5·0 =	5·00
Magnesia		1·0 =	1·00
Phosphoric anhydride	2·05 +	3·4 =	5·45
Water &c.	52·83		52·83
			443 lbs.

from which the amount of limestone to be used can be calculated.

Size and Capacity of Furnaces.—Mr. J. L. Stevenson (*Engineer*, August 25th, 1905), gives the following data as to the standard size of a blast furnace, of the American type.

In a properly proportioned blast furnace the " make " M per 24 hours is

$$M = B^2 \times H \div 100.$$

where B = the diameter at the bosh and H the height in feet.

Given the required make, M, to find the necessary dimensions

$$B = 2{\cdot}85\ (\sqrt[3]{M}.)$$

$$H = 12{\cdot}5\ (\sqrt[3]{M}.)$$

2·85 and 12·5 being constants.

To calculate the volume or burden capacity of a blast furnace, various methods may be used.

Obviously a furnace will usually consist of three sections, the lowest the cylindrical hearth, the next the boshes, an inverted frustrum of a cone and the upper portion the frustrum of a third cone, so that there will be three portions to be added together, or it may be more according to the form of the furnace.

The volume (capacity) of a cylinder where $D =$ its diameter is

$$V = \frac{\pi D^2 H}{4}.$$

For the frustrum of a cone

If $\delta =$ the diameter at large end, and d the diameter at the small end, the volume

$$V = (\delta^2 + \delta\, d + d^2)\ \pi\ H \div 12,$$

all the dimensions being in feet.

The hearth diameter C for a given make should be

$$C = 1{\cdot}8\ \sqrt[3]{M},$$

where 1·8 is a constant.

The tuyere area A in square inches should be

$$A = 1{\cdot}25 \times M.$$

The heating surface of the stoves "S" in square feet should be $S = 444 \times M$.

The volume of air required per minute (V) in cubic feet =

$$V = 140 \times M.$$

These data are useful, but it will be found that British practice does not always conform to them.

CHAPTER XII.

BLAST FURNACE PRACTICE.

The practice in different districts varies much, and even in the same district there may be considerable differences at different works. The differences are brought about by differences in the material used, local conditions and local traditions.

Middlesbrough.—This is now the most important iron-producing district in Great Britain. The ore used is of two kinds, the local Cleveland ironstone, used for making foundry pig, and imported hæmatite ore, used for making hæmatite pig, of which the production is now very large.

The furnaces are usually of large size, 80 ft. to 90 ft. in height, 25 ft. diameter at the bosh, with a capacity of about 20,000 cubic feet. The fuel used is Durham coke, which, being very strong, allows of the use of large furnaces. It contains 8 to 12 per cent of ash and 0·90 per cent of sulphur. The blast is usually used at a pressure of 4 lb. to 7 lb., and at a temperature of 1,000 deg. to 1,400 deg. Fah., heated in firebrick stoves, but recently higher pressures have been introduced. The output of each furnace is about 800 to 1,200 tons per week of foundry pig, and rather more when hæmatite pig is being made, and much larger makes are sometimes obtained.

Average charges with Cleveland stone are about—

	Cwt. Cwt.			
Ironstone, Raw...	64 to 68	about	41	per cent iron.
Coke	22 ,, 25	,,	9·25	,, moisture and ash
Limestone	12 ,, 15			

for each ton of pig iron obtained.

The raw stone is calcined before charging, and it loses about 24 per cent in the process.

In one case, working hæmatite, the charge was

Ore	38 cwt.
Coke	20 ,,
Limestone	8 ,,

per ton of iron. The output in this case being 800 tons a week.

During the last few years the practice has been greatly improved, and much larger outputs are now obtained without any great increase

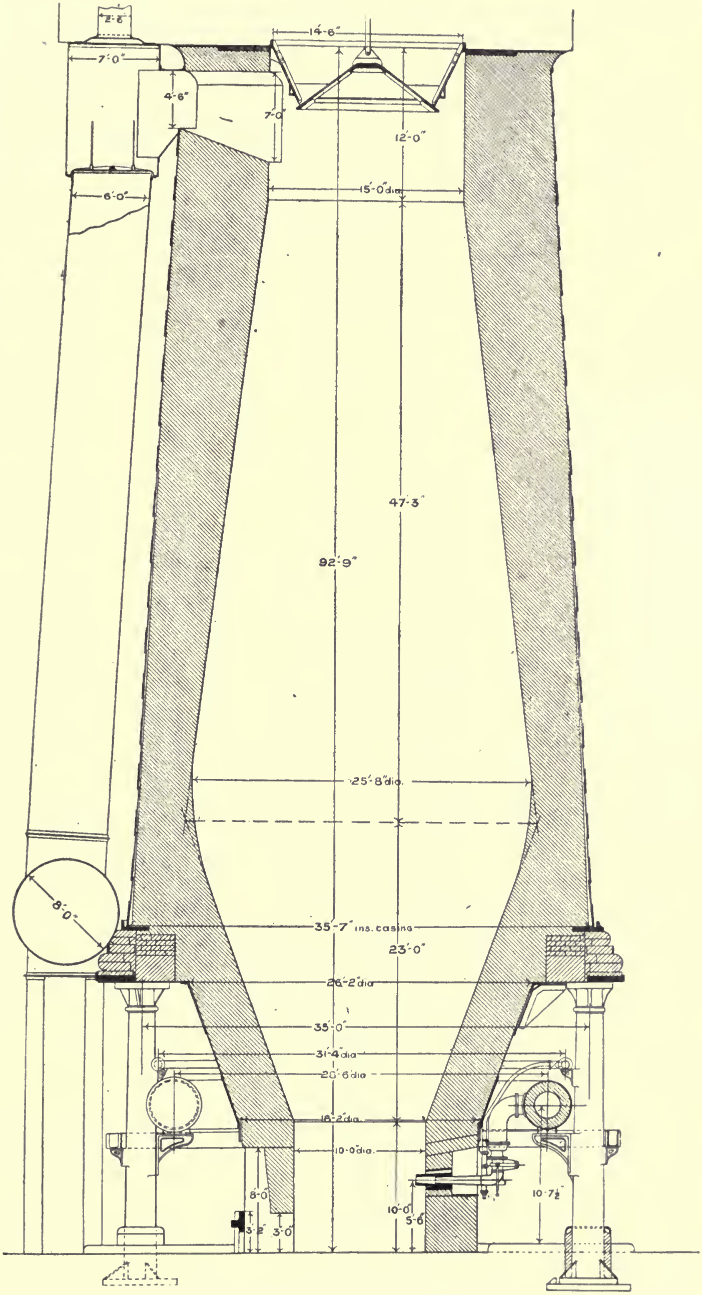

Fig. 62.—Old Cleveland Blast Furnace.

in the size of the furnace. The following working of Messrs. Bell Bros.' No. 11 furnace at Clarence may be taken as a type* :—

Lining.	From.	To.	Total make. Tons.	Cwts.	Average per week. Tons.
1st	—Oct. 26th, 1875	Nov. 9th, 1895 .	476,562	8	457
2nd	—Sept. 23rd, 1896	Dec. 21st, 1905..	449,552	14	931
3rd	—Oct. 9th, 1907	July 18th, 1908	41,752	12	1018

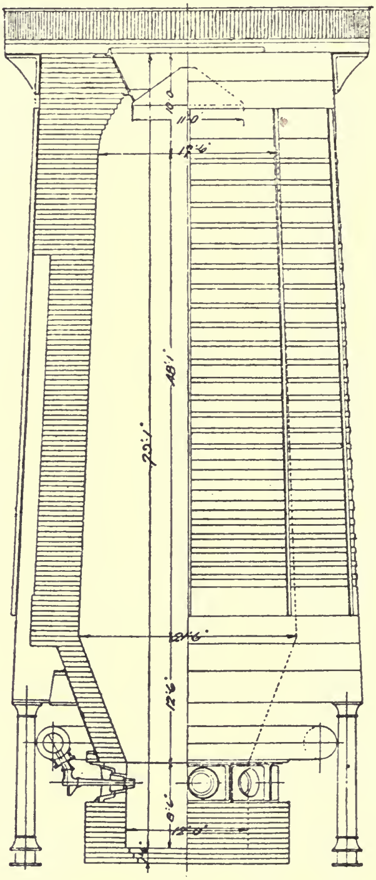

FIG. 63.—Modern Cleveland Blast Furnace.

The average weekly make in the district is now about 1,100 tons, and in one case over 1,300 tons per week was made for over three months.

Fig. 63 is one of the latest furnaces in the district, erected in 1908.

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* See a description of Messrs. Bell Bros.' Blast Furnaces from 1866 to 1908. "Journal of the Iron and Steel Institute," vol. ii., 1908.

The following particulars of the development of the iron industry in this district may be of interest† :—

	1883. Tons.	1893. Tons.	1903. Tons.	1907. Tons.
Cleveland Basic Iron	1,855,508	1,388,043	1,978,795	2,417,062
Other kinds.....	905,232	1,336,141	1,129,255	1,117,006
Total	2,760,740	2,724,184	3,108,050	3,534,068
Furnaces on Cleveland Iron	84	43	41	42
Other kinds	33	41	34	36
Average weekly make per furnace. Tons :				
Cleveland Iron ..	424	717	928	1196
Other kinds	527	526	638	597

Messrs. Bolckow, Vaughan and Co. erected at Eston a furnace 72 ft. high and 25 ft. in diameter, which, using a 50 per cent ore, has had a weekly output of 1,000 tons. In this case the tuyeres have 5½ in. nozzles, and the blast pressure is 5½ lb.

Scotland.—Here the conditions are quite different from those of Middlesbrough. The ores used are calcined local black and clayband (which are now rapidly becoming exhausted), and imported hæmatites and brown ores—largely the latter, from the South of Spain—and from other districts ores of various kinds. For foundry and basic pig, puddler's cinder, mixed with brown and other ores, is often used. The fuel used is raw splint coal, which gives 55 to 60 per cent of a soft weak coke. On account of the weakness of the coke, large furnaces cannot be used. The usual internal working height is about 50 ft., and the diameter of the bosh, 16 ft. to 20 ft.

The blast is supplied at a pressure of about 5½ lb., and is heated to 1,000 deg. to 1,400 deg. Fah. The output per furnace is about 350 to 400 tons of foundry pig per week, with the consumption of about 32 cwt. of coal per each ton of iron produced ; but this obviously will vary with the amount of coke which the coal will yield. The following were charges used at one works for foundry pig :—

	1.	2.
Calcined clayband ...	7 cwt.	9 cwt.
Hæmatite	5 ,,	2 ,,
Puddler's cinder......	1 ,,	2 ,,
Limestone	2¾ ,,	2½ ,,
Coal	14½ ,,	10¾ ,,

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† See Iron and Steel Industries in the Cleveland district during the last quarter of a century. W. Harden, "Journal of the Iron and Steel Institute," 1908, vol. ii.

Within the last few years very great improvements have taken place in blast furnace plant. Fig. 65 gives a section of a blast furnace erected at Glengarnock, designed by the manager, Mr. Edgar Windsor-Richards.

The principal points of this furnace in comparison with the other recent furnaces in the district are, a decrease in the diameter at the bosh, and increase at the stock line, so as to give a more parallel shaft, increase in depth and diameter of the hearth, increase of the height of the columns so as to allow greater access of air to the masonry of the bosh, increase of the number of tuyeres to ten, and increase in the diameter of the hot blast main. The furnace is also supplied with four circles of bronze water-cooling blocks placed at

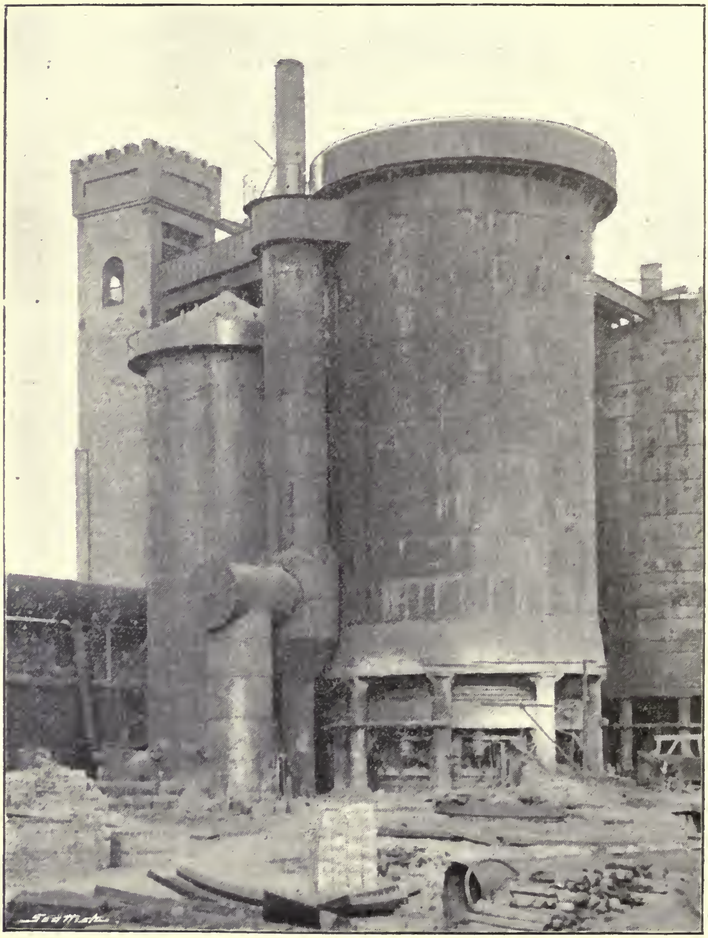


FIG. 64.—View of Glengarnock Furnace.

equal distances up the bosh. The hearth is of stone, built in two layers 2 ft. 6 in. and 3 ft. thick, 18 ft. 6 in. in diameter, and surrounded by a 9 in. firebrick wall. The well is built of 6 in. firebrick blocks up to spring of the tuyere arches. The furnace body is built solid, without lining. To about half way up the barrel of the furnace, it is built of ordinary 9 in. by 4½ in. by 3 in. firebricks, and afterwards is continued to the top with 3½ in. firebrick blocks. The downcomer has also been increased in size, and runs down into the dustbox, forming a water seal.

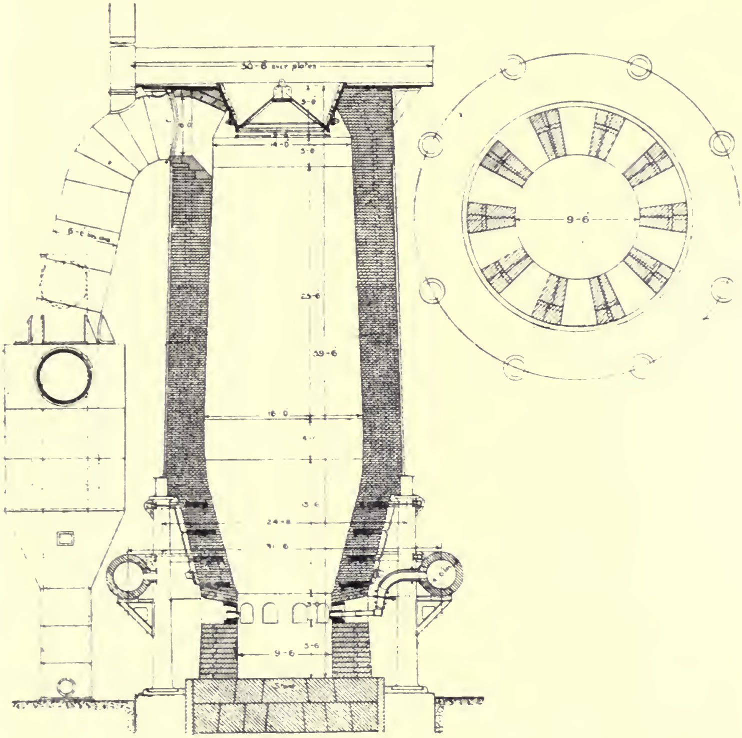


FIG. 65.—Section of Glengarnock Blast Furnace.

The by-products are recovered at all the Scotch works with one exception.

South Wales.—The iron made in this district is mainly hæmatite iron from imported ores, chiefly Spanish, a few furnaces only making foundry pig either from local ores or those mixed with cinder. The furnaces, Fig. 66, are from 65 ft. to 75 ft. high, most of the older ones being about 60 ft., but the more recent ones taller. The diameter at the bosh is from 15 ft. to 20 ft. The fuel used is exclusively coke, about 23 cwt. being consumed for each ton of iron produced, and the output varies from 500 to 1,000 tons per week, as much as 1,400 tons having been made by one furnace.

Northamptonshire.—The ores worked in this district are the local oolitic ores, and a mixture of raw and calcined ore is often used. An average charge may be taken as—

Raw ore	57 cwt.
Raw limestone	14 ,,
Coke	22 to 27 ,,

per ton of iron produced.

The newer furnaces are 65 ft. to 70 ft. in height, 18 ft. to 20 ft. in diameter, with closed tops, blast at about 4 lb., heated by fire-brick stoves to 1,400 deg. Fah., giving an output of about 500 tons of pig per week. The older furnaces are from 54 ft. to 60 ft. high, and 16 ft. to 18 ft. in diameter. The blast is used at about 6 lb., but is heated in pipe stoves. The output of these furnaces is 300 to 370 tons per week.

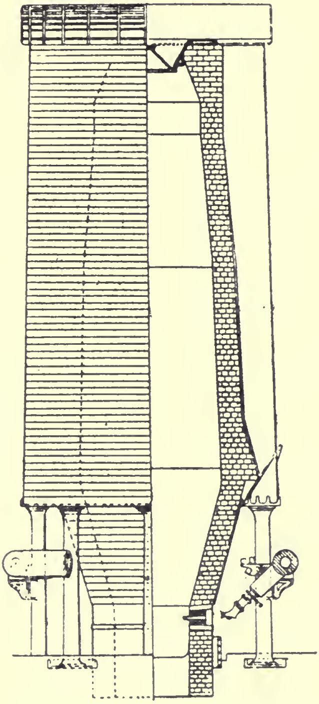


Fig. 66.—South Wales Furnace.

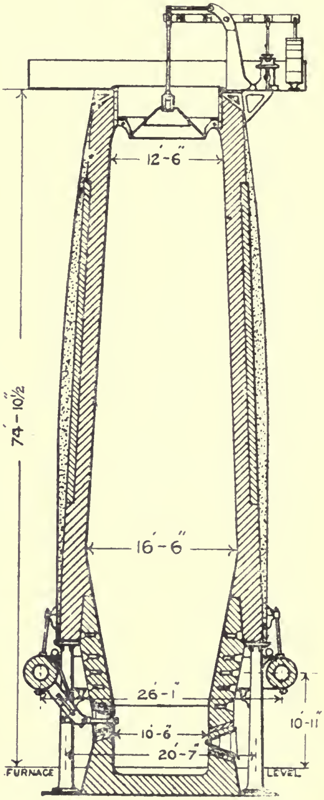


Fig. 67.—American Furnace.

Yorkshire Cold-blast.—Cold-blast iron is now very little made in this country. It is, however, still produced in Yorkshire for the manufacture of best Yorkshire iron. The furnace used at Low

Moor is 70 ft. high, 18 ft. diameter at the bosh, and 15 ft. at the throat, and has a capacity of 10,700 cubic feet. There are three tuyeres with 4 in. nozzles, and the blast is supplied at a pressure of 4 lb. The make is 350 tons a week, and the fuel consumption of 38 cwt. of coke per ton of iron produced. The ore used is a local clay-band, containing about 42 per cent of iron.

The other furnaces in the district making cold blast iron are much smaller and of the older type. Many authorities contend that the best cold blast iron can only be made in small furnaces.

These examples will be sufficient to illustrate the varieties of practice in the United Kingdom. Details are being gradually changed everywhere, the tendency being to increase the size of the furnace to the utmost limit the strength of the fuel will allow, and to increase the rate of driving so as to increase the output.

Germany.—The German furnaces are of moderate size, rarely exceeding 60 ft. in height; an example is shown in Fig. 68. Both local and imported ores are used. The iron produced is chiefly foundry or basic, but little hæmatite pig being made.

The United States of America.—The iron production of the United States is now so large, and is spread over such a wide area, with such varying conditions, that the practice must vary considerably. Hæmatite pig is made in districts where ores free from phosphorus occur, in other localities foundry pig is made. Coke is the fuel almost always used, but anthracite and charcoal are used to a smaller extent. Raw coal, suitable for direct furnace use, occurs, but has not yet been utilised.

Furnaces.—The following particulars are given by Mr. Gayley as to one of the furnaces at the Edgar-Thomson works: The height is 80 ft.; diameter at bosh, 22 ft.; at hearth, 11 ft.; and diameter of bell, 12 ft. Capacity, 18,200 cubic feet. The amount of air required is 25,000 cubic feet per hour, and it is delivered at a pressure of 9 lb. or 10 lb., through tuyeres with 6 in. nozzles. The gases escape at a temperature of about 350 deg. Fah., and contain 11·7 per cent of carbon-dioxide, and 27·5 per cent of carbon-monoxide.

The average burden is—

Ore (62 per cent iron)	32·2 cwt.
Coke	17 ,,
Limestone	10 ,,

for each ton of iron. The coke used is Connellsville, and contains 10 per cent of ash. The iron produced contains about 1·6 per cent of silicon, and the slag 33 per cent of silica, and 13 per cent of alumina. The best week's output was 2,426 tons, with a consumption of 15·58 per cent of coke per ton of iron, and the average over 15 months was 2,208 tons per week, with a consumption of 16·77 per cent of coke per ton.

This may be taken as a fair type of an American furnace as to size and output, though there are many of larger size, and which have made larger outputs.

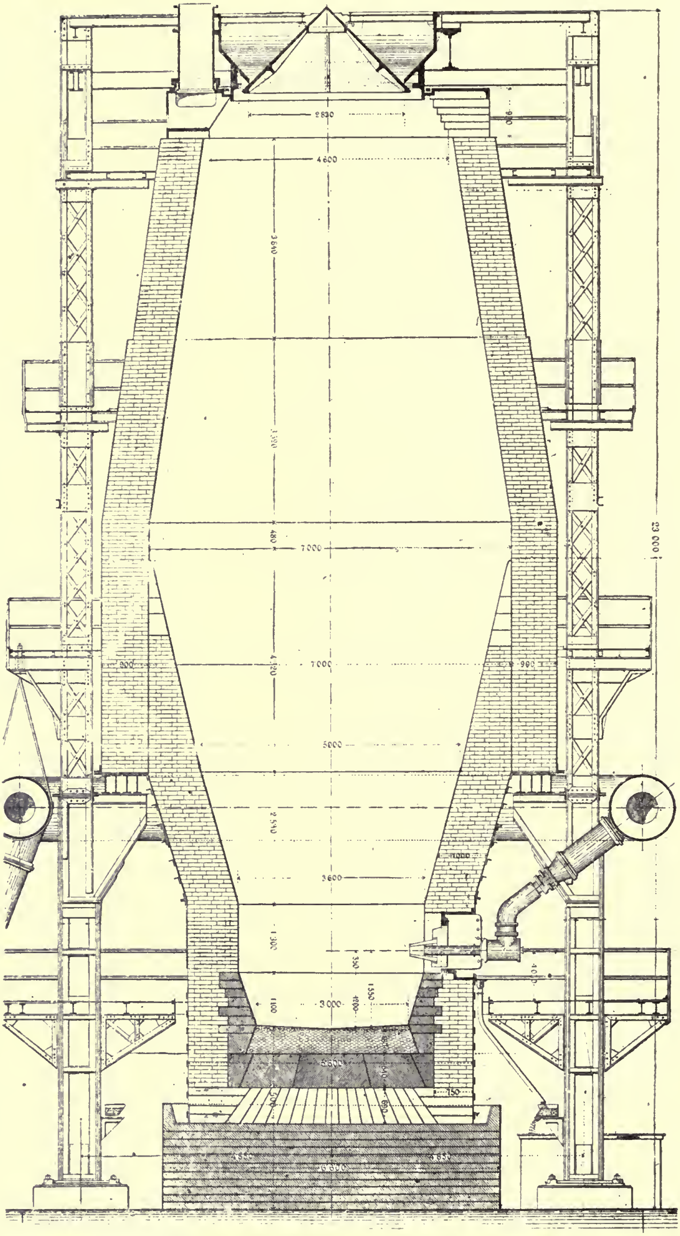


FIG. 68.—German Furnace (Dimensionsin Metres).

It will be seen at once that whilst the American furnaces are no larger than those in this country, the output is very much greater, this being brought about without any increase in the consumption of coke per ton of iron produced. The larger production is due to more rapid driving, and this in its turn to a larger supply of air. The arrangement of the plant, in many cases, is very different from that adopted in this country.

As already mentioned, in this country one large blowing engine is usually made to drive all the furnaces, the air being sent into a common main, and passed through the same heating stoves. In America, on the other hand, each furnace is provided with its own two or three small blowing engines, and its own heating stoves. Much larger tuyere nozzles are used, so as to allow of the passage of more air, and this is supplied at a higher pressure. Owing to the rapid combustion the temperature is very high, and the boshes are always provided with means of cooling.

Great advances have also been made in the methods of dealing with the materials mechanically, so as to reduce, as far as possible, the amount of labour, whilst at present very little has been done in this direction in this country.

Southern States of America.—In the Southern States the ore is much more irregular and the coke is softer. The furnaces, therefore, are somewhat smaller, and the output is about 700 tons to 800 tons a week. As the ore is often phosphoric, the iron made is of foundry quality.

Anthracite Furnaces.—Though at one time anthracite was largely used, there are few if any furnaces now running on it alone, though in some places it is used mixed with coke. The furnaces used were about 60 ft. to 70 ft. high, and somewhat narrow. The consumption of fuel was about 2,500 lbs. per ton of iron, and the blast was supplied at a pressure of 8 lbs. or 9 lbs.

Charcoal Furnaces.—These are now used only in a few remote localities. They are of small size—up to 40 ft. high, with a diameter of 9 ft. or 10 ft. They make from 50 tons to 100 tons of iron per week, with a consumption of 22 cwt. or 23 cwt. of charcoal for each ton of iron. The blast pressure is from ½ lb. to 1 lb., and it is only slightly heated.

MANUFACTURE OF SPECIAL VARIETIES OF IRON.

Speigeleisen and Ferro-manganese.—These alloys, which are now largely used in steel making, are made in the blast furnace. They are required to contain a uniform and definite percentage of manganese, with but little silicon. The iron is supplied in the form of hæmatite and the manganese in the form of manganese oxide. The furnaces are only of moderate size, those used in New Jersey being 34 ft. 9 in. in height, 8 ft. in diameter at the bosh, and 5 ft. at the hearth. Air is supplied at a pressure of 3 lbs. to 5 lbs., and at a temperature of about 950 deg. Fah. If the blast be used too hot there is a greater tendency to the reduction of silicon. The output of the furnaces mentioned is about 230 to 250 tons of ferro-manganese, containing 80 per cent manganese, per week. The consumption of fuel is 4,800 to 5,000 lbs. per ton of iron, and the slag produced must be very basic.

In one British works making ferro-manganese the fuel consumption was 3 tons for each ton of alloy obtained. The ores used contained 45 to 50 per cent of manganese, and about 62 cwts. was needed for each ton of alloy, so that between 40 and 50 per cent of the manganese was lost in the slag.

The following analysis of slag from an American ferro-manganese furnace will show its general character :—

Silica	20·14
Alumina	4·44
Ferrous oxide	31·37
Manganese oxide	15·96
Zinc oxide	3·76
Lime	15·61
Magnesia	2·59

As will be seen, the slag contains a considerable quantity of manganese. Many manganese ores contain zinc, and zinc oxide is apt to collect at the top of the furnace. To allow of its removal cleaning doors are provided in the charging hopper, or the bell and cone are so arranged that they can be lifted out.

Silicon Ferro-manganese is an alloy of iron and manganese, containing a considerable quantity of silicon.

Silicon Iron.—This is pig iron containing 10 to 15 per cent of silicon. It is prepared by working with a large quantity of fuel, *i.e.*, a light burden, a very hot blast, and but little lime in the charge. The furnace used is always small, the consumption of fuel is high, and the slags are very acid, and, therefore, difficultly fusible.

Chromium Iron.—This is an alloy of iron and chromium. When the chromium is not required to be above 40 per cent it is made in the blast furnace from chrome iron ore. The blast is used at a high temperature, and the fuel consumption is 3 or 4 tons for each ton of alloy obtained. The whole of the chromium must be reduced or the slags are too viscid to flow. To aid in the production of a suitable slag various fluxes are added, such as fluor spar and alkaline carbonates.

Working the Furnace.

Blowing-in.—A new furnace must be heated very gradually so that the masonry may not crack. A temporary grate is erected on the hearth, and on this is made a wood fire, coke is added, and when this has burnt up a little limestone to flux the coke ash. When the wood has burnt down so as to bring the coke to the level of the tuyeres, a small blast is put on, more coke is added, and a little more blast is given, then a little ore and limestone and so on, the blast and the quantity of ore is gradually increased. When the first tap is made the gases, which have up to this time been allowed to burn in the air, are turned into the gas main.

At first the burden is always light and the iron is often high in silicon.

Blowing-out.—When it is necessary to stop a furnace, it must be blown out. The burden is gradually reduced, till at last nothing but fuel is added—the object being to melt out the whole contents of the furnace—and the blast is continued till the furnace is nearly empty. In America the furnace is sometimes cooled—or drowned out—by deluging it with water, and the cooled material is afterwards removed from the bottom of the furnace.

Damping-down.—When a furnace has to be temporarily stopped, all the apertures by which air can find ingress are luted with clay. A furnace thus closed will retain heat enough to allow of smelting being restarted after several months.

Tapping.—When the furnace is at work the tap hole is closed with a plug of clay, and when the furnace is to be tapped, this is forced in or broken up by means of a crowbar and sledge-hammer. Sometimes it happens that it is extremely difficult to get the hole open in this way, and other methods have to be resorted to, the most usual being to melt out the refractory tap with an oxy-hydrogen or oxy-coal-gas jet. After the metal has run out the tap hole is closed with clay. In this country a plug of clay is thrown into the hole by hand and rammed hard. In America the clay is often forced in from a tube, " a mudgun," by air pressure.

Scaffolds.—When the furnace is working, the charge should sink uniformly, the descent being ascertained by feeling the position of the top of the charge by means of iron rods inserted through the test holes in the charging hopper. If the surface does not sink regularly, or if it does not descend after a long enough period has elapsed, the charge must have stuck somewhere, and a scaffold be forming. The scaffold may extend over the whole area of the furnace, and thus hold up the whole charge, or it may only keep up a portion. Van Hoten says that scaffolds are found separately for each tuyere, but that if formed simultaneously at all the tuyeres they may unite and form an arch. Various methods are used to dislodge scaffolds. The first usually is—where it is possible—to increase the temperature and quantity of the blast so as to melt it down, cr to take off the blast suddenly, and suddenly put it on again, and repeat this several times, the variations in pressure thus produced tending to dislodge the scaffold. If these methods fail, petroleum may be blown in to melt the scaffold down, or holes may be cut into the masonry, and additional tuyeres may be introduced near where the obstruction is supposed to be, or, in bad cases, a hole may be drilled through the wall of the furnace and a charge of some explosive be introduced and exploded.

Slips.—When a scaffold gives way a slip takes place ; this brings down the unfused material too rapidly, and may damage the lining of the furnace.

Bears.—As a furnace works the bottom of the hearth is often cut down below the tap hole, so that when the furnace is blown out a mass of metal or bear is left on the hearth. Iron may find its way into the joints of the masonry, and there solidify into a bear, which is very difficult to remove or break up.

Electric Smelting.—The great development of the use of electricity in metallurgical work has led to many proposals for the adoption of electricity in the smelting of iron, and many experiments have been made with varying success. The main difficulty is financial, that is, the production of a pig iron at a price which will compete with that produced in the blast furnace.

The process is not electrolytic, the current being only used as a source of heat. The ores to be reduced, mixed with the necessary reducing agent and fluxes, are charged into a furnace, not unlike a small blast furnace, into the base of which carbon electrodes are passed. A powerful current is passed, a very high temperature is produced, the reduced iron is heated to a high temperature, and so also is the slag.

In some experiments an efficiency of 58 per cent of the current used was obtained. No air enters the furnace, the coke (or charcoal) being only required for reduction ; and the electrodes of carbon are also used up, to the extent of about five kilos per ton of pig iron produced

The advantages claimed for electric reduction are many.

1. The cost of the construction of the furnace is less.

2. No blowing machinery or hot blast stoves are required.

3. The amount of fuel required is only about one-third of that required in a blast furnace.

4. Finely divided ores can be used without briquetting.

5. The gas produced has a high thermal value, being free from nitrogen.

6. It is possible to regulate the quality of the iron far more accurately than in the blast furnace, it can be made lower in carbon and in silicon.

7. The labour required is reduced, and so also are the costs of transport.

Against these advantages must be put—

1. Sufficient electric power must be obtainable, and unless the cost of this be low, the process will be too expensive.

2. The furnace hearth and the electrodes must be kept cool by circulating water or other means.

3. The furnaces are difficult to control and to keep in order, owing to the very high temperature.

At present electric smelting has not passed the experimental stage, though a small plant in Sweden has been worked so as to pay expenses, and in a Report of the Swedish Iron and Steel Institute it is stated that the problem is solved, if electricity can be supplied at low rates.

CHAPTER XIII.

UTILISATION OF BY-PRODUCTS.

Of the material introduced into the blast furnace the iron forms only a very small proportion, the rest is all waste or by-products. Taking as an example a furnace making foundry pig from Scotch ores, the income and output for each ton of iron produced will be about as follows :—

Income.			Output.	
(1) Iron ore	2·5 tons.			
Iron		·95 ton.	Pig iron	1 ton.
Oxygen		·43 ton.		
Earthy matter		1·12 tons.	Slag	1·5 tons.
(2) Limestone	·5 ton.			
Lime		·28 ton.		
Carbon-dioxide		·22 ton.		
(3) Coal	1·75 tons.		Gases	8·25 tons.
Carbon		1·10		
Ash		·16		
Gases		·49		
(4) Air	6·0 tons.			
	10·75 tons.			10·75 tons.

So that in this case for each ton of iron there will be 9·75 tons of by-products. The by-products are three kinds : (1) Slag. (2) Gases and volatile matters. (3) Accidental products.

Slags.—The nature and composition of blast-furnace slag has already been fully described. The amount of slag produced varies very much with the richness of the ore, the amount of limestone which has to be used as flux, and the amount of ash in the fuel. A furnace with a charge and output, such as that mentioned above, will make about 350 tons of iron and 525 tons of slag per week, but the make of slag may be much larger or much smaller, according to circumstances. An enormous amount of solid matter has therefore to be disposed of, for the amount given is only for one furnace. With ten furnaces it would amount to 5,250 tons per week. Thus the huge cinder heaps, which are so characteristic of the iron-making districts, accumulate year by year. These heaps become very costly, the land occupied is valuable, the piles are therefore made high, and this increases the cost of haulage. Various attempts have been made to utilise the slag with only partial success, and at present the chief use is for making roads or ballasting railways, and as comparatively little is required for these purposes the heaps continue to increase.

In the Cleveland and some other districts paving blocks are made of the slag. Building blocks have also been made by casting the slag in moulds, but these have not been a success. Excellent blocks are, however, made by granulating and crushing the slag to sand, mixing it with lime or with slag cement, if necessary, and compressing in moulds under very great pressure.

A good hydraulic cement can also be made from many slags. The essential hydraulicising compound seems to be a silicate of lime having the composition 3 Ca O, Si O_2. Few slags contain as much lime as this, and even if they did the compound is apparently broken up by fusion, into lime and a less basic silicate. The slag is ground, mixed with the necessary amount cf lime, heated in a kiln to a temperature at which combination takes place, and the mass frits, but does not fuse. This "frit" is then ground, and a cement is produced which closely resembles Portland cement.

One of the most successful methods of utilising blast furnace slag in the production of cement, is that invented by Dr. Colloseus, of Berlin. This process has been successfully worked abroad, and also at the Coltness Iron Works in Scotland, where it is in constant operation. The method consists in pouring a steady stream of the molten slag, as tapped from the furnace, out of a ladle on to a rapidly-rotating drum suitably encased in the "granulator." Just before striking the drum, the slag is made to pass through a jet of water containing magnesium sulphate in solution, and the grains thus formed are prevented from clinkering together by impact with the drum. The alkaline solution reacts with the slag at the high temperature, catalysing it and forming the silicates of lime and alumina into such a condition that the product contains no superfluous lime, and sets within a reasonable time. The granulated slag passes by a chute into conveyors which deposit it for cooling and mixing in a large store, thence it passes to the grinding house, where it is handled by a set of crushers, ball-mills, and tube-mills, which make a very fine powder which is an ideal Portland cement. It has stood well in physical tests, and has been used in the construction of roads.

Slag wool is made by allowing a stream of molten slag to run from a spout in front of a powerful blast of air or steam. The slag is broken up into minute globules, which are carried forward, each carrying after it a fine tail or thread of slag. The material is blown into chambers of wire gauze, the heavy drops fall out, and the light woolly material is retained. Slag-wool is used mainly as a non-conducting packing for covering steam-pipes and other purposes.

If any of these methods of utilising slag were very extensively carried out it is likely, considering the enormous amount of material available, that it would be difficult to dispose of the products.

GASES.

The blast furnace gas is always of value as a fuel, and it is now generally used for heating the blast and raising steam, for though its calorific power is low owing to the presence of carbon-dioxide, a large quantity is always available. When coke is the fuel the combustible constituent is almost entirely carbon-monoxide, but where coal is used hydrogen and various combustible hydro-carbons are also present.

With ordinary splint coal as fuel about 120,000 cubic feet of gas is produced for each ton of fuel consumed, and with coke the quantity is considerably larger.

When the gas is used for steam raising the gas and air are best mixed in a combustion chamber lined with fire brick before passing under the boiler which they are to heat; for if the mixture be allowed to come in contact with the cold surfaces before combustion is complete, the combustion may be imperfect. Usually the gas is supplied from the main, to a small brick-lined box in front of the furnace, into which air passes through a perforated door.

The following analysis will give an idea of the composition of the gas from various types of furnace:—

	Coke fed.	Coal fed. (Unwashed.)		Coal fed. (Washed.)	
Carbon-dioxide	11·39	7·90	6·60	6·60	6·00
Carbon-monoxide	28·61	28·00	27·40	27·20	28·20
Marsh gas	·20	2·73	2·64	2·68	2·76
Hydrogen	2·74	6·77	6·86	7·66	7·44
Nitrogen	57·06	55·50	56·50	55·86	55·60

Burning blast-furnace gas under a boiler is an uneconomical and unsatisfactory method of using it, and is only continued because the supply of gas is so large that economy is not necessary. It is far more economical to use the gas direct for driving internal-combustion engines, and no doubt in the near future this method of use will be considerably extended.

TAR AND AMMONIA.

When coal is the fuel used in the blast furnace, the gases carry over with them a considerable amount of tarry matter and a small quantity of ammonia from the coal, and these can be recovered. Scotch splint coals, such as are in general use for blast furnaces in Scotland, contain about 1·4 per cent of nitrogen, and when the coal is distilled in the blast furnace about 16 per cent of this comes off in the form of ammonia. This is equal to about ·222 per cent of nitrogen given off as ammonia, or 4·97 lb. of nitrogen, or 23·5 lb. of ammonium sulphate for each ton of coal consumed. This amount seems small, but when the large quantity of coal consumed is considered, it will be seen that the amount of sulphate obtainable is very large. Several forms of plant have been designed for the recovery of the tar and ammonia from blast-furnace gases, based on various principles. Three types may be mentioned.

(1) *Cooling and Washing.*—All plant now in use is of this type. The tar, and the ammonia in solution in water, are obtained by cooling the gases and washing them with water, either by scrubbing by a falling shower or by bubbling through water.

(2) *Washing with Sulphuric Acid.*—In this process the gases were slightly cooled by washing with water, and are then made to ascend a scrubber down which sulphuric acid is made to fall, the ammonia being thus fixed as sulphate. This process was only in use at one works, that of the inventors, Messrs. Neilson, of Summerlee; the tar was only partially recovered, and the ammonium sulphate was apt to be contaminated with tarry matters, which discoloured it. The process has now been abandoned, a plant of the Gillespie type having been erected to replace it.

(3) *Mixing with Sulphur Dioxide and Washing Out the Resulting Ammonium Sulphite.*—This process was introduced at the Langloan works, but is not now in use, the plant having been replaced by one of Messrs. Dempsters'. It was intended at first to oxidise the sulphite in solution to sulphate by means of air, but this was not found to be practicable, and the solution had to be distilled with lime.

All the processes now in use, therefore, belong to the first class, and they differ only in the details of the methods used for cooling and washing. Three forms of plant are in use in Scotland :—

(1) The Alexander and M'Cosh.
(2) The Dempster.
(3) The Gillespie.

The Alexander and McCosh Plant.—The first plant for the recovery of by-products was erected by Messrs. Alexander and M'Cosh at the works of Messrs. Baird & Co., Garthserrie. The works consisted of sixteen furnaces, but only eight of these were put up on the first plant, a duplicate plant being erected for the other eight when success had been assured. Each furnace consumed about 60 tons of coal in the 24 hours, so that the amount of gas to be dealt with was nearly 56,000,000 cubic feet per day, and as it was intended to replace the furnaces by others of more modern type, it was necessary to make the plant large enough to deal with the greater amount of gas that would then be available. The plant (Fig. 69) consists essentially of three parts :—

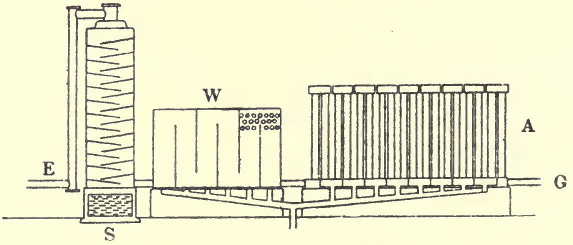


Fig. 69.—Diagram of Alexander and McCosh Recovery Plant. G gas main; A atmospheric condenser; W water condenser; S scrubber; E exhaust.

(1) Atmospheric condenser.
(2) Water cooler.
(3) Scrubber.

The gas is collected from the furnace into a 7 ft. main, passes through dust boxes, and then to the atmospheric condenser. The atmospheric condenser consists of a series of 200 pipes 2½ ft. in diameter, and 20 ft. high. They are arranged in 10 sets of 20 pipes each, connected alternately at the top by cross pipes, and at the bottom by the box on which they stand, diaphragms having a 7 in. water seal being placed so as to compel the gas to pass up the tubes. Each particle of gas, therefore, has to travel through 20 tubes, or 400 ft. The tubes are freely exposed to the air, and in hot weather are cooled by a water spray. The gas enters this condenser at about 200 deg. C. (400 deg. Fah.), and leaves at about 49 deg. C. (120 deg. Fah.).

Though the gas is now cooled far below the boiling point of the tar and water but little of either separates, no doubt because they are in the condition of a very fine spray, which settles very slowly. The gas then passes to the water cooler. The water cooler is a large iron chamber 45 ft. long, 45 ft. high, and 18 ft. wide, divided into seven chambers by diaphragms, with openings alternately at the bottom and top so that the gases pass up one chamber and down the next. These chambers are crossed by 2,700 3 in. iron pipes, connected by bends outside so that the water enters at the end where the gases leave, and traverses all the pipes in the same horizontal plane. The gas leaves this condenser at a temperature of about 25 deg. C. (65 deg. Fah.) and passes to the scrubber.

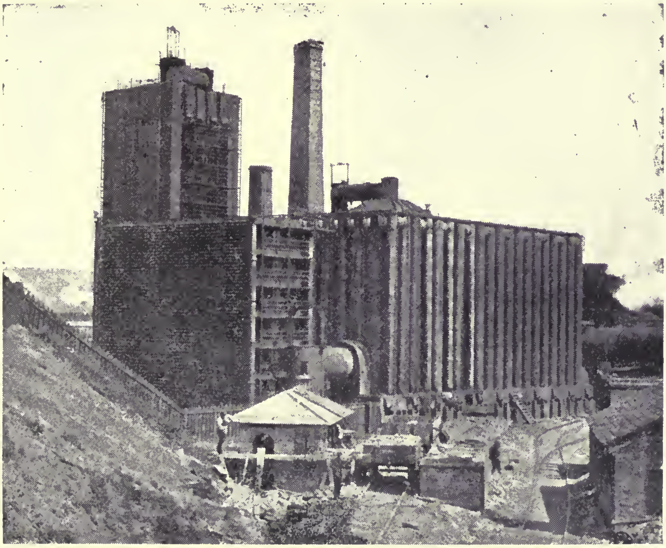


Fig. 70.—General View of the Alexander and McCosh Recovery Plant at Gartsherrie.

The scrubber is a tower 80 ft. high and 20 ft. square, crossed by a series of sloping diaphragms or shelves perforated with holes, with a space of 20 in. between the bottom of each and the wall of the tower, so as to allow of the passage of the gas even if the holes should be stopped up with tar. As the gas ascends it is scrubbed by a descending fine rain of water, which washes out the tar and the ammonia.

As the resistance offered by the passage of the gas through the various condensers is considerable, an exhaust is necessary. In this case Root's blowers are used, which give an exhaust of 3 in. of water and deliver the gas to the furnaces and stoves at a pressure of about 2 in. of water. The gas is free from tar, and contains ammonia equal to about two ounces of sulphate per ton of coal consumed. The tar and ammonia liquor are run into large tanks where they separate by gravity. The works have now been reconstructed, and a smaller number of furnaces of larger size erected, but the ammonia plant has not been much changed.

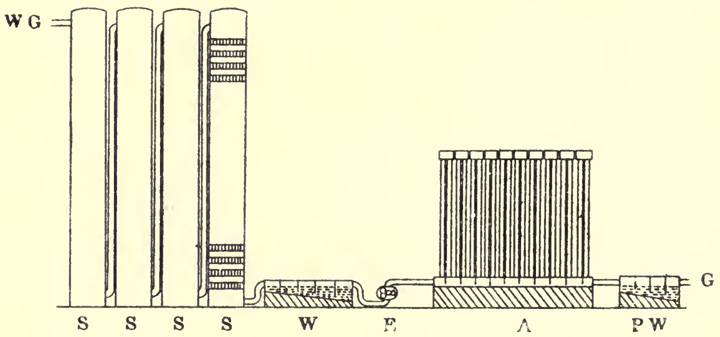


Fig. 71.—Diagram of the Dempster Process.

G gas main ; A atmospheric condenser ; E exhaust ; S S scrubbers ; P W primary washer ; W washer ; W G washed gas main.

The plant subsequently erected by the same firm at another of their works, slight modifications have been introduced—at one works, for instance, the atmospheric condensers are dispensed with.

The Dempster Plant.—This plant (Fig. 71) is based on exactly the same principles as that of Messrs. Alexander and M'Cosh, but differs from it in details.

The gas from the mains passes through dust boxes and then through the primary washers. These are large iron boxes divided into four divisions by diaphragms, and filled with water or tar, through which the gas has to travel. The bottom of the box slopes, so that the tar runs down to the one end, whence it is drawn off. From the primary washer the gas passes to the atmospheric condenser, which is exactly similar to that used in the Gartsherrie plant.

From this it passes to the exhausters usually in the form of horizontal direct-acting blowing engines, at Glengarnock the steam cylinders being placed in the engine-house and the gas cylinders outside, so as to facilitate cooling. The exhausters draw the gas from the furnaces and force it on through another series of washers, the secondary washers, which are similar in form to the primary washers, and then to the scrubbers. Four scrubbers are used, those at Glengarnock being 100 ft. high and 12 ft. in diameter. The scrubbers are filled with boards set on edge, so as to give a very large condensing surface. The gas enters the bottom of No. 1 scrubber, rises to the top, is brought down by a pipe to the bottom of No. 2, which it ascends, then Nos. 3 and 4, and away to the stoves. Fresh water is supplied at the top of No. 4 scrubber, and when it reaches the bottom it is pumped to the top of No. 3, and so on. Thus the gas traverses the scrubbers in one direction and the water in the other.

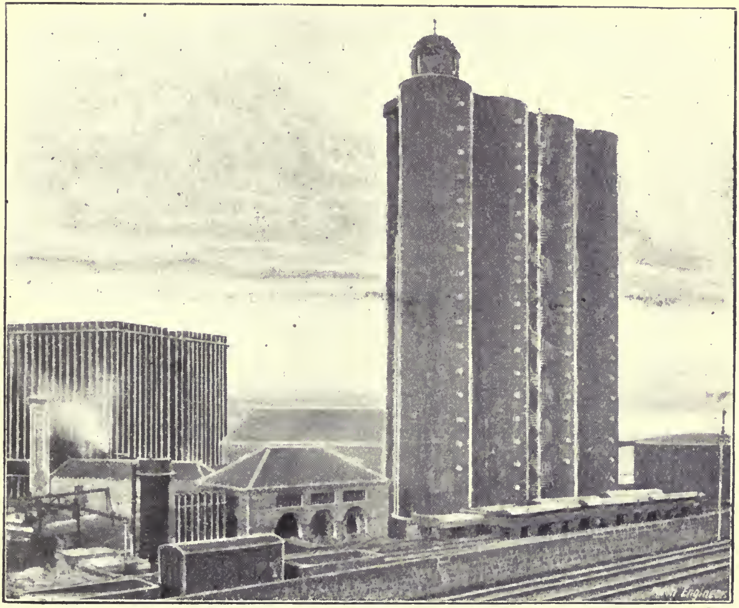


FIG. 72.—Dempster Plant, Showing Scrubbers, &c., at Glengarnock.

Mr. Dempster puts down the cost of his plant at about £6,000 a furnace.

The Gillespie Plant.—Washing, as usually conducted, is not very efficient. The gas passes up through the water in large bubbles, only the surface of which comes in contact with the water, so that considerable quantities of soluble materials may be carried through even a great thickness of water. Scrubbers are effective, but they are very costly to erect. Mr. Gillespie's plant is so arranged as to make washing as effective as scrubbing, and therefore to do away with the huge costly scrubbers. The principal peculiarity of his plant, therefore, is in the construction of the washers, of which three sets are used, two before and one after the exhausting engines.

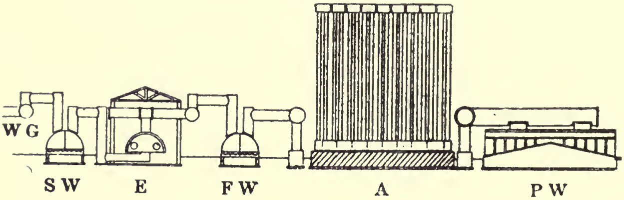


Fig. 73.—Diagram of Gillespie Plant.

P W primary washer; A atmospheric condenser; F W first washer; E exhaust engine; S W second washer; W G washed gas main.

The washer (Fig. 73) consists of a long iron chamber or box with an arched top, divided into two portions by a horizontal floor, the space above being again divided by a vertical division, so as to form two longitudinal chambers, into one of which the gas is delivered, and from the other of which it is drawn away. Beneath the horizontal division are arranged vertical plates placed transversely, the lower edges being serrated with a large number of fine teeth or notches. The lower portion of the chamber is filled with water to just above these plates, which thus form a water seal for gas passing

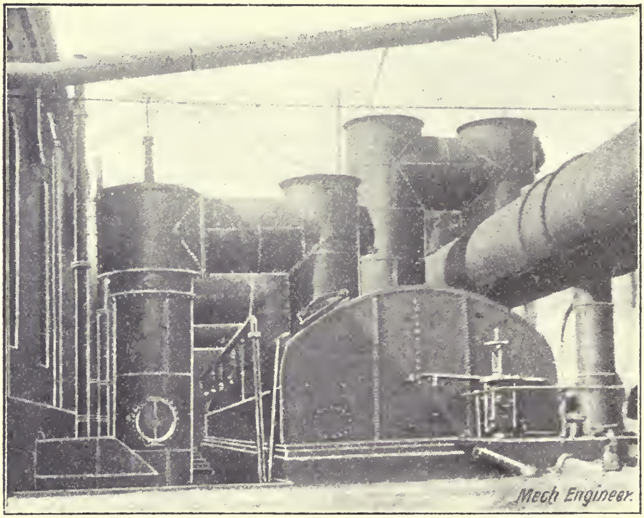
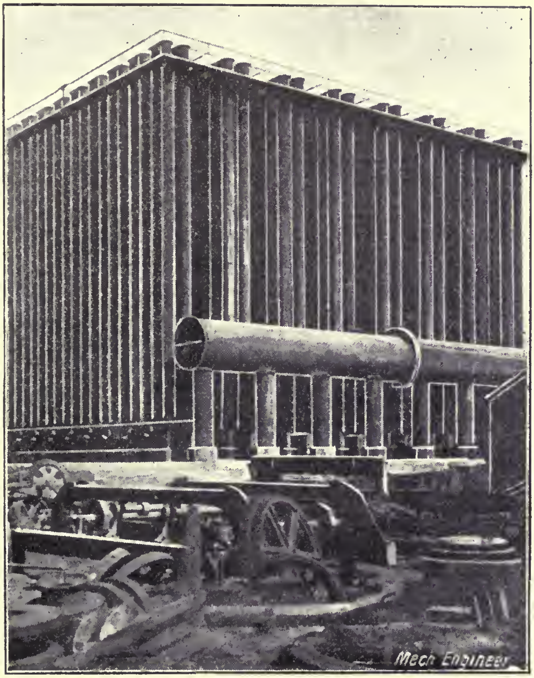

Mech Engineer.

Fig. 74.—Gillespie Washer.

from one side to the other. Openings are made in the horizontal floor, so arranged that gas entering the washer has to pass under these divisions on its way through. As the area of the washer is very much larger than that of the delivery pipes the rate of flow of the gas is very much reduced, and at the same time the flow is broken up by the serrations into numberless very small bubbles, which expose a very large surface to the water, and the gas is thus thoroughly washed.

The gas from the furnace passes through a primary washer, which also acts as a seal, then to the atmospheric condenser, which consists of a large number of tubes, each set being mounted on a separate tar receiver, so that any one set can be cut off for repairs or other purpose without interfering with the remainder ; thence it passes through another set of washers, then through the exhaust engines, through the third washer, and away to the furnaces.



Mech Engineer

Fig. 75.—Atmospheric Condenser.

Plant of this type has been erected at the Wishaw works of the Glasgow Iron and Steel Company, and has worked successfully for some years. The gas is brought from the four furnaces by an 8 ft. gas main to the primary washer, which it enters at 250 deg. Fah., and leaves at 130 deg. Fah. Thence it passes to the atmospheric condenser, and through 18 pairs of tubes, and it leaves this at a temperature of about 70 deg. Fah. It then passes through another washer, through the exhausters—in this case Root's blowers—through the third washer, and to the return gas main.

In several of the latest plants of this type turbine exhausters worked by Parsons' turbines are in use.

In a plant of this type 119 lb. of pitch, 10 gallons of oil, and 23·3 lb. of ammonium sulphate were obtained from each ton of coal consumed.

The products stated to be obtainable per week at Wishaw are:—

Coal consumed	2,000 tons		
Pitch recovered	100 tons	=	£120
Oil recovered	20,000 gals.	=	£125
Sulphate of ammonia	20½ tons	=	£225

The cost of the plant for four furnaces was £28,500, the cost of running the plant, wages, and superintendence are put at £30 a week, and the sulphuric acid costs 20s. per ton of sulphate.*

THE PRODUCTS.

The Gas.—The gas is passed to the stoves and boilers for use. It was at one time feared that the washed gas would be less suitable for use as a fuel than the unwashed gas, some engineers putting the loss of heating power as high as 20 per cent. The gas has, however, been found to be quite well suited for the purpose for which it is required.

Analysis shows no difference between the washed and unwashed gas, because the liquid tarry matter settles out before the gas can be analysed. The washed gas must necessarily have less heating power than the unwashed, because the tarry matters which are removed are combustible; it also burns with a less luminous flame. On the other hand, the washed gas is cooler, and therefore carries much less water than does the gas direct from the furnace. The washing also removes all dust, &c., so that the washed gas is much cleaner in use, and also can be used direct in the gas engine.

The Tar.—The tar has a specific gravity of about ·95—·96, therefore it rises to the surface, when the liquors are run into the storage vats, and can be drawn off. The tar is very different from coal-gas tar, containing very small quantities of the aromatic hydrocarbons, but large quantities of the paraffins and phenols. The tar is, of course, not present as such in the coal, but is produced by the breaking up of the bituminous portion during distillation. The nature of the products varies therefore very much according to the temperature of distillation, this being much lower in the blast furnace than in the gas retort.

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* *Engineering*, vol. lix., page 427.

The tar is heated in boilers by which water is expelled, leaving between 40 and 50 per cent of its volume of boiled or anhydrous tar. As the water which is driven off carries with it some ammonia, it is condensed and added to the ammonia liquor.

The boiled tar is then distilled, yielding three products—

(1) *Lucigen Oil*, which has a specific gravity of about ·970, which is mainly used for burning in the lucigen and similar blast lamps.

(2) *Creosote Oil*, which has a specific gravity of about ·989. It contains phenols, and is used for various purposes, such as preserving timber, &c., and at one works a disinfectant is prepared from it under the name of "neosote."

(3) *Pitch.*—The distillation is stopped whilst the pitch is still liquid enough to run from the still. It is run out and allowed to solidify. By varying the time of stopping, the pitch can be made hard or soft. The amount of pitch yielded is usually about 50 per cent of the anhydrous tar. The pitch is now largely used for making fuel briquettes.

Ammonia.—The water which is condensed contains the ammonia. No doubt the bulk of the ammonia leaves the furnace in the form of free ammonia, but there are also present small quantities of various salts, such as sulphate, cyanide, sulphocyanate, &c., so that a small portion of the ammonia is in combination. The free ammonia is expelled by boiling, and the addition of a little lime liberates that which is combined. Various modern forms of automatic evaporators are now generally used. The liberated gas is passed into sulphuric acid, the sulphate is separated, dried, and is ready for the market.

The amount of sulphate obtained varies with the nature of the coal and the perfection of the condensing plant. It is usually assumed that 16 per cent of the nitrogen in the coal will be recovered as sulphate, and the actual make varies from 22 lb. to 25 lb. of sulphate per ton of coal consumed.

In most cases the liquors, after separation of the ammonia, are run to waste, but in a few cases this is not possible. They are then evaporated, and the potash, salts, &c., which are recovered, are of some value.

Gas for Internal-combustion Engines.—When the gas from coal-fed furnaces is to be used in internal-combustion engines, the methods described do not free it sufficiently completely from tar to prevent the engine becoming choked. Various methods for final cleaning have been suggested, the most successful being to allow the gas to pass through small holes or slots in a metal screen, and to impinge upon a solid screen placed opposite the holes. The sudden impact and change of direction causes a precipitation of the tar.

When the gas from coke-fed furnaces is to be used for internal-combustion engines, it must be freed from dust. Washers of various forms have been designed, the principle of most of them being to pass the gas through vessels containing water, which is thrown about in the form of spray, by rapidly rotating dashers. Forms of plant in which the gas is only bubbled through water, are not satisfactory.

ACCIDENTAL PRODUCTS.

As already remarked, a considerable quantity of cyanides is produced in the furnace. Many attempts have been made to recover this, but at present without success. In old furnaces the cyanide often accumulates to such an extent that it leaks out through the masonry round the tuyeres.

A copper-coloured crystalline body containing titanium as a cyano-nitride is often found in furnaces using titaniferous ores. When ores contain lead the metal is reduced, and is partially volatilised, and partially collects beneath the iron and is tapped out with it.

A considerable quantity cf dust collects in the flues. It is of no value, in most cases, and its composition varies with the nature of the ores. When these ores contain zinc the dust may be rich enough in this metal to be worth treatment.

CHAPTER XIV.

HISTORY OF CAST IRON.

Origin of Cast Iron.—The date at which cast iron was first made is unknown, but it is usually said to be about 1350. The first cast iron was probably made in Germany, and was no doubt produced accidentally in the high bloomery.

Cast iron was introduced into Great Britain about the year 1500. Blast furnaces were soon erected in many parts of the country where wood was abundant, and, therefore, a supply of charcoal, for fuel, could be secured. In Scotland furnaces were erected near Loch Maree about 1609, and soon after in other places. They were all of small size, and used charcoal as fuel.

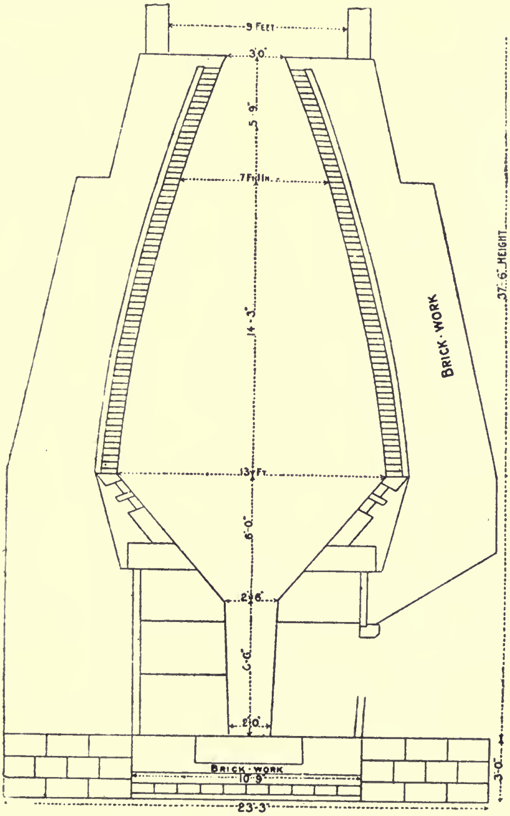

FIG. 76.—Early Furnace at the Carron Works.

Coal in Blast Furnaces.—The first attempts to use coal in the blast furnace which was attended with any success was that of Dud Dudley in 1619, but the work was not taken up by others till 1713, when Abraham Darby brought the method into successful use by coking the coal. In 1740 there were 59 blast furnaces in blast in England; in 1790 the number had increased to 106, of which 81 used coke and 25 charcoal. The weekly make was about 10 tons from a charcoal and 15 tons from a coke furnace. The last charcoal furnace in England was only blown out a few years ago, the last in Scotland—that at Bonawe—in 1866, and the last in the South of England, once the leading iron-producing district in the country, was blown out in 1827. This date, therefore, marks the completion of the transference of the iron industry from the wood-producing to the coal-yielding districts.

In 1760, the Carron Ironworks was started at Carron, near Falkirk, thus commencing the Scotch iron industry on its modern lines. The spot was selected because the river Carron was suitable for the supply of power for the blowing engines. The furnaces were very small, and were charged through openings in the side near the top, like a modern cupola. The blowing engine was worked by water power.

In 1786, the Clyde Ironworks, Tollcross, near Glasgow, was started, and from this works came, a few years later, the two discoveries, one of which revolutionised the iron industries of the world.

Blackband Ironstone.—In 1801, David Mushet, of the Clyde Ironworks, discovered that the material called by the miners "wild coal," and which was thrown away as useless, contained a large quantity of iron, but it was many years before the discovery was fully taken advantage of.

The Hot Blast.—In 1828, James Beaumont Neilson—then manager of the Glasgow gas works—invented the hot blast. Not having any connection with or interest in the iron industry, he approached the owners of the Clyde works, and they, seeing the possible value of the invention, gave him the necessary facilities for testing it. The first form of apparatus was very simple, consisting only of an iron box—through which the air was passed, heated by a fire. Many modifications were made, till, in 1832, Neilson introduced the U-pipe stove which for many years was almost universally used.

In 1829 James Condie, at Calder Ironworks, invented the water tuyere, without which the hot blast would, probably, never have become a success. His form of tuyere, the Scotch tuyere, is still in general use.

Before the introduction of the hot blast the weekly make of each furnace at the Clyde Ironworks was about 37 tons, and the consumption of coal—which was first coked—was about 8 tons per ton of iron produced. To-day the furnaces are larger, the output of each is about 350 tons, the coal consumption about 1 ton 12 cwt., and the blast is heated to 1,400 deg. Fah.

In 1830 the Gartsherrie Ironworks was opened, and the owners, Messrs. Baird, were the first to take out a licence to use the hot blast, the royalty being fixed at 1s. per ton of iron produced. No. 1 Gartsherrie furnace is shown in Fig. 77; the circular portion was added some years later to increase its height. It was pulled down in 1896.

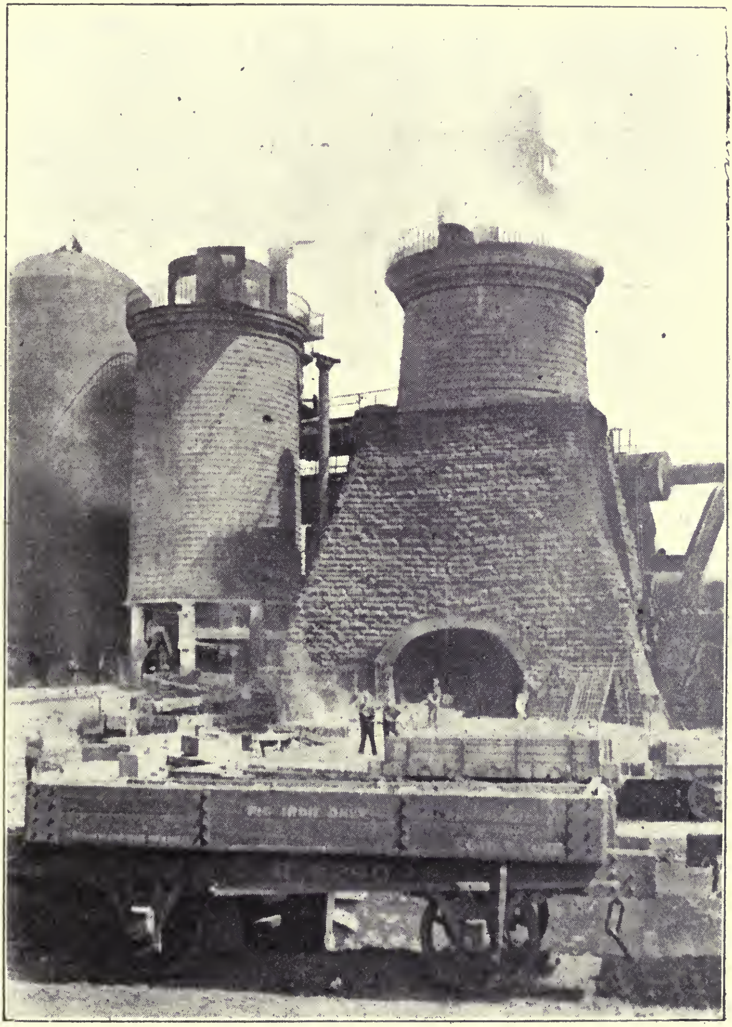

Fig. 77.—No. 1 Furnace, Gartsherrie.
Erected 1836; demolished 1896.

In 1831, Messrs. Dixon, of Calder Ironworks, were the first to use raw coal as fuel in place of coke.

In 1834, the hot blast was introduced into England, a modification of Neilson's U-pipe stove being used. This form, in which the pipes were taller and of less span than in Neilson's form, came to be known as the "Staffordshire" stove. A little later Messrs. Lloyds, Foster and Company proposed to utilise the waste gases of the blast furnace for heating the blast. The pipe stoves continued in use, but gas was substituted for coal as fuel.

In 1860, Mr. E. A. Cowper, of Middlesbrough, described* a firebrick stove which he had erected at the Ormesby works, by which the blast could be heated to 1,300 deg. Fah. The stoves were 7 ft. 6 in. in diameter, filled with a chequer work of firebrick and heated by coal fires. Later in the same year Mr. Cowper took another step and heated his stove by gas from the blast furnace.

It is worthy of note that Mr. Neilson, the inventor of the hot blast, was present at the meeting at which Mr. Cowper's paper was read. He spoke in the discussion, and recognised at once the importance of the new invention, which perfected his invention of 32 years before.

Size of Furnaces.—In all districts the furnaces have undergone changes, both in form and in size, during the last 50 years, the changes following closely upon the introduction of the hot blast. The development has been different in different districts, owing to differences in the nature of the fuel and ore. The largest furnaces are those of the Middlesbrough district.

The following figures from Sir Lowthian Bell relate to that district:—

Date.	Height.	Capacity.	Temperature of Blast.	Weekly Make.	Total per ton of iron.
	Feet.			Tons.	Cwt.
1835	40—50	5,000	Cold	70	120
1845	40—50	5,000	650 deg. F.	120	85
1855	40—50	5,000	800 deg. F.	220	62
1865†	80	20,000	1000 deg. F.	450 to 550	40

By-products.—The first attempt to use the gas for heating purposes was made about 1836, but it was long before it came into general use. The invention of the bell and cone charging apparatus by Parry, in 1850, by overcoming the difficulties of charging, gave it a great impetus.

In 1880 Messrs. Baird, of Gartsherrie, erected the first plant for the recovery of tar and ammonia from blast furnace gases.

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* Journal of the Institute of Mechanical Engineers, 1860.

†Gases used for heating the blast.

CHAPTER XV.

THE FOUNDRY.

The only use made of pig iron, except where it is the raw material for the preparation of wrought iron and steel, is casting in the foundry. The work of the foundry belongs rather to the engineer than to the metallurgist, and, therefore, it will only be necessary to call attention to a few prominent points, leaving the reader to refer to works on the subject for further information.

Pig Iron for Foundry Use.—Pig iron suitable for use in the foundry is called "foundry pig," and each make is known by some special mark or brand indicating the works at which it was made, and, therefore, by inference, the quality. Each founder has his favourite brand or mixture of brands which he considers to be best suited for his work.

The grades of iron used are Nos. 1, 2, and 3, or mixtures of these. No. 1 for very light ornamental castings, No. 2 usually with the addition of some No. 1 or No. 3 for ordinary work, and No. 3 for heavy castings.

Scotch foundry pig has a very high reputation, fetches a high price, and is very largely used all over the world. Staffordshire "all mine" is largely used for some purposes, but the commoner and cheaper Cleveland irons are now very generally used for ordinary work. Occasionally for special purposes cold blast iron is specified.

Good foundry iron usually contains 2 to 2·5 per cent of silicon, this ensuring that the bulk of the carbon will be in the graphitic condition, and phosphorus up to 1 per cent. The phosphorus imparts fluidity to the metal, but when present in large quantity tends to make it brittle. The amount of combined carbon will depend on the grade of the iron.

The use of mixtures in place of single brands is very general, and it has the advantage of, to some extent at least, compensating for accidental variations of composition, since it is not likely that all the irons used would vary in the same direction. At the same time it allows the founder to vary the iron to suit his needs and taste. It must be confessed, however, that, as a rule, founders make their mixtures with very little conception as to the real advantages and disadvantages of such procedure, and many seem to think that a mixture of brands is, under all circumstances, necessary, or at least advisable. This is by no means the case; the object of the mixture can only be to obtain an iron of uniform composition, and there is no reason why an iron of any required composition and properties should not be made direct, and unless the composition of the various irons used is accurately known it is obvious that the composition of the mixture must be uncertain, for nothing of certainty can be gained by mixing uncertain constituents. Mixing is usually based on the assumption that irons with the same brand have the same composition and qualities, but this is by no means always the case. If founders would specify exactly what properties they require, the smelter would probably have little difficulty in supplying a suitable pig.

Scrap cast iron or even scrap steel is very often added to the cupola charge.

Effect of Remelting.—It has been contended, and, indeed, is generally believed by founders, that remelting improves the quality of pig iron. This is, however, not by any means always the case. Sometimes the iron is greatly improved, at other times it may be seriously deteriorated. Experiments which have been made have given very discrepant results, varying with the nature of the iron, and the differences have largely been due to the idea that pig iron was a definite body, and, therefore, the composition of the samples with which the experiments were made was often not taken into account.

The atmosphere of the cupola is oxidising, the amount of carbon present being insufficient to ensure a powerfully-reducing atmosphere such as exists in the ordinary iron-smelting blast furnace. Oxidation, therefore, takes place, and the most oxidisable constituent is removed most readily. This is silicon, and, in remelting, silicon is almost always reduced. Whether the iron will be improved or not will, therefore, largely depend on whether or not it contains too large a percentage of silicon. Each time the iron is melted the amount of silicon is reduced, but there is little or no change in the amount of carbon; indeed, very frequently the percentage of carbon is increased by remelting. That this should be the case is easily understood when it is remembered that the iron, before, during, and after melting, is in contact with carbon, with which it can combine.

As already explained the first effect of the reduction of silicon is to throw the carbon from the graphitic to the combined condition, and thus lower the grade of the iron, ultimately making it white, and as the silicon is removed the metal can more readily take up sulphur from the fuel, this also tending to whiten it.

Turner gives a series of analyses of pig iron after repeated meltings* :—

Pig, before melting	Carbon 2·67	Silicon 4·22	Sulphur ·03
,, after 16th melting .	,, 2·88	,, 1·00	,, ·20

It is evident that whether remelting will improve or deteriorate an iron will depend entirely on the amount of silicon it contains. In the case given by Turner, the iron was improved up to about

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* Iron.

the eighth melting, after which it began to deteriorate with each additional melting till by the sixteenth it had become white.

If the iron be too high in silicon it will be improved by remelting; but for the removal of silicon melting in the cupola is expensive and uncertain. A much better method is to melt the metal in a reverberatory furnace, and keep it molten and exposed to the air till sufficient silicon is oxidised out, or to add mild steel or white scrap, low in silicon, till the silicon is diluted to the required amount. The addition of low carbon scrap will, of course, reduce the percentage of carbon, as well as that of silicon, and white scrap may introduce sulphur.

If a metal has gone "white" by remelting, this will always be due to the removal of the silicon. The metal can be brought back by the addition of the necessary amount of silicon in the form of silicon-iron, and this is often necessary where considerable quantities of white or rusty scrap have been used. The mere addition of silicon-iron to the cupola charge is usually insufficient, as it is impossible to ensure perfect mixture unless the whole charge is tapped into a receiver. Sulphur is removed, or rather, perhaps, its absorption prevented by the addition of silicon, so as to keep the iron grey. For the removal of sulphur, ferro-manganese is frequently added to the cupola charge, the manganese combining with the sulphur, and forming manganese sulphide, which passes into the slag, and ferro-sodium, an alloy of iron and sodium, has been used for the same purpose.

The Cupola.—The furnace used for melting iron for foundry purposes is a small blast furnace which is called a cupola. It is usually cylindrical externally, cased with iron plates. The interior may be cylindrical, or it may be narrowed to form a hearth, as in the iron-smelting blast furnace. It is charged through an opening in one side near the top, and above this is a chimney or "tunnel-head" to carry away the flame and products of combustion clear of the workmen. Near the bottom of the cupola are the tuyeres for the admission of air. The bottom is nearly flat, and at one side is an arched opening which, when the cupola is at work, is closed with brickwork or with a clay slab which is well luted, and through which a hole is left for tapping off the metal, this being closed with clay when it is not required. The temperature of the cupola is not high enough to ensure complete fusion of the slag formed, and the arched opening above mentioned is left so that the solid matter left may be raked out through it at the end of the "run."

Working the Cupola.—As a rule cupolas are not worked continuously, but are run for a few hours or a day as may be required. When a cupola is to be started a wood fire is lighted at the bottom, and on this is put a bed of coke. When the coke has burnt up charging is commenced by adding alternate layers of coke and pig iron—the pigs being broken into pieces 12 in. to 15 in. long—together with a little limestone.

All the openings of the cupola are left open at first, but after two or three hours, when the charge has burnt up the breastplate is wedged into position and luted, and a feeble blast given. After a little time the taphole is closed and the full blast put on. The metal soon begins to run down, and when enough has accumulated it is tapped out into a ladle or directly to the moulds, as may be required. When sufficient iron has been melted, the blast is turned off, the breastplate is taken down, and the solid residue on the hearth is raked out with iron rakes. When more iron is required than the hearth will hold, the charge is tapped into a large ladle and covered with ashes, so as to retain its heat till more is melted.

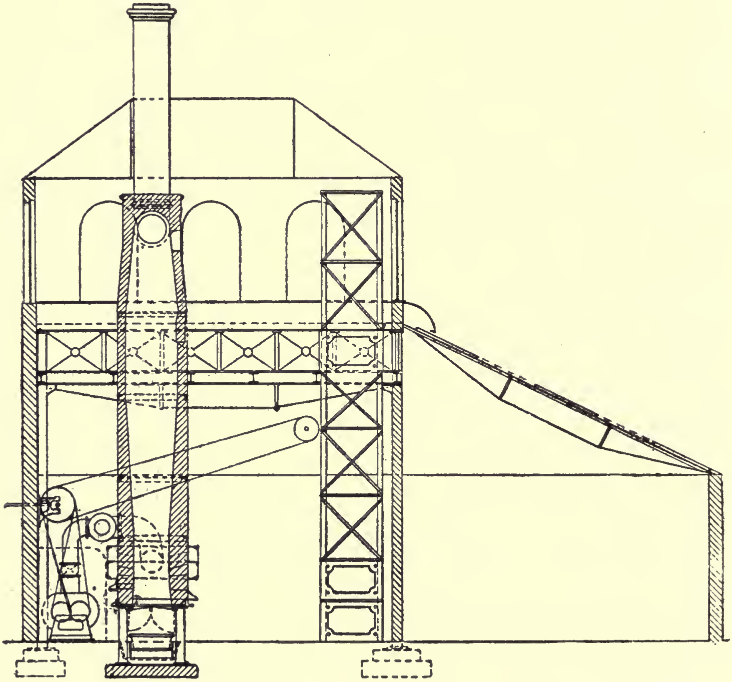

Fig. 78.—A Modern Foundry Cupola.

Size, &c., of Cupola.—The size of the cupola varies very much, according to the nature of the work which it has to perform. The diameter varies from 36 in. up to 84 in., or even more, and the height from bottom to the charging opening is four or five times the diameter; when the diameter is greater than 48 in., the cupola should be narrowed at the tuyeres, or the blast may be unable to penetrate to the centre of the charge, but the hearth may be widened below to the full diameter, so as to give it a large capacity.

A cupola 3 ft. in diameter and 12 ft. high will melt two tons of iron per hour, one 5 ft. in diameter and 15 ft. high will melt about 16 tons per hour.

Fuel Consumption.—As the iron has only to be melted in the cupola, and no important chemical changes are to be produced, the amount of fuel required is small, varying from 1 cwt. to 2½ cwt. of coke per ton of iron melted. The larger cupolas, which run for a considerable time, are naturally more economical than the smaller ones, which work only for short spells ; because, in the latter case, a much larger proportion of the coke is used for heating up.

Air Supply.—The amount of air required to consume 1 cwt. of coke, assuming all the carbon to be burnt to carbon dioxide, is about 15,000 cubic feet, and the amount for each ton of iron melted will vary with the amount of fuel consumed. The air is supplied at a low pressure, usually only 2 in. or 3 in. of mercury (1 to 1½ lbs. per square inch). If the blast pressure be too great, the blast is said to be "cutting." The rapid rush of gas may cause the ejection of solid material from the top of the furnace. At the same time the amount of air may be so large, and so rapidly delivered, that the atmosphere becomes too strongly oxidising, and iron may oxidise and pass into the slag. On the other hand, if the pressure be feeble the blast is said to be "soft," combustion is too slow, and the working is wasteful.

The amount of limestone required is about 7 lbs. to 10 lbs. for each ton of iron melted. It is required to combine, with the sand always adherent to pigs cast in the ordinary way, the silicon oxidised from the iron and the ash of the coke, so as to form a fusible slag. If the pigs are free from sand, as those cast over a casting machine, much less limestone will be required.

Various Forms of Cupola.—Very many modifications of the ordinary form of cupola have been suggested, with a view of increasing the output or improving the working.

Very frequently the cupola, instead of being provided with the breast-opening for the removal of unfused material, is carried on short iron columns, and the bottom is made to open downwards like a trapdoor. These "drop-bottom" cupolas have now become common. Before starting the bottom is made tight with a layer of sand.

Sometimes the cupolas are provided with more than one row of tuyeres, one above the other, the tuyeres being usually supplied by air from the same air belt.

The object of the second or upper set of tuyeres is to complete the combustion of the carbon-monoxide to carbon-dioxide. How far it effects this, or whether it simply makes the furnace work faster by giving a second zone of combustion, it is not easy to say ; but probably very much will depend upon the arrangement of the tuyeres and the force of blast given.

In the Greiner and Erp Cupola the tuyeres are arranged in a spiral round the body of the cupola, and in the Stewart Rapid Cupola there are two rows of tuyeres, the lower one being near the bottom, fed from the same air belt. This cupola is also provided with a receiver, communicating with the body of the furnace by

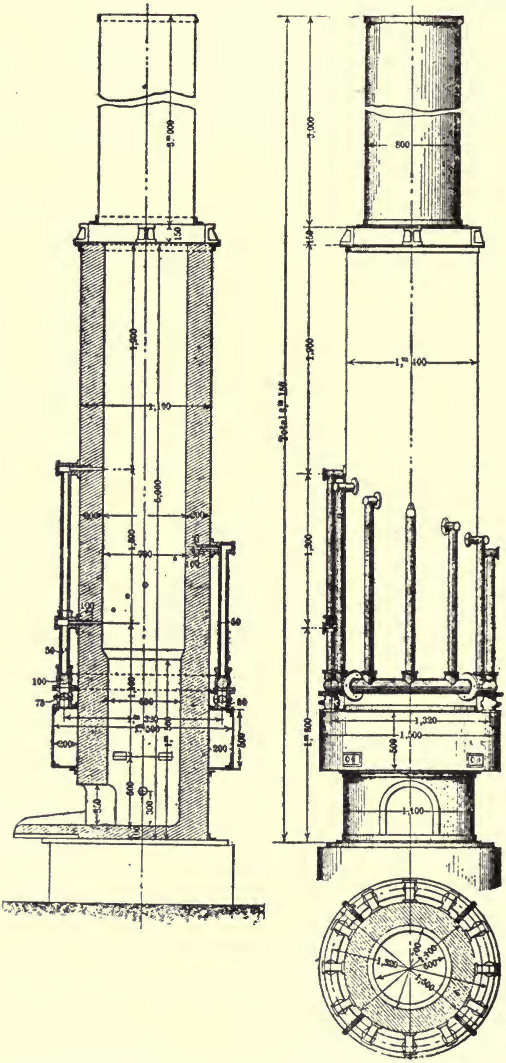

FIG. 79.—Griener & Erps' Cupola.
(The tuyeres are arranged in a spiral round the body of the Cupola.)

means of a pipe lined with ganister. The metal is allowed to run into this receiver, and when enough has accumulated it is distributed to the moulds as usual. This cupola is very economical in fuel.

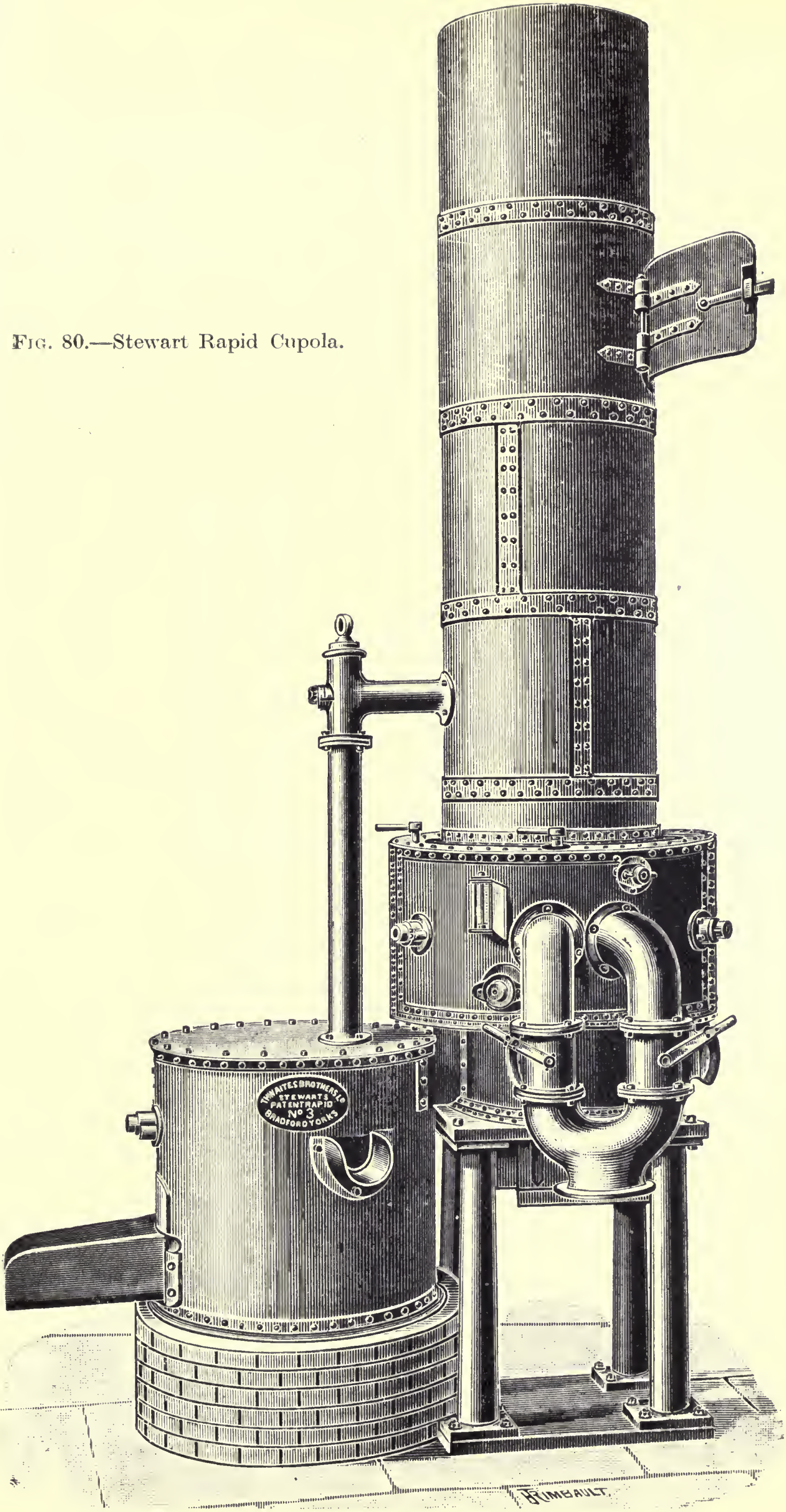

FIG. 80.—Stewart Rapid Cupola.

Centre-blast Cupolas.—In ordinary cupolas the air is supplied by tuyeres arranged around the body, but many founders consider that it would be much better if the air were supplied to the centre of the charge. This is done by cupolas, in which an airpipe passes up through the bottom to convey the air. The principal difficulties in the construction of such cupolas are to make the airpipe sufficiently durable to withstand the high temperature and the action of the molten iron or slags, and to fit it to the "drop-bottom." In large cupolas (over 50 in.) the centre pipe can be left a fixture, and the bottom can be made to drop independently of it. Fig. 81 shows West's Centre-blast Cupola, which may be taken as an example.

Attempts have been made to use the hot blast for foundry purposes, but without any great success.

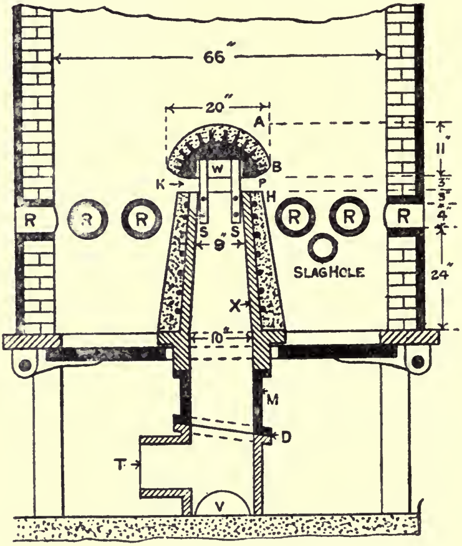

FIG. 81.—West's Centre-Blast Cupola.

A—Fireclay casing to protect blast pipe. It is fixed on an iron headpiece B; R—Openings for admission of air; T—Air main; M—Tube connecting air main with cupola.

Air Supply.—The air for the cupola is usually supplied under small pressure from either a fan or blower, these being better, for a continuous air supply at low pressure, than blowing engines.

Several cupolas have been designed, in which an induced draught is used instead of a forced draught. Chimney draught has frequently been tried, but the melting power of such cupolas has been found to be too small to make them successful.

In the Woodward and Herbertz cupolas the draught is produced by a steam jet blown into the pipe which carries away the product of combustion, the top of the cupola being closed. Cupolas of this type are very little used.

Many cupolas have been designed to be fed with gas or oil, but they have never come into use.

Patterns.—Before a casting can be made by the ordinary method of sand moulding a pattern—usually of wood—must be made of the form and size of the required article, with due allowance for the shrinkage of the metal on cooling.

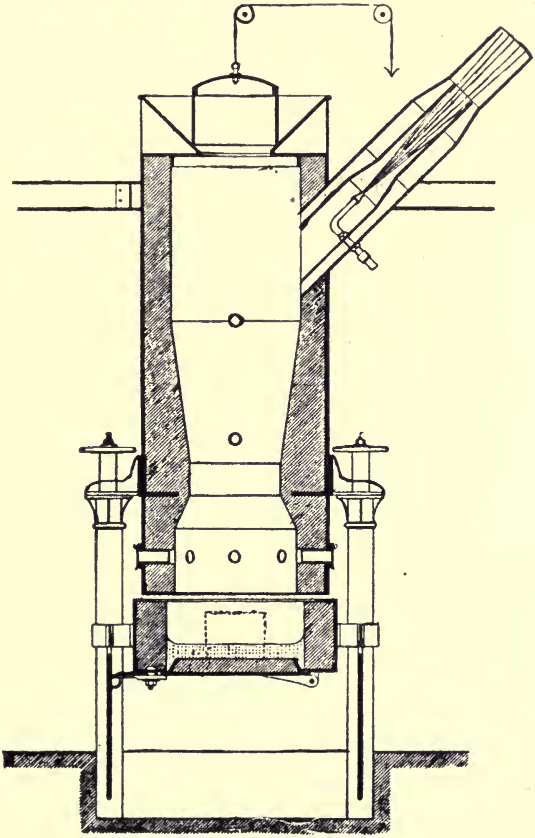

FIG. 82.—Herbertz Cupola.

(The bottom is separated slightly from the body, so as to leave an opening all round the body by which air can enter.)

Pine wood is usually used for making the pattern, but spruce, beech, cherry, mahogany, and other woods are sometimes preferred. When the pattern is to be used many times it is painted, smoothed, and varnished. The allowance for shrinkage is about $\frac{1}{8}$ in. for each foot length.

The weight of the casting can be calculated from that of the pattern. If the pattern is of white pine weighing 1 lb. the casting will weigh 14 lbs., whilst if the pattern be of mahogany and have the same weight the casting will weigh 8 lbs. When a large number of castings are required, and generally for light work, a casting is made, and this is filed up and used as a pattern for subsequent castings.

Moulding Sand.—The mould in which the metal is to be cast is made by embedding the pattern in "moulding sand." The sand must be very refractory, just sufficiently plastic or binding to hold together and retain the form of the impression when the pattern is removed. It must not sinter or burn by the heat of the molten metal and must be sufficiently porous to allow the escape of steam and gases given off in the mould. A good sand consists mainly of silica with only enough alumina to cause it to bind, and for use it is mixed with from 7 to 10 per cent charcoal or coal dust, so as to make it porous. This is more or less burned out as the sand is used, and so must be replaced from time to time.

Moulding.—When the metal is to be cast into the sand mould as this is made, it is called "green-sand" moulding, whilst when the sand mould is dried before use, it is called "dry-sand" moulding.

Large moulds are made in sand on the foundry floor; smaller ones in iron frames, "boxes or flasks," which can be more readily moved. The boxes may be made in two or three parts, as may be most convenient for the article being cast. When two portions of a sand mould come together, and will have to be separated again, the surfaces of contact are covered with a thin layer of dry siliceous sand—"parting sand"—which prevents adhesion.

Green-sand Moulding.—The pattern is embedded in the sand, and is then removed, leaving a cavity of exactly its own form and size. If any portion breaks away in the removal of the pattern, it is carefully mended. Passages or gates are made for the pouring in of the metal, and vent holes for the escape of the gases and the air displaced. The surface of the mould is sprinkled with a layer of "blacking," the mould is closed up, and is ready to receive the metal.

For further particulars the student must refer to one of the many works on the foundry.

Dry-sand Moulding.—The sand used is not mixed with charcoal or coal dust, and the mould is dried for some hours in a stove and coated with blacklead before it is used. Dry-sand moulds are much more porous than those of green sand, and usually give sounder and smoother castings.

Loam Moulding.—This method of moulding is used chiefly for large articles, such as large iron pots, steam cylinders, &c., of which a large number are not required. No pattern is used. The moulding material is "loam," a mixture of clay and sand. The mould is built up with bricks or other suitable material, and is faced with loam, which is carefully worked to the required form and dried before use. When an inner and an outer surface are required, the mould for the latter is built up on an iron ring, so that it can be lifted bodily into place. The details vary very much with the form of the article to be cast: each has its own difficulties, and how these will be met depends on the ingenuity and skill of the moulder.

Chill Casting.—When it is required to make one surface of a casting very hard, the mould at the place where hardness is required is made of iron or steel. The molten metal coming in contact with this, is suddenly cooled or chilled, the separation of the carbon as graphite is therefore prevented, and the metal is hardened.

The principal classes of articles for which chilling is used are those subject to friction, such as wheels, rolls, &c. In the case of wheels or rolls the chill is the outer surface of the mould, which is an iron or steel ring.

The iron to be used for chilling should be a good grey iron (No. 3 preferably), fairly close grain, not too high in silicon, and containing but little phosphorus. Silicon tends to throw the carbon into the graphitic condition, and, therefore, to prevent chilling; and phosphorus, by increasing the fluidity of the metal, facilitates the separation of the graphite. The iron used should, therefore, be hæmatite pig. The mould is warmed to above 100 deg. Cen. before the molten metal is run in, so as to prevent condensation of moisture on the surface of the chill.

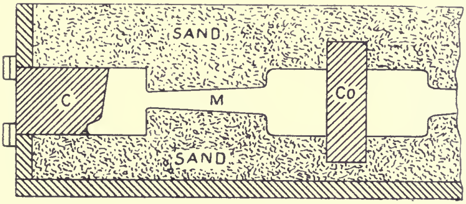

Fig. 83.—Mould for Chill Casting.

C—Chill. Co.—Core. M—Mould space.

The depth of the chill obtained depends on the quality of the iron used, and the size of the chill, since the greater the weight of metal in this, the more rapidly will the heat be carried away.

Malleable Cast Iron.—When a suitable casting is heated in oxide of iron, or other oxidising material, the carbon is burnt out and carbon-free or malleable iron is left. Castings to be made malleable must be made of suitable iron. It must be close-grained, containing but little graphite. The silicon, therefore, must be low—not more than 1 per cent—less, if possible. Phosphorus must not be present except in small quantity, or the casting will be brittle, but the iron should contain manganese. In a very thin casting the carbon may be reduced to about ·15 per cent, but it is very difficult to effect anything like complete removal from thicker masses. Large articles usually consist only of a skin of carbonless iron, with a core of cast iron, in which the carbon has been liberated in the form of small grains, so that the metal consists of a ground mass of iron in which the carbon grains are scattered. It is much stronger than cast iron, and less brittle, but is lacking in the toughness and strength which is characteristic of that o wrought iron, as these properties are largely due to the work which is put upon it. Malleable castings are always uncertain, and should never be used in positions where they will be subject to great stress.

Forms of Casting.—The strength of a casting is very much influenced by its shape, as this determines the rate of cooling, and, therfore, the arrangement of the crystals. If the casting be of large size, so that solidification takes place more rapidly at one part than at another, stresses may be set up which may be sources of weakness, or which may cause distortion in the finished articles. It sometimes happens that this distortion is unavoidable, and allowance must be made for it in making the mould. The design of castings therefore requires very great care.

PART III.

CHAPTER XVI.

PROPERTIES OF MALLEABLE IRON.

Malleable or wrought iron may be defined as iron, containing only very small quantities of impurities, which does not harden when it is heated to redness and quenched in water, and which has not been fused but has been aggregated into a mass by the welding together of smaller pasty masses, or, in place of the last clause, which contains intermixed slag and oxide.

Malleable iron was undoubtedly the first form of iron with which man was acquainted, and for many ages was the only form known and as all articles were made from it by hammering the smith was the most important artificer of his age.

Malleable iron is infusible at temperatures attainable in ordinary furnaces fed with solid fuel, but it can be melted readily enough in gas-fired regenerative furnaces. When it is strongly heated it becomes plastic, and so can be hammered or rolled into any required form, and separate portions can be united by welding. Chemically it is nearly pure iron, often containing as much as 99·9 per cent of the metal; but even the small quantities of impurities present may very much modify its qualities. Though it does not harden like steel when quenched in water, sudden cooling alters the structure and the properties of the metal.

Foreign Constituents in Malleable Iron.—Carbon.—Carbon is always present, the usual amount being from ·1 to ·25 per cent. The carbon is all present in the combined form, and as the action of carbon is to harden the metal, the lower the percentage, the softer will the iron be. When the carbon rises to about ·25 per cent the metal begins to be hard and steely, has a higher tensile strength and less ductility, and may show signs of hardening when it is heated to redness and quenched in water.

Silicon.—Silicon is always present in small quantities. It hardens the metal, but to a less extent than does carbon; about ·1 per cent seems to have no injurious effect, but when it rises to ·25 it apparently begins to be harmful. There is, however, great difference of opinion as to the maximum amount of silicon allowable, and the hardening is not proportional to the amount of silicon found by analysis. This arises, no doubt, from the fact that the iron contains intermixed slag, composed partly of a basic silicate of iron, which is, at any rate, partially, decomposed, the silicon in the silica from it being calculated as silicon in the iron. Whilst a small quantity of silicon in the iron may be injurious, a much larger quantity of intermixed silica will have little if any effect; and therefore, though little information is given by an ordinary determination of silicon, an iron which contains a considerable amount will always be viewed with suspicion.

Phosphorus.—This element is always present, and is undoubtedly very injurious, as it makes the metal hard and brittle. There is, however, no agreement among observers as to the amount which need be present before an injurious effect is noticed. Eggertz states that ·25 per cent will make the metal cold, short; but Karsten gives ·5 as being the lowest quantity which will produce this effect, and other observers have given both higher and lower figures. It is probable, if not certain, that phosphorus can exist in malleable iron in two forms, viz., as phosphorus in combination with the iron, and as intermixed globules of phosphides of iron or manganese (Fe_3 P, Mn_3 P_2) which were not eliminated during the shingling. In the latter form it is likely to have little injurious effect, as the actual percentage of phosphide is always small. Baron von Juptner* finds that when malleable iron is dissolved in acid, part of the phosphorus is evolved as hydrogen phosphide (H_3P) and part remains in the insoluble residue; its behaviour, therefore, being strikingly similar to that of combined and graphitic carbon in pig iron. The phosphorus which is evolved as hydrogen phosphide is that which is present in combination with the whole of the iron, and this, he suggests, should be called "hardening" or "dangerous" phosphorus, whilst that which remains in the insoluble residue, being in the form of phosphide, should be called phosphide phosphorus.

In one case he found that of two samples of iron, A and B, which gave an analysis respectively ·4423 and ·4557 per cent of phosphorus, whilst both were bad, A was decidedly the worst. On further examination he found that of the phosphorus in A 80·33 per cent was evolved on treatment with acids, whilst only 63·35 per cent of that in B was so evolved. From this it can be calculated that the amount of dangerous phosphorus in A was ·3552 per cent and in B ·2886 per cent, and this would account for the difference in quality.

Sudden cooling tends to throw the phosphorus into the "hardening" condition, so that an iron containing phosphorus may be hardened by sudden cooling, even though the carbon be too low to produce any hardening effect. The more carbon there is in the iron the less tendency there seems to be for the phosphorus to pass into the hardening condition; so that the less carbon is present, *i.e.*, the softer the iron, the greater is likely to be the injurious effect of phosphorus, and, therefore, the smaller the quantity that will be allowable.

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*Journal Iron and Steel Institute, 1897, vol. I., p. 22.

Phosphorus may also be present in the intermixed slag as phosphate.

Sulphur.—Sulphur is rarely present, except in very minute quantity, and it is always injurious, tending to make the metal brittle at a red heat, and thus difficult to work. About ·05 per cent of sulphur is sufficient to have a deleterious effect on the metal.

Copper.—This element is rarely present in malleable iron, and little is known of its action ; this is, however, said to resemble that of sulphur.

Manganese.—Manganese is never present, except in very small quantity, as it is eliminated during the process of manufacture. The quantities that can be present have no influence on the quality of the metal.

Intermixed Impurities.—Malleable iron always contains intermixed impurities, mainly fragments of slag and oxide of iron, and, perhaps, phosphide of iron. The amount may vary from about ·5 to 2·5 per cent, with an average of about 1 per cent. They may be in comparatively large portions, irregularly scattered as in puddled bar, or in much smaller particles more evenly distributed, as in good bar iron. They have an important influence on the quality of the iron.

Structure of Malleable Iron.—When a bar of malleable iron is nicked and then broken it should show a decidedly fibrous fracture, the fibre depending on the quality of the iron, and on the amount of work which has been put upon it. As the bloom comes from the hammer it consists of malleable iron, with intermixed oxide of iron and slag, which have not been squeezed out during shingling. During subsequent operations the slag is to a small extent, perhaps, eliminated ; but the principal effect of the work is to break up the masses into much smaller portions, and to distribute them more evenly through the iron. As the metal is rolled these fragments become extended into long filaments in the direction of the rolling. It is to the presence of these elongated filaments of slag and oxide, preventing the perfect welding of the iron into one mass, that the fibre of malleable iron is due. At the temperature at which the rolling takes place the iron molecules are sufficiently mobile to rearrange themselves in positions of least stress, so that they do not become elongated. The "fibre," therefore, is due to the presence of fibres of a weak body intermixed through the strong iron, and is not a source of strength but of weakness, and malleable iron is weaker than mild steel of similar composition in which there is no fibre. At the same time a fibrous malleable iron is better than an iron in which there is no fibre, because the presence of fibre shows that the iron has been sufficiently worked to distribute the impurities evenly through it.

Physical Properties of Malleable Iron.—Malleable iron should be malleable both at ordinary temperatures and at a red heat. When it shows cracks when rolled cold it is said to be "cold short," and when it cracks when worked at a red heat it is said to be "red short." These defects may exist separately or together. A cold short iron may be none the worse for forging purposes, though quite useless for cold work ; but a red short iron, though it may work well enough cold, should always be rejected for important work, because its red-shortness may have given rise to flaws and cracks which may be a source of weakness.

Good malleable iron should have a tensile strength of 22 to 26 tons per square inch, with an extension of about 20 to 30 per cent on an eight-inch test piece. Contraction of area before fracture is often specified ; but this is almost useless, as it is impossible to measure it with any degree of accuracy. Across the fibre the tensile strength will be less, about 18 to 20 tons, and the elongation say 6 to 8 per cent. These figures are for bars or plates less than $\frac{3}{4}$ in. thick. For thicker plates and for angles, tees, &c., the strength may be considerably less. Wrought iron can be made of very much higher strength by addition of carbon, but this is at the cost of ductility, so that high tensile strength, unless accompanied by great ductility and low carbon, is not an advantage. The characteristics for which malleable iron is most valued—its softness, &c.—are incompatible with very high tensile strength ; so that the best quality irons, such as best Yorkshire, are not characterised by excessive tensile strength.

A bar, not too thick, should be capable of being bent back on itself cold without fracture, and thicker bars must stand bending to an angle depending on their thickness without showing any signs of cracking. The metal is usually also subjected to various hot tests, it being punched, forged, and bent over in various ways to prove the absence of red-shortness. The amount of punching, bending, &c., which any sample will stand will depend very much on the quality of the metal and the form into which it has been rolled.

The tensile strength and ductility are very much increased by work, so that the thinner the metal the stronger it should be. Cold working increases the strength very considerably, but at the same time renders the metal harder, and to remedy this it is usually annealed after working.

Varieties of Malleable Iron.—The grades of malleable iron are extremely uncertain, for though in general the same names are used by various makers there is no standard to which all are expected to conform, and no guarantee is attached to the use of any name.

The commonest grade of iron is often sent out without any mark or maker's name ; this is bought entirely at buyer's risk, and no responsibility as to quality is taken by the maker. It is made to compete with cheap foreign bars, and is used for railway spikes and other purposes where no fibre is required. The lowest recognised grade is usually marked with a crown—whence it is called "crown" quality, or ordinary merchant bar—and the maker's name. The "crown" grade is usually considered as the lowest made by the maker whose name it bears and the mark carries no guarantee of quality or tensile strength, but the metal must be good and suitable for bolts and general purposes. As the makers in each district are more or less associated and sell at the same price, the iron of the various firms must be similar in quality. The other grades are :—

Crown Best.
„ Best Best.
„ Treble Best.

As remarked above, the names have very little real meaning, but they are supposed to mark advances in the quality of the iron, each indicating that the metal has been subjected to an additional piling and rolling. There is, however, no relationship between the iron of different makers, one maker's "crown" being sometimes as good as another maker's "best best." Where iron of definite quality is required it should always be specified to pass suitable tests according to the quality of iron required.

Various other marks are used by makers, such as "Charcoal" (used only for sheets), "Refined," &c., which may mean anything or nothing, and usually only indicate a quality of iron made by that particular maker. Foreign merchants often try persistently to get makers to mark unbranded bars as refined and best refined. The Scotch makers only mark the best quality as best refined.

Horseshoe iron is a specially soft quality of iron made by many makers for the use of country smiths, who require iron of a very uniform and easily-worked quality. It is now being largely replaced by mild steel.

At one time malleable irons were largely classified according to the districts where they were made, and as Staffordshire early became a famous iron-producing county, Staffordshire iron soon became well known, and was very frequently specified. The name has now almost lost its meaning, since exactly similar irons are made in almost all districts. Probably Staffordshire iron, as the terms is at present used, would include iron made in any of the Midland counties. As, however, there is no means of determining whether a given sample of iron is "Staffordshire" or not, the term should be abandoned in specifications.

Best Yorkshire Iron.—This is the only geographical brand that has retained its meaning. It indicates a special class of iron made at one of several Yorkshire works, of which the most important are Low Moor, Farnley, and Monkbridge. The iron is made from cold-blast pig iron, and the greatest care is taken at every stage to ensure uniformity, the processes which are used having undergone no change since the manufacture commenced. The iron, therefore, is of unvarying quality, is thoroughly reliable, and necessarily expensive.

Forms of Malleable Iron.—Malleable iron comes into the market in various forms, so as to be suitable for all classes of work. In some cases the iron is the raw material for the production of various articles, as in that supplied to the smith, or it may be itself a finished article. The usual form in which malleable iron is sent out when it is to be worked up into other forms is that of bars.

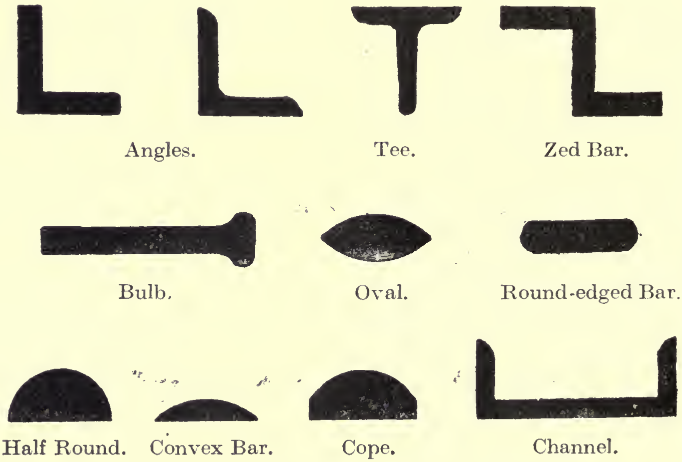
Bars.—These may be flats, squares, or rounds. Flats are usually from 1 in. to 6 in. wide and from $\frac{1}{2}$ in. to $1\frac{1}{4}$ in. thick, squares from $\frac{1}{2}$ in. to 3 in. side, and rounds from $\frac{1}{2}$ in. to 3 in. in diameter—all being made in lengths of from 12 ft. to 20 ft. Of course, larger and smaller sizes can always be made when required.

Angles.—These have an L section, and are made in various forms and sizes.

Tees have a T section, the arms having various proportions.

Many other forms are also rolled, such as channels, zeds or Z bars, girder or H bars, firebars, rails, ovals, bulbs, half-rounds, convex bars, copes, &c., &c.

As for many purposes mild steel has replaced malleable iron, some sections, as for example rails, are now rarely rolled in iron.



Angles. Tee. Zed Bar.

Bulb. Oval. Round-edged Bar.

Half Round. Convex Bar. Cope. Channel.

FIG. 84.—Sections of Rolled Iron.

Sheets and Plates are rolled of various sizes, those under $\frac{3}{16}$ in. thick being called sheets, and the thicker ones plates. The thicker the metal the broader the sheet can be rolled, up to the limits of the capacity of the mill. The largest plates that can be rolled in ordinary mills are about 30 ft. long and 6 ft. 6 in. broad. The thicker sheets are usually sent out " hard " as they come from the rolls ; the thinner ones are more generally annealed, unless ordered hard.

The following classification of sheet iron is given by Skelton* :—

(1) Common quality, suitable for Indian markets.

(2) Export quality, suitable for the Australasian and similar Colonial markets.

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*" Economics of Iron and Steel," p. 107.

(3) Ordinary good qualities, suitable for home markets.

(4) Keg quality, suitable for keg making or kindred iron platework.

(5) Best close annealed quality, suitable for working up into buckets, trunks, &c.

(6) Best best annealed
(7) Treble best annealed } Special working up qualities to answer particular requirements.

As the forms of malleable iron required vary so much and each requires special rolls, most makers send out sheets or books containing details, usually with illustrations of the forms and sizes they are able to supply without delay, and the cost of turning new rolls for the purpose.

Malleable iron may be prepared either (1) directly from the ore, or (2) from pig iron. The first method is that by which it was first prepared, and for many centuries was the only one known ; but the second, though introduced very much later, has now become practically universal, as being much less costly and at the same time yielding a more uniform product.

Two methods have been used for the preparations of malleable iron from pig iron : (1) The process in open fires ; (2) the method in a reverberatory furnace, which was invented by Henry Cort in 1784, amd which soon replaced the older process almost everywhere.

A comparison between the chemical composition of pig iron and that of malleable iron shows that the difference lies in the amount of foreign constituents present in the pig which are absent in the malleable iron. The most important are carbon and silicon, and as these are easily oxidisable, they can be oxidised out, more or less readily, and all processes for the preparation of malleable iron from pig iron depend on the action of oxidising agents at a temperature above the melting point of pig iron, but below that of malleable iron, so that the latter may separate in a pasty mass, and the various processes differ in the way in which the oxidation is brought about.

The following figures will show the difference between pig iron and malleable iron :—

	Pig.	Bar.
Iron	92·5	99·6
Carbon	3·5	·1
Silicon	2·0	·1
Sulphur	Trace	Trace
Phosphorus	1·0	·2
Manganese	1·0	None

CHAPTER XVII.

PUDDLING.

Puddling.—The puddling process as at present carried out differs in some respects from that invented by Cort. In Cort's process white pig iron was used, which never became thoroughly liquid, the process being therefore called dry puddling, whilst in the modern process grey pig is used, which becomes quite liquid, and the process is called wet puddling or pig boiling.

The Furnace.—The furnace used for puddling is a small reverberatory furnace, having a low roof, a comparatively large fireplace, and a tall chimney, provided with a damper, to produce a good draught. See Figs. 85 and 86.

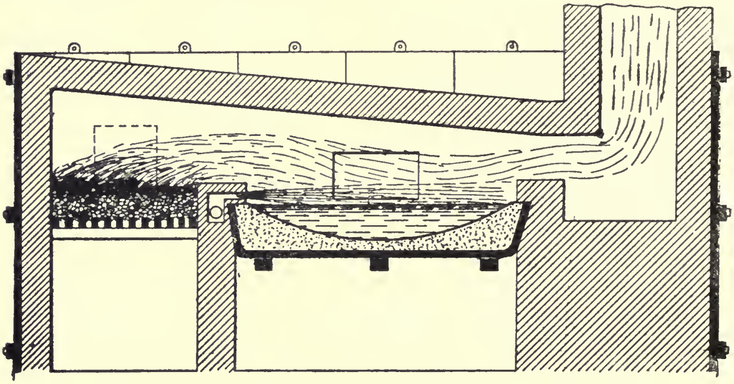

FIG. 85.—Section of Puddling Furnace.

The fireplace is of about eight square feet in area, though it may be larger, being usually somewhat less than half the area of the hearth. The larger the fireplace the more fuel will be consumed, and, therefore, the higher will be the temperature that can be attained ; but at the same time the more difficult it is to maintain a layer of fuel of even thickness on the bars, which is essential to good firing. The fireplace must not be so wide that the coal cannot be evenly distributed from the door. It is provided with a charging opening furnished with an iron frame, the lower portion of which is extended into a flat ledge. In most cases this has no door, but when necessary is closed by heaping coal slack on the ledge till the opening is covered. The ashpit is usually open.

The hearth is about 6 ft. long, 3 ft. 9 in. wide at the fire bridge, and somewhat less at the flue bridge. It has one working opening on the front or working side of the furnace, this having an iron frame, in the bottom of which is a groove, "the cinder notch," by which slag can flow out of the furnace. The hearth bottom is a cast-iron plate or tray so supported as to allow free access of air beneath to keep it cool, and on this is laid the working bottom. The edges of the brickwork project a little over the edges of the tray so that the fettling may be brought up close to the masonry, and the hearth is made to slope in all directions towards a taphole placed beneath the working door. As the furnace is subject to considerable changes of temperature it is well stayed with vertical buckstays and cross ties, and is usually cased with cast-iron plates.

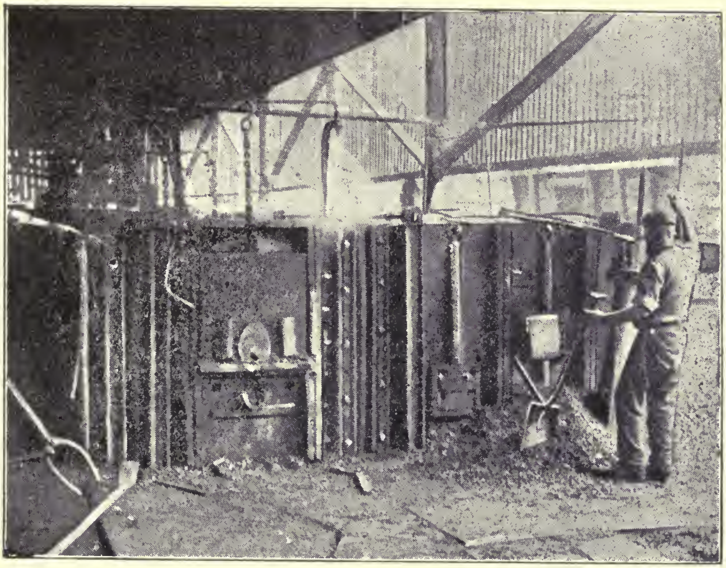

Fig. 86.—Puddling Furnace (Lanarkshire)

Making the Bottom.—The iron bottom is covered with a layer of some refractory material rich in oxide of iron, such as hæmatite, purple ore (which is nearly pure ferric-oxide obtained as the residue after the extraction of copper from burnt pyrites by the wet process), calcined black band ore (pottery mine), bulldog made by roasting tap cinder (which is essentially a mixture of ferric-oxide and silica), hammer scale or other similar material. In Scotland hæmatite and purple ore or tap from scrap furnaces are almost exclusively used. The fettling is spread over the plate to a depth of two or three inches, a mixture of lumps and fines being used, and a fire is put on hot enough to just soften the material. A quantity of clean scrap is then introduced, heated to welding temperature, made into a ball, and well worked over the bottom. By this means the bottom is compacted and the interspaces filled up with liquid magnetic oxide. The ball of iron is then removed, and the sides of the hearth are made up to the required form with the same fettling.

Working a Charge.—When a new furnace is being started some tap cinder is put in, but when a charge has been worked, enough slag is left in the hearth to provide the necessary bath for the metal.

The furnace being hot from the previous charge, the workman carefully examines the bottom and fills up with fettling any holes that may have formed. The charge is then introduced, the pigs being for convenience broken into two or three pieces. The firehole is stopped with slack, and the working door is closed.

(1) The metal soon begins to soften and then melts; as melting proceeds the puddler draws any unmelted fragments towards the centre of the furnace. When the charge is completely melted it is briskly stirred, and the damper is lowered, so as to reduce the temperature somewhat.

(2) The melted metal is completely covered with slag, and is in a state of tranquil fusion, and the slag is mixed in with the metal from time to time. Frequently at this stage hammer scale or other oxidised material is added so as to increase the oxidising power of the slag.

(3) The surface of the metal becomes disturbed from the evolution of carbon-monoxide—seeming to boil—whence the name pig boiling, so often given to this method of puddling.

The slag being pasty froths up, and, rising above the slag notch, flows out into a small iron truck put to receive it. During this stage the puddler keeps the slag well mixed in with the metal, and as the tools rapidly become hot and soft, they are cooled in a vessel of water (the water bosh). Several sets of tools are kept in use.

(4) As the ebullition diminishes the iron becomes stiffer and more difficult to work, and as a large quantity of slag has escaped and the remainder becomes tranquil, the mass of iron is seen in the form of a mass of bright granules. The temperature is urged to the highest possible point, and the stirring is constant, till at last the iron passes into the condition of a mass of granules of malleable iron, or "comes to nature."

(5) The mass of malleable iron consists of only slightly coherent granules, and therefore is comparatively easily broken up into balls each weighing 100 lbs. or 120 lbs. by means of iron tools. The balls are lifted from the furnace and carried to the hammer for shingling.

During the whole process constant attention is given to the fire, and the temperature is modified somewhat by the use of the damper.

The process may be divided into the five stages numbered above. These may be called :—

(1) Melting down, or the melt.
(2) Slag formation, or silicon oxidation.
(3) Boil, or carbon oxidation.
(4) Purificaton or final oxidation of impurities.
(5) Balling up.

The stages are somewhat differently given by Urbin* as follows :—

(1) Fusion of the pig iron.
(2) Purification of the pig iron.
(3) Refining for grain.
(4) Carburising the grain.
(5) Refining by flame.

These stages are not as convenient for descriptive purposes as those given above, for though they mark changes that may be seen by the puddler, they do not, in all cases, mark any important changes in the chemical action.

Products of the Process.—The products of the process are puddled bloom and slag or cinder.

The puddled bloom is essentially a mass of granules of malleable iron, containing in the interspaces much slag, which is, to a large extent, mechanically removed during subsequent operations.

The cinder.—This consists essentially of a silicate of iron and manganese. The composition varies at different stages of the process, that produced during the early stages being more silicious than that made later. In Scotland the whole of the slag is allowed to escape over the slag notch, except a small quantity which is left in the hearth ; but in some other districts some is tapped out, the slag being then classed into boilings, that which comes over the notch, and tappings, that which is tapped out.

The following analyses will give an idea of the nature of the cinder :—

ANALYSES OF TAP CINDER.

	1	2	3
Silica	7·71	11·76	29·60
Ferrous Oxide	66·32	58·67	48·43
Ferric Oxide	8·27	17·00	17·11
Manganous Oxide	1·29	·57	1·13
Alumina	1·63	2·86	1·28
Lime	3·91	2·88	·47
Magnesia	·34	·29	·35
Sulphide of Iron (FeS)	—	3·11	1·61
Sulphur	1·78	—	—
Phosphoric Acid	8·07	4·27	1·34
	99·32	101·39	101·32
Iron	57·37	—	44·22

(Percy, "Metallurgy of Iron," p. 668.)

Uses of Puddlers' Cinder.—Puddlers' cinder being rich in phosphorus is used in the manufacture of phosphoric pig iron for the basic steel processes. Roasted with free access of air, it is

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*"Practical Guide to Puddling."

converted into "bulldog," which is very refractory, since both silica and ferric oxide are difficultly fusible, and do not reunite to form a silicate—

$$2\,FeO\,Si\,O_2 + O = Fe_2O_3 + Si\,O_2$$

Chemistry of the Process.—The pig iron supplied to the furnace having been cast in sand moulds, always has a considerable quantity of sand adhering to it. As the iron melts the surface becomes oxidised, and the oxide combines with the silica, forming a ferrous silicate, the amount of silicate thus formed, together with the slag left in the hearth, being enough to completely cover the bath of molten iron. Considerably more oxide is formed than can combine with the silica, and this remains mixed with or dissolved in the slag, probably as magnetic oxide Fe_3O_4.

The subsequent oxidising action is largely due to this oxide acting as an oxygen carrier, since the iron itself is protected from the action of the air by the layer of slag. As the silicate itself is exposed to the air it may undergo further oxidation, a higher oxide of iron and a more acid silicate being formed, *e.g.*—

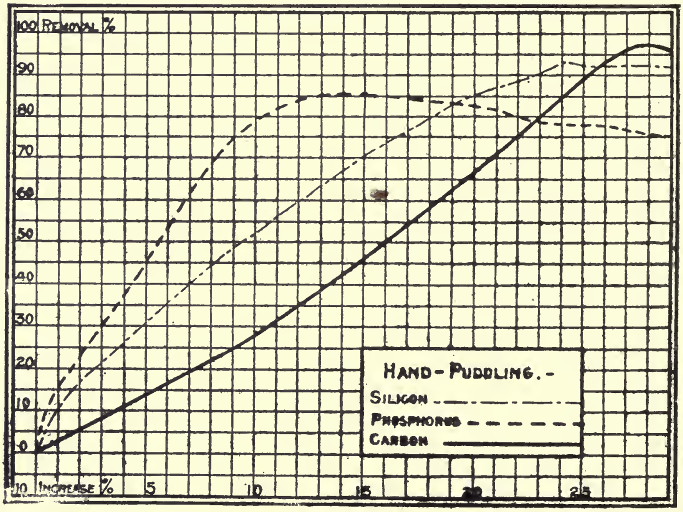

FIG. 87.—Sir Lowthian Bell's Removal, of Impurities, Curve.

$$4\,(2\,FeO,\,Si\,O_2) + O = Fe_3O_4 + 5\,FeO,\,4\,Si\,O_2$$

During the second stage the oxidation continues, the silicon being oxidised. Assuming the oxide present to be the magnetic oxide, which is probable, the reactions may be—

$$Fe_3O_4 + 2\,Si = 3\,Fe + 2\,Si\,O_2$$
$$Fe_3O_4 + Si = 2\,FeO,\,Si\,O_2 + Fe$$

or perhaps $2\ (2\,FeO,\,Si\,O_2) + Si = 2\,FeO,\,3\,Si\,O_2 + 2\,Fe$, the silicon being oxidised and passing into the slag as ferrous silicate.

If the metal contains a large quantity of manganese, this will oxidise early in the process, and will yield a slag containing a large quantity of manganese silicate which is not a good oxygen carrier, and therefore must be tapped off.

In the next stage the iron oxides act on the carbon—

$$Fe_3O_4 + 4\,C = 3\,Fe + 4\,C\,O, \text{ or perhaps}$$
$$2\,FeO, Si\,O_2 + C = FeO, Si\,O_2 + C\,O + Fe.$$

The oxidation of the silicon begins at the very commencement of the process, but is not completed till near the end. The following figures from a paper by Messrs. Crace, Calvert & Johnson, in the *Philosophical Magazine* for 1857, will illustrate the way in which the impurities are removed during puddling.

	Time.	C.	Si.	S.	P.
Cold Blast Staffordshire Pig .	o'clock.				
No. 3, charged	12	2·275	2·720	0·301	0·645
Sample No. 1	12·40	2·726	·915	..	..
,, No. 2	1	2·905	·197	..	..
,, No. 3	1·05	2·444	·194	..	..
,, No. 4	1·20	2·305	·182	..	..
,, No. 5	1·35	1·647	·183	..	..
,, No. 6	1·40	1·206	·163	..	..
,, No. 7	1·45	·963	·163	..	..
,, No. 8	1·50	·772	·168	..	..
Puddled Bar No. 9	..	·296	·120	0·134	0·139

The removal is well shown by the curve Fig. 87 by Sir Lowthian Bell. The vertical distances give the amount of the constituents removed in percentages of the amount originally present, and the horizontal distances the time since the commencement of the operation.

The oxidation of the carbon, it will be seen, begins at once, but it does not show itself by producing a boil till the silicon is considerably reduced. The carbon removal is slow at first, but becomes more rapid as the oxidation goes on. The removal is nearly complete, not more than ·1 per cent being left.

Silicon is removed rapidly at first, the rate of removal then falling. Not more than ·1 per cent of Si should be left in the finished metal.

The removal of phosphorus is somewhat peculiar. About 80 per cent of this element is removed, apparently only a portion passing into the slag, the rest remaining in solution as a phosphide which separates in a liquid condition as the iron solidifies, and is forced out during shingling. It seems also as if some of the phosphorus oxidised earlier in the process is re-reduced towards the end.

Manganese is almost completely removed early in the process. Sulphur is reduced in quantity, but never completely removed, the amount of removal seeming to depend on the length of time the process takes.

Selection of Pig Iron for Puddling.—Since the iron must be melted to form a fluid mass, a grey iron should be used ; No. 4 is usually selected. It should be fine grained, and the puddler likes to see a rose, *i.e.*, a patch of more largely crystalline material in the centre. As the ingot cools more slowly in the centre, more graphite may separate there than in the more rapidly cooled outer portions of the ingot.

Carbon.—The amount of carbon is immaterial. The presence of a large quantity of carbon may slightly prolong the boiling period, but this prolongation may assist in the removal of other impurities.

Silicon.—This is one of the most important constituents in determining the suitability of an iron for puddling, and the iron should not contain more than 2 per cent nor less than 1 per cent of silicon. A large percentage of silicon is objectionable.

(1) It leads to loss of iron. All the silicon will leave the furnace as ferrous silicate. Assuming the slag to be $2\,FeO, Si\,O_2$—and it may be much more basic—each 28 parts of silicon will remove 112 parts of iron in the slag, so that 1 per cent of silicon would remove about 4 per cent of iron.

(2) If the quantity of silicon be large : enough may be left in the finished metal to injure its quality. The iron comes to nature when the carbon is reduced to about ·1 per cent, quite irrespective of the quantity of silicon left, so that if all that element be not removed before the carbon is gone it will remain in the iron. This is, however, not likely to occur with any ordinary iron.

(3) When the amount of silicon is large there may be insufficient amount of iron oxidised to form a good slag, the slag will then be acid, *i.e.*, too rich in silica, and as such a slag is difficultly fusible, the charge works " cold." As a result the slag may not be liquid enough to be squeezed out during shingling, and too much may therefore be left mixed with the metal, thus making it brittle and unworkable. The coldness of the slag may be, to some extent, removed by the addition of hammer scale or other oxide of iron or basic cinder.

If the percentage of silicon be too low the iron oxidises too rapidly and in too large a quantity to be taken up by the silica, and the slag therefore contains a large excess of oxide of iron, and is pasty or " dry." Such slag is not only difficult to expel during shingling, but it does not dissolve and carry out the oxide of iron during that process as a good slag should do.

In working a charge of scrap iron a slag is obtained which is nearly pure black oxide of iron.

Phosphorus is an objectionable constituent. It helps to make the iron fluid when first melted, but as only about 80 per cent is removed, enough may be left to injure the metal.

Sulphur is always objectionable, and is only partially removed. One of the objections to the use of a white iron for puddling is its liability to be high in sulphur.

Manganese.—This element is completely removed early in the process. It is objectionable if present in large quantity, as it prolongs the operation and increases the loss and the quantity of slag.

It is evident that the quality of the resulting metal depends somewhat on the quality of the pig used, and this should therefore be very carefully selected. At the same time good iron may be made from a great variety of pigs by a skilful puddler, by modifying the conditions of working, since the amount of oxidation can be to a large extent regulated by means of the draught, and by the addition of other materials.

Loss of Iron in Puddling.—As the conversion of pig iron into malleable iron depends on the oxidation of impurities, it follows that there must be a loss of weight, and this will be increased by the iron which is carried into the slag as silicate, or passes into it as oxide. Assuming an iron to contain carbon 3·5 per cent, silicon 2 per cent, manganese 1 per cent, phosphorus 1 per cent, and to have 1 per cent of adherent sand, the loss will be :—

Carbon	3·5 − ·1 =	3·4
Silicon	2 − ·1 =	1·9
Phosphorus	1 × ·8 =	·8
Manganese		1·0
Iron to form slag		9·2
Iron as oxide, say		1·0
Sand		1·0
Parts in 100 of pig iron		18·3

and as the slag might contain much more ferric oxide, the loss might be greater. In practice the loss is always less than that calculated as above, because the fettling and slag added either supply oxide of iron to the slag, or are partially reduced and give iron.

In Staffordshire the loss is put down as about 7 per cent to 10 per cent, in Scotland 10 per cent to 15 per cent, and in Middlesbrough about the same.

Fuel Used.—Puddling is a very wasteful process. The furnace is short, and the gases leave at a very high temperature. Most of the reactions evolve heat, so that all that the fuel has to do is to maintain the necessary temperature, yet the amount of coal used varies from 20 to 27 cwt. for each ton of bar produced.

Charge. &c.—The charge worked is always small, being 4 to 4½ cwt. in Staffordshire and 5 to 6 cwt. in Scotland. The time taken depends on the nature of the pig used, and varies from about 1½ to 3 hours, from four to eight heats being worked in 10 hours, the average in Scotland being about six heats.

Modifications of the Puddling Process.

The details of the process are modified in different districts. In Scotland the furnaces are always worked with a closed hearth, and a stream of steam and air is sent to the furnace by means of a steam jet similar to that used in gas producers. The steam jet gives a better regulation of the draught than the use of a damper alone.

As already remarked, the amount of heat carried away by the escaping gases is very large. This is now usually utilised by placing steam boilers so that they may be heated by the products of combustion. Horizontal double-flue boilers are now generally used, one being placed over or at the end of each two furnaces. The products of combustion pass through the flues back along the sides of the boiler, and away to chimney.

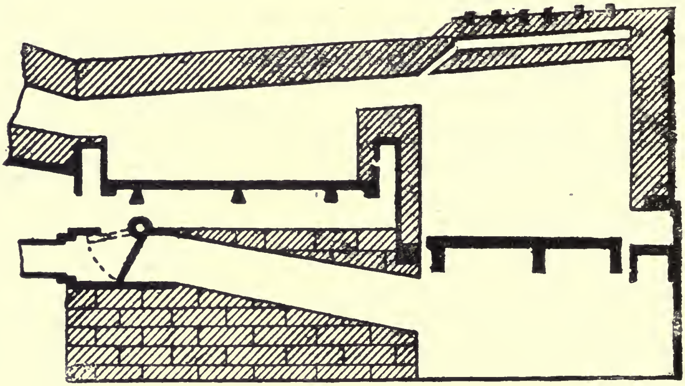

Fig. 88.—Scotch Puddling Furnace.

Double puddling furnaces, *i.e.*, with two working doors, have been tried, but have not proved a great success. They save fuel, but use a large quantity of fettling, and the metal produced is not as good. They are usually worked with mechanical rabbles. The working of the charge depends so much on personal skill that it is difficult for two men (one at each side of the furnace) to exactly work together.

Gas-fired Puddling Furnaces.—Gas is used to some extent as a fuel for puddling furnaces, either made in separate producers or by means of a producer attached to the furnace. In the latter case the producer is nothing more than a very deep fireplace, and regenerators cannot be used. The puddling furnace is so small that it does not lend itself to the economical use of gas, and therefore gas is only used to a limited extent.

Mechanical Puddling.—The physical labour of puddling is very considerable, and many attempts have been made to reduce this by mechanical means. In most of the mechanical puddlers mechanism on the top of the furnace is so arranged as to give a reciprocating motion to the puddling tools, which are guided by the workman, who is thus relieved of the heavy physical labour. As, however, no machine of this class can "ball up"—and this is the hardest work—they have never come largely into use. At one works in Lanarkshire double mechanical puddlers are used, and heats of 7 cwt. are worked in about two hours.

The Danks Furnace.—This form of puddler has been worked in the United States and to a less extent in this country. It was very favourably reported on by a committee of the Iron and Steel Institute, and great things were expected of it. Chiefly, perhaps, because mild steel has to such a large extent superseded malleable iron, it has never come largely into use.

The body of the furnace consisted of a rotating iron vessel carried on suitable bearings and turned by gearing. It was lined with refractory fettling, this being made rough by the insertion of lumps of hæmatite whilst it was in the pasty state. The fireplace was at one end, the hearth being closed and supplied by a steam blast. At the other end was a movable fluebox by which the products of combustion were carried away to the chimney, and in the end of which was an opening for the admission of the puddling tools.

The iron was melted in a cupola and a charge of about 650 lbs. run in, or the pig was charged through the flue end and melted. The furnace was then slowly rotated. The boil began in about 10 minutes with grey iron, or in a much shorter time with white iron. As soon as the metal began to thicken the rotation was stopped, the fire urged to the utmost, and the liquid slag tapped out. The rotation was then resumed at six to eight turns a minute, the puddler drawing down any separated masses of iron into the ball. When the metal came to nature it was all collected into one ball, the rotation stopped, the flue piece lifted away, and the bloom was lifted out bodily and taken to the squeezers.

The bloom weighed about 670 lbs. and was thus somewhat heavier than the charge introduced, the gain being due to the reduction of some of the fettling. The time occupied was from one to one and a half hours, in America seven heats being worked in 12 hours. The fettling needed repair every eight or ten heats, and 12 cwt. of fettling was used for each ton of bar, the fuel consumption being about 20 cwt. per ton of bar. It was claimed for this process that the impurities were more completely eliminated than by ordinary hand puddling. The chief disadvantage of the process seems to have been the heavy wear and tear of the plant.

Cort's Process.—The puddling process, as invented by Cort, differed in two respects from that now used : (1) the iron used was white pig, and it was never properly fused, but remained in a pasty condition all the time, and (2) the bottom of the furnace was sand. The invention of the oxide of iron bottom was second only in importance to the invention of the puddling process itself.

Best Yorkshire Iron.—This iron has long had a very high reputation for its uniformity and quality. These depend not so much on any special purity of the materials used as on the great care with which all the processes are conducted.

The iron used at all the works making this quality of iron is made with cold blast, and contains about 1 to 1½ per cent of silicon, ·5 per cent of phosphorus, and about 3·5 per cent of carbon, of which about ·6 is combined.

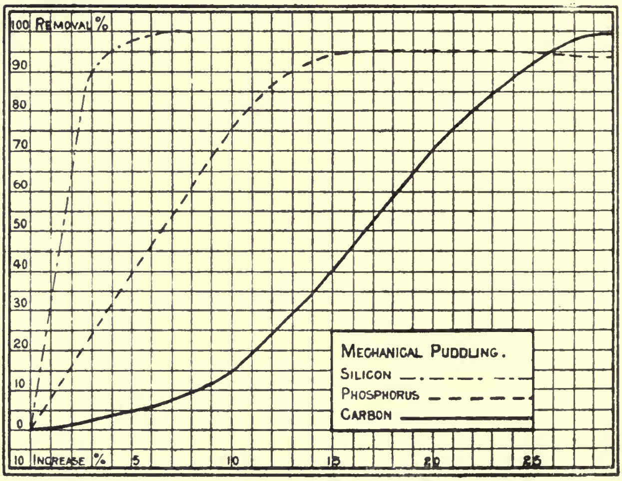

Fig. 89.—Curve Illustrating Removal of Impurities during Mechanical Puddling. (*Bell.*)

The process consists of two distinct stages : (1) refining in an open hearth, and (2) puddling.

Refining.—The object of the refining is to remove the silicon as completely as possible, with part of the phosphorus, and to leave a white iron, which, unlike white iron produced directly in the blast furnace, will not contain a large quantity of sulphur.

The hearth (Fig. 90) consists of a rectangular chamber 4 ft. by 3 ft. 4 in. and 1 ft. 6 in. deep, surrounded by water-cooled iron blocks, except at one side, which is an iron plate provided with a taphole. At the back are two water-cooled tuyeres about 1¾ in. in diameter, directed downwards so that the air can play on the surface of the metal, the air being supplied at a pressure of 1¾ lbs.

to 2 lbs. A bed of coke is put on the hearth, and on this about 30 cwt. of pig iron, the coke is lighted, and the blast is turned on. The iron quickly melts and sinks below the coke, but the downward current of air from the tuyeres keeps it in motion and has a constant oxidising action. In about two hours the operation is complete, the foreman judging when to stop, the exact point of stopping being a matter of great importance. The metal and slag are then tapped into flat moulds placed at one side of the hearth. Water is thrown on the surface to solidify the slag and metal. The slag is removed, and the refined metal is left in slabs about 3½ in. thick. The metal is white, contains about 3·5 per cent of combined carbon, about ·13 per cent of phosphorus, and very little silicon.

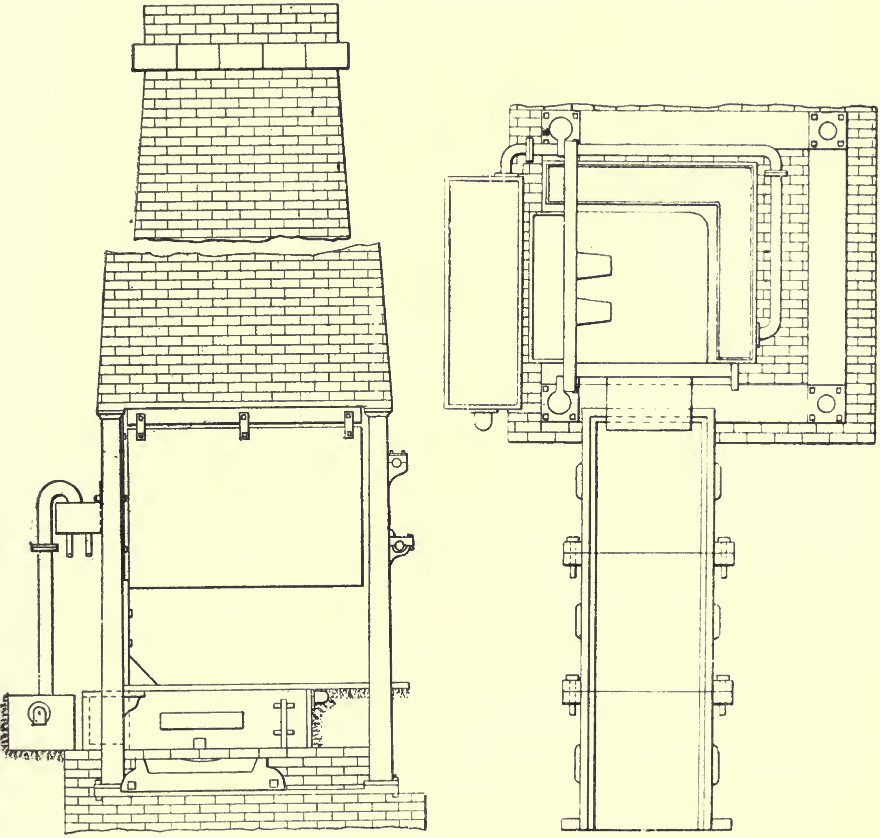

FIG. 90.—Yorkshire Refinery.

Side Elevation. Plan.

During the refining, therefore, almost the whole of the silicon is removed, a considerable portion of the phosphorus—much more now the hearth is of iron than in earlier times, when it was of sandstone—whilst, owing no doubt to the contact of the metal with the coke, the carbon is very little reduced in amount, though it passes completely into the combined form.

Puddling.—The refined iron being white the process used is dry puddling.

The furnace used differs in many respects from an ordinary puddling furnace. At the end of the furnace beneath the chimney is a chamber, "the dandy," which is heated by the products of combustion. There being no silicon in the iron, no oxide of iron fettling is required, the charge being worked on the iron bottom.

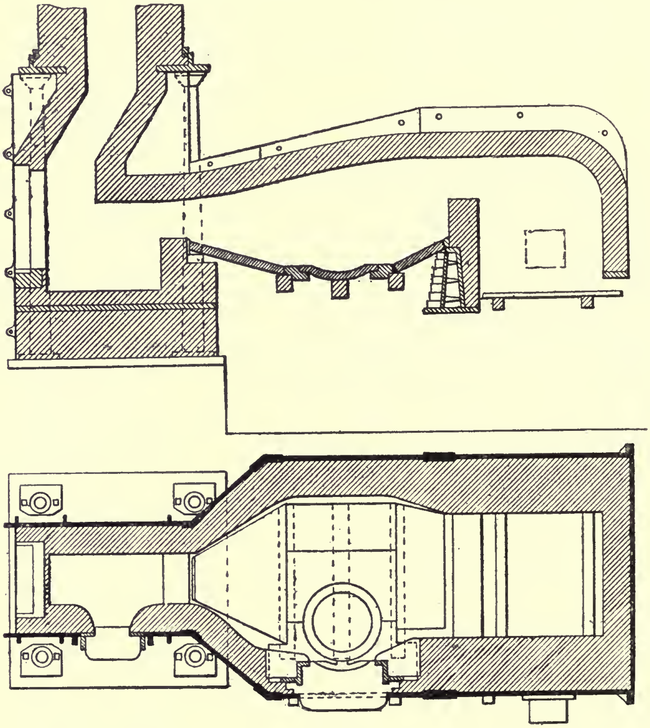

Fig. 91.—Section and Plan of Yorkshire Puddling Furnace.

About 3 cwt. of the refined iron is introduced into the heating chamber, and when red hot is transferred to the puddling chamber. Here it is kept at welding temperature in a pasty condition till the carbon is removed and the iron comes to nature. It is then broken up into three or four balls which are taken to the hammers. The time occupied is about one hour, and 10 heats are worked each shift of ten hours. The short time necessary for the puddling is, of course, due to the previous removal of the silicon in the refining.

The excellence of Best Yorkshire Iron, however, depends not so much on the details of manufacture as on the great care which is bestowed on every operation.*

The Roe Puddling Furnace.—One of the latest of the mechanical puddlers is that invented by Mr. J. P. Roe, which was described in a paper read before the American Institution of Mining Engineers.

The furnace body is rectangular, strongly braced and lined with refractory basic material. It is carried on large hollow trunnions, and semi-circular side plates fitted with teeth working in a gearing, are attached, so that the furnace can be tilted. The fuel, usually oil, is blown in through the trunnions, and a semi-circular chimney communicating with a flue is provided to carry off the products of combustion. At one side of the furnace, at the end of a line at right angles to the axis, is the working door. The rectangular chamber is 20 ft. by 8 ft. 8 in., the shortest dimension being in the line of the trunnions.

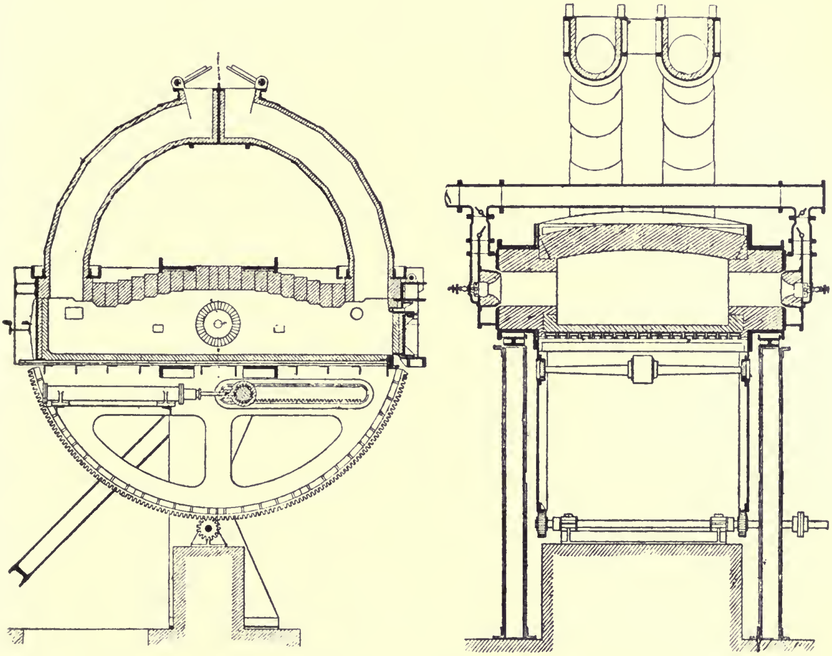

FIG. 92.—The Roe Puddling Machine: Longitudinal and Cross Sections.

The charge is introduced, and the necessary agitation is obtained by oscillating the furnace body, and when the slag is poured off

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* For further details of the manufacture of Best Yorkshire Iron see report of lecture by Mr. Windsor Richards in the "Engineer," October 16th, 1896.

the balling up is brought about in the same way. Slag melted in an auxiliary furnace is run in, in the liquid condition so that the metal is covered with slag, and mill scale is added from time to time to act as an oxidising agent. Molten iron from a mixer is preferably used so as to save the time of melting.

The molten slag is first run in, then the charge of molten iron, usually about 3,000 to 4,000 lbs., and the furnace is oscillated two or three times, the oxidising agent is added, and the furnace is again oscillated, oxidising material (ore or scale) being added from time to time between the oscillations. As the metal comes to nature the angle of oscillation is increased, so that the mass slides with sufficient momentum to compress itself. The door is opened and the cinder is poured off, the mass again slides out into the squeezer, the door is closed and the furnace is ready for the next charge.

CHAPTER XVIII.

OTHER METHODS OF PREPARING MALLEABLE FROM PIG IRON.

Hearth Processes.—Before the introduction of puddling, malleable iron was and even now in some few localities is prepared not in the reverberatory furnace but in an open hearth. Of these processes—which are now chiefly of historical interest—two only need be mentioned.

Howe classifies the hearth processes into three groups :—

(1) Single smelting.
(2) Double smelting, or Walloon.
(3) Triple smelting.

Both those to be described belong to the second class ; those belonging to the first and third classes having ceased to be of any importance.

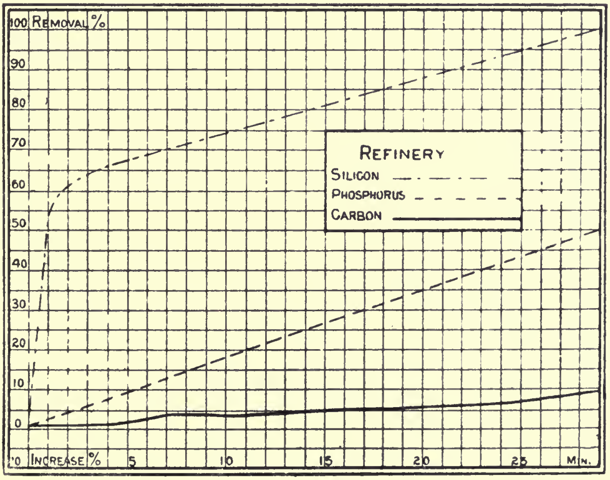

FIG. 93.—Removal of Impurities in Refining. (*Bell.*)

The South Wales Process.—This process is fully described by Dr. Percy.* It was extensively used in South Wales and continued in use almost unchanged for the preparation of sheet iron for tinning, till malleable iron was superseded by mild steel for that purpose. The process consists of two stages, the pig being melted

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*" Metallurgy of Iron and Steel," p. 581, *et seq.*

and partially refined in a hearth fed with coke (the melting finery), the removal of the carbon being completed in two smaller hearths fed with charcoal.

The melting finery is about 2 ft. 4 in. square and 8 in. deep. It is surrounded on three sides by iron troughs, through which water can be kept circulating, and in front by an iron plate, through the bottom of which is a tap hole. The bottom is of firebrick. There are two tuyeres placed side by side at the back of the hearth.

Two charcoal fineries are provided for each coke finery, and these are so placed that the metal can be tapped from the melting finery to them. The charcoal finery is about 21 in. square and 8 in. deep, and is provided with one tuyere.

The iron is melted in the melting finery, and is then tapped into the two charcoal fineries, the slag being kept back as completely as possible, but some always finds its way over; this is allowed to solidify, and is then removed in a lump. Some charcoal—damped to avoid loss—is thrown on to the surface, the blast is turned on, and the metal, which, though solidified, is friable, is broken up by an iron bar, and fragments of iron left on the hearth from the previous charge are added. During the process the metal is kept well stirred, and is constantly raised up from the bottom so as to bring it under the influence of the blast. The cinder is tapped off from time to time, and more charcoal added as required. In about an hour the metal "comes to nature," the blast is reduced, the portions of metal are pressed together into a ball, and removed to the hammer.

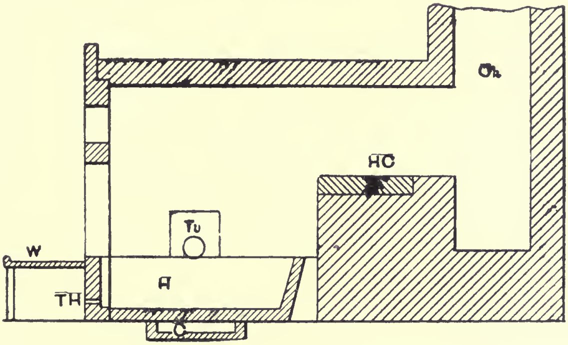
The charge for the coke finery is about 500 lbs. to 600 lbs., and each charcoal finery holds about 250 lbs. The success of the process depends largely on skilful manipulation.

The Lancashire Process.—This process is still used in Sweden, where the hearth is often called the Swedish-Lancashire hearth. The hearth is made of iron plates, with a tap hole in the front plate. The plates may or may not be cooled by water, and the bottom is a water-cooled iron plate. The hearth is about 2 ft. 6 in. long and 2 ft. wide. It has either one tuyere on one of the long sides, or in the modern American hearths one on each side. At the back of the hearth is a chamber through which the products of combustion pass on their way to the chimney, and the blast is heated by passing through a pipe which is exposed to the products of combustion. In front of the hearth is a workplate.

The pig iron to be used is put in the flue chamber to be heated before the previous charge is withdrawn. The hearth is examined to see that there is sufficient slag to keep the bottom plate well covered, charcoal damped with water is put in, and the hot pig iron is brought down into the hearth. The blast is put full on, and charcoal is added as required. As the charcoal burns away the pigs sink, and they are lifted from time to time, so that the melting metal may be well exposed to the air. During melting considerable oxidation takes place, and the metal coming in contact with the cool bottom and sides of the hearth is partially solidified.

When the charge is melted the workmen continually lift the pasty mass with iron rods, thus exposing it to the oxidising action of the blast and at the same time mixing in the slag, by which, as in puddling, the removal of the carbon and silicon is largely brought about. As the action goes on the metal becomes stiffer and at the same time the slag becomes thinner, and in about an hour the metal comes to nature.

The metal is broken up into several pieces, which are lifted above the tuyere till they rest on the top of the charcoal. As the lumps settle down from the burning away of the charcoal they are lifted again, part of the iron melting and sinking to the bottom of the hearth; and as this melted metal must be protected from the action of the charcoal, oxidising slag, such as hammer scale, is added so as to form a sufficiently thick layer at the bottom of the hearth. When the mass at the top of the charcoal is nearly all melted, the iron, which is now in a pasty condition, is all raked together and pressed into a mass. The ball is lifted out, with most of the slag adhering to it, and is taken to the hammer, where it is hammered out into a billet, the slag being broken off in the process.



H Hearth. W Workplate. TH Tap Hole. Tu Tuyere. C Cooler.
HC Heating Chamber. Ch Chimney.

FIG. 94.—Swedish-Lancashire Hearth.

It will be seen that the process consists of three stages :—

(1) A melting-down stage, during which the pig iron is melting and oxidising.

(2) A period of decarbonisation, &c., beneath the surface of the charcoal, ending by the metal becoming pasty.

(3) A remelting on the top of the charcoal, the metal sinking down and collecting on the bottom in a pasty mass, which is lifted out and hammered.

No analyses are available giving the composition of the iron at different stages, so that it is impossible to state exactly the order in which the changes take place.

Howe* gives a detailed account, with drawings, of the working of the process in America.

According to Percy,† in Sweden each finery yielded about 6·6 tons of iron per week, the yield being 86·75 per cent of the pig iron charged, the fuel consumed being ·9 ton for each ton of bar. Howe gives the yield of the hearths in the United States as being about 9 tons, the loss of metal being about 13 per cent.

For charcoal finery processes, iron low in silicon and carbon is selected, and as charcoal is free from sulphur there is no fear of this element being absorbed from the fuel. Charcoal refined iron seems to be tougher and purer than puddled iron—probably it is freer from intermixed slag—and many users contend that the iron made in these hearths is tougher than mild steel of the same composition.

Direct Production of Malleable Iron.

Malleable iron was known long before cast iron, and was for many ages always made directly from the ore. When pig iron was produced in large quantity it was found to be much cheaper to prepare the malleable iron from it, and the direct processes gradually died out. They are, however, still used in some remote localities, and from time to time attempts have been made to reintroduce them in modified forms.

Fig. 95.—Egyptian Iron Smelting.

The principle of these processes is always the same. The iron is reduced in small furnaces at a temperature lower than that which is attained in the blast furnace, so that but little silicon is reduced at the same time, and the iron is not left long enough in contact with the charcoal for it to take up much carbon. These furnaces are usually called "bloomeries," as the iron is obtained in blooms or balls.

The Catalan Forge.—This furnace, which is still in use in the Pyrenees, may be taken as the type of the processes for the direct production of malleable iron.

The furnace proper is a small hearth, somewhat narrower at the bottom than at the top. It is lined with refractory material at the sides and bottom, the back and front being built of blocks of iron, the back vertical and the front slightly convex. The hearth is set in a platform of masonry, and is provided with a taphole by which the liquid slag can be tapped out.

The blast is supplied by an arrangement called the trompe, the air being drawn down by a descending current of water. A cistern

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* "Metallurgy of Steel." † "Iron and Steel," p. 596.

of water is fixed at a height of 20 ft. or more above the level of the furnace. From the bottom of this two large wooden pipes pass to an air chest below, the upper ends of the pipes being perforated with a number of holes sloping downwards, and the water passes from the cistern to the pipe by means of a conical funnel, which can be closed by a plug. As the water flows out of the funnel the air is carried down with it by friction, and entering the air chest the air separates and passes to the tuyere, whilst the water flows away through an escape opening. The tuyere itself is usually a sheet of copper bent round so as to form a cone, and is arranged so as to point into the hearth at an angle of about 40 deg. The trompe will give a considerable quantity of air at a low pressure, and the air will necessarily carry with it a considerable quantity of water in the form of vapour and spray.

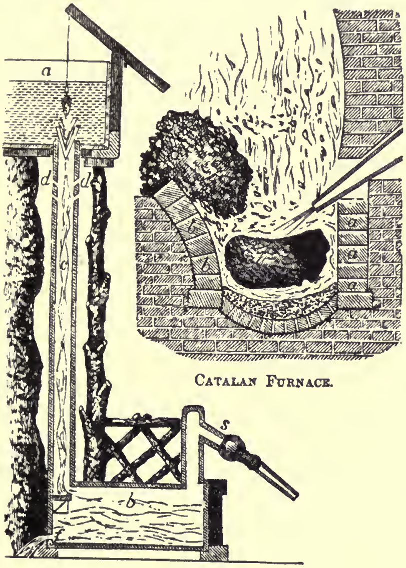

Fig. 96.—Catalan Forge and Trompe.

The ores used must be rich and easily reducible, and are usually red or brown hæmatites. A charge having been removed, the hearth is cleaned out and a little charcoal is put in. As soon as this burns up the hearth is filled up to the top with charcoal. A sheet-iron division is then inserted across the hearth in front of the tuyere. The space between the tuyere and the division is filled up with charcoal, and on the other side the ore—broken into pieces not larger than an egg—is piled up, and the surface is covered with a layer of damp charcoal and ore, both finely divided. The blast is then put on at first gently, and is slowly increased so that in two hours it will attain its full pressure. As the charge sinks, more charcoal and ore are added, and the liquid slag which sinks to the bottom is tapped off from time to time. As the reduced iron descends, the workman moves it towards the blast nozzle so as to heat it strongly. After four to six hours' working, enough metal will have collected. The pasty mass is then pressed into a mass, broken up into blooms, lifted out, and taken to the hammer, and the remaining slag is tapped off.

In about six hours 9 cwt. to 10 cwt. of ore, containing about 50 per cent of iron, will have been worked off. The blooms obtained will weigh about 3 cwt. to 4 cwt., and about 10 cwt. to 11 cwt. of charcoal will have been consumed. The loss of iron into the slags is therefore from 20 to 25 per cent of that present in the ore.

The chemistry of the process is much the same as that of the other reduction processes. The oxides of iron are reduced by the carbon or the carbon monoxide, and, the temperature not being hot enough to melt it, it sinks to the bottom of the hearth. There it is protected from the action of the charcoal by the layer of ferrous-silicate slag; indeed, if the slag be sufficiently basic, carbon actually taken up may be removed, but there is always a danger that the metal may retain excess of carbon, and therefore be steely. The slags are silicates of iron.

Furnaces differing in form but on exactly the same principle have been used all over the world. Dr. Percy describes a furnace in use in India, consisting of a cylinder of clay strengthened with wooden bands, about 3 ft. high and 1 ft. in diameter. It was worked by means of a very simple bellows, and the fuel used was charcoal.* Very similar furnaces have been found in South Africa and other places.

American Bloomeries.—Howe† describes a hearth as still in use in the United States for the direct production of malleable iron. It consists of a hearth 20 in. to 30 in. wide, 27 in. to 32 in. long, and 15 in. to 25 in. deep above the tuyere, and from 8 in. to 15 in. below it, provided with a single D-shaped tuyere, the air being heated to 550 deg. to 800 deg. Fah. by passing through an iron pipe over the hearth. The operation is thus described by Howe: "The hearth being filled heapingly with burning charcoal, charcoal and coarsely pulverised, washed, and nearly pure ore, are thrown on at short intervals, usually one to five, occasionally 12 to 25, minutes, together with slag from previous operations if the gangue be very scanty. The ore reduces in sinking, the usually siliceous gangue forms with unreduced ore a basic ferruginous slag, which is tapped intermittently. The reduced iron gradually agglomerates into a pasty ball (loup), which after nearly three hours is pried through the charcoal towards the tuyere for greater heat; is then drawn, hammered to a bloom, reheated, usually in the bloomery itself, rarely in a chamber heated by its waste gases, and rehammered."

"Eight loups, each of 300 to 400 lbs., are produced in 24 hours at an outlay of 250 to 350 bushels of charcoal and 1·25 to 1·5 days' labour per 2,000 lbs. of ore, with a yield of 80 per cent of the iron in the ore." The cost of working at one mill is given as $45·00 per ton.

The High Bloomery.—In many parts of Europe the bloomery was increased in size, and became the high bloomery or Wolf's oven. This was a short furnace, 10 or more feet high, and about 2 ft. 6 in. in diameter, provided with one or two tuyeres. At the bottom was an arched opening, which could be closed by temporary brickwork when the furnace was at work, and through which a taphole was left for the escape of liquid slag. The furnace having been cleaned out, was filled with charcoal, lighted, and the blast

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* Percy, "Iron and Steel," p. 261. † "Metallurgy of Steel," p. 270.

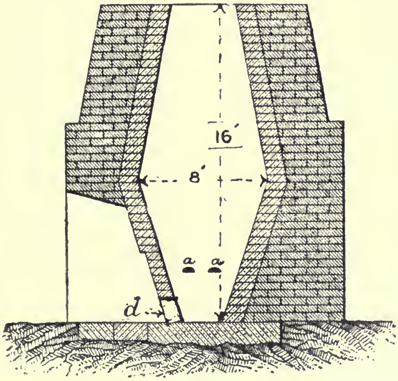
turned on. A mixture of ore and charcoal was then added in small portions at a time as the charge sank. When sufficient metal had accumulated, no more fuel or ore was added, and the charge burned down. The temporary brick closing was then removed and the bloom taken out.

FIG. 97.—Ideal View of Early High Bloomery.

In this hearth there was a great tendency to carburisation unless the proportion of ore to charcoal be kept very high, the metal becoming steely or even passing into cast iron.

There is little doubt that cast iron was discovered by its accidental production in a furnace of this type.

Modern Processes.—Many processes have been suggested for the direct production of malleable iron in recent times. They may be divided into two groups—(1) those in which the iron is obtained in the usual form of a bloom, such as the Siemens direct process, and (2) those in which the iron is obtained in the form of a sponge, as the Blair process.



a a Tuyeres.
d Drawing hole.

FIG. 98.—Wolf's Oven or High Bloomery.

(1) **Bloom Processes.—The Husgafvel Process.**—This process, which was introduced about 1875, is a modern adaptation of the high bloomery. The furnace is something like a blast furnace in appearance, but it consists of a double shell of sheet iron, the air

for the blast being made to circulate in a spiral in the space between, so as to keep the plates cool and itself become heated. The hearth is in the form of a movable truck, and is provided with four water-cooled tuyeres and four slag notches at different levels. It is carried on trunnions, so that the charge can be "dumped out," and rests on a movable platform. Above the bottom is a movable section which can be replaced when necessary.

The fuel is generally charcoal, though coke has been used, and the finely divided ore and charcoal are charged at the top, and as combustion goes on, the charge gradually sinks. The conditions in the hearth are so strongly oxidising that any carbon taken up in the descent is removed. The slag is tapped at intervals from the slag notches, so as to just leave enough to keep the reduced metal well covered. When sufficient metal has accumulated the blast is stopped. and the hearth is at once removed with the iron and replaced by a fresh one.

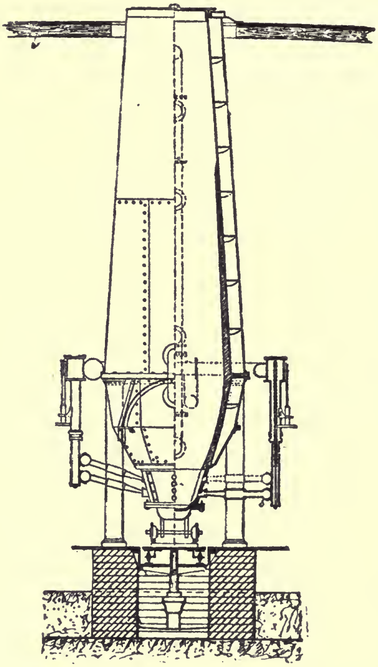


FIG. 99.—Husgafvel Furnace. Half Elevation and Half Section.

According to Howe,* the bloom obtained in this process is likely to be very irregular in composition, and this is borne out by the analyses he gives.

The Siemens Direct Process.—The furnace used consisted of a rotary chamber, carried on suitable bearing wheels, very similar in form to that used in the Dank's puddling furnace. It was about 8 ft. 6 in. external diameter and 9 ft. 6 in. long, fired with gas and air passed through regenerators, and for convenience of working the gas and air entered and left the furnace at the same end, the working door being at the opposite end. The furnace chamber was lined with brick, and on this a fettling of iron oxide was laid. The lining was roughened, so that the charge should not simply slide as the furnace rotated, by pipes carrying water being embedded in the lining and being brought near the surface at places.

The charge of finely divided ore, mixed with limestone or other flux, and charcoal or small coal, was charged through the end door,

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* "Metallurgy of Steel," p. 273.

and the hearth was slowly rotated. Reduction commenced almost at once, and slag began to form. In about three hours the slag was tapped off. The furnace was then rotated more rapidly, then stopped for final balling up by hand, and the balls were lifted out. As in all direct processes, the loss of iron was very heavy, the slags being mainly ferrous silicate, the total time occupied in working a charge being about 4½ hours.

(2) **Sponge Processes.**—In the Clenot processes a mixture of iron ore and charcoal was heated in an externally fired brick retort, the reduced metal then passing through a water-cooled chamber, so that it did not oxidise on coming into the air. The process never came into use.

A modified form was patented in the United States in 1872, and is known as Blair's process. In thisgas was used as the heating agent, and the charge was heated directly by it. The apparatus consisted of a vertical cylindrical reduction chamber, about 4 ft. 6 in. diameter, and 40 ft. to 50 ft. high, surrounded by an outer heating chamber, the two chambers communicating about two-thirds the way up. The upper end of the reduction chamber was open for charging, and the lower end was continued into a water-jacketed cooler.

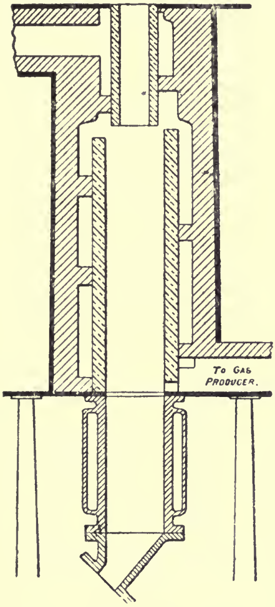

Fig. 100.—Blair Furnace.

A mixture of ore charcoal and a little lime was charged into the top of the reduction chamber. Hot gas (C O and N) from a gas producer fed with coke was passed into the heating chamber, thus heating the material in the reduction chamber, The reduction was, no doubt, mainly brought about by the charcoal, but the carbon monoxide in the gas may have helped very considerably. The furnace would turn out about two tons of sponge a day, nearly the whole of the iron being deoxidised.

The direct processes have been very little used since the introduction of puddling, and it does not seem at all likely that they will ever become more general, even if they do not, as seems very probable, disappear completely.

They are costly to work, the output is small, the fuel consumption being very high ; the yield of metal is low, a large percentage of the iron passing into the slag, and, more important still, it is extremely difficult, if not impossible, to ensure metal of uniform composition and quality.

CHAPTER XIX.

THE FORGE AND THE MILL.

The spongy mass of iron obtained from the puddling furnace, the hearth, or the direct bloomery is soft and incoherent, consisting of irregular granules of iron, only loosely adherent, and containing in the interstices a considerable quantity of still liquid slag. The object of the next set of operations is to compress this into a solid bar of convenient size and to force out any liquid slag. These operations are carried out in the forge, and consist of two stages :—

(1) Shingling, by which the bloom is consolidated into a roughly rectangular slab.

(2) Rolling, by which it is reduced to a convenient size of bar or billet.

Shingling.—The object of the shingling is to solidify the metal and expel as much as possible of the inter-mixed liquid material. It must therefore be carried out as rapidly as possible whilst the iron is still in a very plastic condition, and before the slag has time to solidify. It is obvious that the less fusible the slag the higher will be the temperature at which the bloom must be shingled.

Two methods of shingling are in use : (1) Hammering and (2) squeezing. The first is now almost universal, whilst the second is occasionally used for very heavy blooms.

Hammers.—The hammers used are of two kinds. (1) Gravity hammers, in which the blow is struck by a falling weight, hammer-head or tup, power being required only to raise the weight which by its fall is to strike the blows; such hammers are often called power-hammers to distinguish them from the hand-hammer. (2) Hammers in which the force of the blow is increased by the action of steam or other agency.

Gravity hammers were at one time exclusively used, but they are now almost entirely replaced by steam hammers. A very large number of hammers have been designed, and are used in machine shops, but only those forms which have been largely used in the forge will be described. They are :—

(1) Tilt hammers.

(2) Helve hammers.

(3) Drop hammers, or single-acting steam hammers.

(4) Double-acting steam hammers.

The Tilt Hammer.—This is probably the oldest form of hammer used in the forge, and was apparently designed to imitate, as far as possible, the blow given by a hand hammer. It was used in connection with the older direct processes, such as the Catalan forge, and is still used in some of the small Swedish charcoal fineries. It consists of a beam of wood, suitably built up and strengthened where necessary, supported on an axis in the middle, carrying the hammer head at one end, this being raised by means of cam acting on the other. Tilt hammers are always of small size, usually from 1 cwt. to 5 cwt., and they are driven at a high speed—indeed, their chief characteristic is the rapid delivery of very moderate blows, a method only suitable for dealing with the very smallest blooms.

The Helve Hammer.—In the helve hammer the fulcrum is at one end and the hammer head is at, or near, the other. In the nose or frontal helve the lifting cam acts at the extreme end of the bar beyond the head; and in the belly helve it acts between the head and the fulcrum, but much nearer the former. Hammers of this class were at one time used quite generally in forges, and are still in occasional use. They were often of considerable size, the moving parts weighing up to 10 tons and the lift being 18 in. to 24 in. worked at a speed of up to 60 blows a minute.

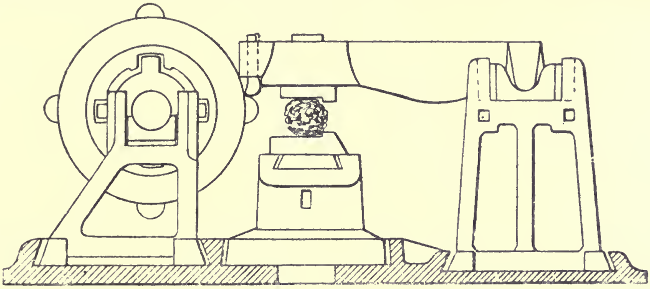

FIG. 101.—Helve Hammer.

Steam Hammer.—In the steam hammer the lifting force is steam. The hammer head is attached to the piston rod of a steam cylinder, so that it moves up and down with the piston, the head being carried in suitable guides. The steam hammer was invented by Watt in 1784, but was first reduced to a practical form by Nasmyth in 1842—hence it is often called the Nasmyth hammer.

The introduction of the steam hammer at once enormously enlarged the power of the hammer as a forging tool by increasing the possible weight of the moving mass and the height of the drop, and the introduction of the double-acting hammer gave a power of modifying the force of the blow, which is of the greatest value.

In the single-acting hammer the head is lifted by the admission of steam beneath the piston, and is then allowed to fall by its own weight, the force of the blow being sometimes reduced by cushioning steam beneath the piston as it descends. The moving parts may be made to weigh many tons, and a fall of several feet may be given.

When the hammers are of large size, the foundations must be made very solid. It has often happened that a large hammer has been found after erection to be unworkable owing to the vibration due to insufficient foundations. The anvil block must be firm and secure, and is very often supported on a mass of cast iron, weighing many tons, cast into a hole made to receive it. Hammers of large size such as are used for steel forging will be considered later.

The details of steam hammers differ enormously. The chief points to be attended to are to provide efficient guides, and to allow ready access to the anvil.

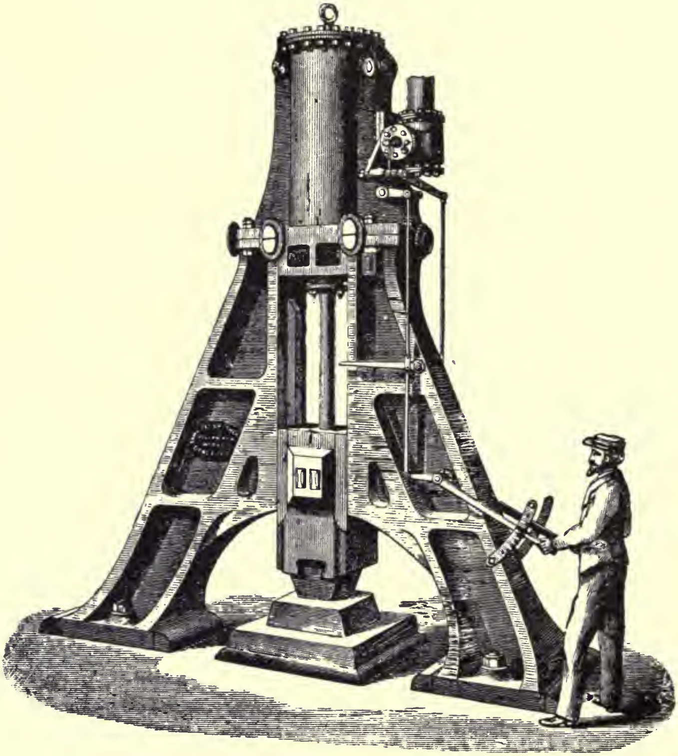

FIG. 102.—Steam Hammer. (Made by Messrs. Thwaites.)

In some hammers the valve gear works automatically, but it is usually worked by hand, so that the hammer-man can control the blows both as to time and force. In the double-acting hammer the blow is completely under control, and the hammer may be brought down with full force, or it may be brought down so gradually as to give a squeeze rather than a blow. It is thus possible to nurse up a piece of doubtful iron so that it may yield a bar, whilst under the deadweight fall of the helve it would go to pieces. Some engineers therefore think that the introduction of the steam hammer has led to the lowering of the quality of bar iron.

With any deadweight hammer the power can be indicated by the weight of the moving parts, a 10-ton hammer, for instance, being one in which the moving parts weigh 10 tons. With the double-acting steam hammer such information is valueless ; indeed, even with a drop hammer it is of little use unless the height of the drop be known ; but the nomenclature still continues in use. The use of steam above the piston increases the velocity of descent, and therefore has the same effect as increasing the drop by an amount that would give the same speed by the action of gravity, and the power of the hammer may therefore be well expressed by the weight of the moving parts and the height of fall necessary to give the velocity with which it strikes the object.

The force of the blow struck varies directly as the velocity, so that increase in the velocity enormously increases the force of the blow, and the power of a hammer is often increased fourfold by being made double acting.

Hammers of large size are only required for steel forging, those used in the malleable-iron forge being only from $1\frac{1}{2}$ tons to $3\frac{1}{2}$ tons.

Effect of Hammering.—The bloom is brought from the furnace on an iron truck or bogie, or is supported in the tongs, and carried by means of an overhead railway. It is taken to the hammer as quickly as possible, and on its way a large amount of liquid slag runs out, its place being, of course, taken by air, which oxidises some of the iron. The bloom is placed on the anvil block and the hammer head is brought down gently, and this is repeated so as to give the bloom two squeezes ; the slab is then turned over, hammered with repeated turnings into a square block, and then turned up so as to receive two blows on the ends. For broad bars the bloom is hammered into a flat slab, and is then turned on edge and hammered with repeated turnings till it acquires the proper breadth. Each time the hammer strikes the bloom a shower of red-hot liquid material—molten slag—is expelled, so that the workmen have to protect themselves by iron leggings, &c. The hammered bloom, when finished, is still red hot, and is passed at once to the rolls.

In shingling blooms of scrap iron, squeezing action is never used, but the full force of the hammer is applied at once and the piece is flattened, then doubled over, and is afterwards squared up as required. The effect of hammering is very irregular. The fall of the hammer imparts its energy to the mass of iron ; but this is largely taken up by the upper portions, the lower portion resting on the anvil receiving very little, so that the bloom must be constantly turned, and if it be a large one, the middle portion may be very little consolidated, so the resulting bar may be very irregular, though this will, no doubt, be to a large extent remedied as the bloom passes through the rolls. The hammer is, however, not satisfactory for working very large masses. Again, as the force of the blow depends on the distance through which the hammer head falls, the full force of the blow can only be obtained when the article being hammered is small. A large mass will receive a very much less severe blow, and thus the bloom which requires most compression receives least. The difference can, of course, be made much less, when a double-acting hammer is used, by varying the force of the steam. Mr. Ramsbottom, of Crewe, designed a double-acting hammer, which is still used for hammering steel ingots for making railway carriage wheels. In this there is no fixed anvil, but the mass to be hammered is suspended between two hammer heads carried on small trucks, which move together horizontally and thus strike a blow on each side of the block.

Squeezers.—To overcome the defects of the hammer, especially as applied to large blooms, such as those obtained from the Danks furnace, many forms of squeezer have been designed.

The simplest of these is the crocodile squeezer. In this there is a fixed bottom jaw and a movable top jaw, which rotates round an axis. As the top jaw descends it presses the bloom, and when it rises the bloom can be pushed further in, so as to receive a still further squeeze.

Most of the squeezers consist of sets of rolls of various forms, either circular, or more usually camlike, so that the space between the rolls decreases as they rotate. Many have been introduced ; but none of them have come largely into use, and it is doubtful whether there are any squeezers at present in use for shingling in this country.

Further Treatment of the Bloom.—At one time the hammered bloom was worked down into a bar under a quick-working tilt hammer ; but this method of working is now very rare, if it be not extinct, and the rolls are now always used.

The puddling rolls or forge train consists usually of two pairs of rolls, called respectively the roughing and the finishing rolls. The rolls are about 3 ft. to 5 ft. 6in. long, and 18 in. to 22 in. in diameter. They are mounted in suitable housings, and are connected to the driving shaft by means of coupling boxes and a piece of shaft weaker than the main shaft or the neck of the rolls, so that, in case of any sudden and unexpected stress, it may yield first. The bottom roll is driven direct, and the top one is driven from it by means of pinions the same diameter as the rolls. In the roughing rolls the first one or two grooves are Gothic in shape, and are notched so as to catch the heavy bloom. The other grooves in the roughing and in the finishing rolls are gradually modified in form towards that which it is intended to roll, which will usually be a flat bar 3 in. to 7 in. wide, and $\frac{1}{2}$ in. to $1\frac{1}{2}$ in. thick, 3 in. or 4 in. bars being usually $\frac{11}{16}$ in. to $\frac{3}{4}$ in. thick.

The bar is passed through the grooves in regular order, being returned over the top of the rolls, and when it has passed through them all it is put aside as puddled bar for further treatment.

Puddled Bar.—The puddled bar is malleable iron. It breaks with a crystalline fracture, shows distinct lamination, and if good has a decided fibre. The slag and oxide which are disseminated through it are in comparatively large fragments, and may have been rolled out more or less flat. During the processes a considerable quantity of scale will have been produced—hammer scale or roll scale, according as it was produced at the hammer or the rolls. This scale consists entirely of oxide of iron, approximating to the composition of the magnetic oxide Fe_3O_4. Hammer slag—the material forced out during shingling—contains a considerable quantity of silica and phosphorus.

THE MILL.

From the forge the puddled bar is passed to the mill for further treatment to convert it into "merchant bar."

The processes consist of :—

(1) Cutting the bar into pieces of suitable length and piling.
(2) Re-heating.
(3) Rolling.

Shearing and Piling.—The bars are cut up by means of shears into pieces of uniform length, usually 12 in. to 48 in., or even longer for large sizes. A number of these pieces are piled together so as to make a rectangular pile from 4 in. to 12 in. square. The bars are either piled all in the same direction or in alternate layers at right angles. When—before the introduction of mild steel—heavy forgings were made, great attention was given to piling, a different method being used for each form of article to be made. Now, as only small sections are rolled, the piles are almost always the same.

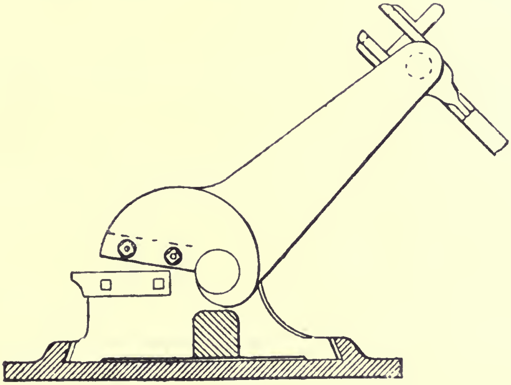

FIG. 103.—Shears (Truran).

The Mill Furnace.—The mill, or re-heating furnace, is used for heating the piles to welding temperature. It is a small reverberatory furnace, something like a puddling furnace. The proportion of fireplace to hearth is less, and the bottom of the furnace is made of iron plates, and on this is laid the working bottom of sand. The bottom is made to slope towards the chimney, so that any slag which forms will run down, and also from front to back; the fire brick crown having about the same slope.

The size of the furnace will of course vary with the size of the piles to be heated.

Gas furnaces are now largely used for re-heating. These will, however, be described later under steel.

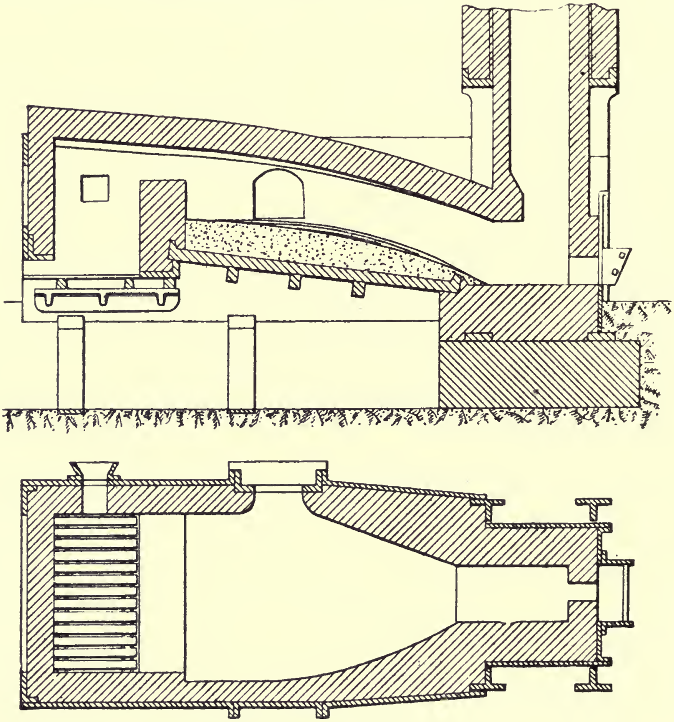

Fig. 104.—Mill Furnace.

The pile is carefully placed on the hearth of the furnace by means of a flat iron tool or peeler, the pile being so placed as to stand across the furnace parallel with the fire bridge. About 20 to 40 cwt. of iron in the form of piles, each weighing from 70 lbs. to 750 lbs., is introduced into the furnace, the door is lowered into position, luted, so as to exclude air, and the fire is made up, the fire-bars cleaned, &c. The piles are turned from time to time, and will attain welding temperature in from 15 minutes to one hour, according to their size.

As soon as the pile is properly hot, it is removed from the furnace by means of tongs, and put on to an iron bogie; or, in many works, the tongs are rested on a link, attached to a carriage on a small overhead tramway, and is at once run to the rolls.

As soon as the charge is out, the bottom of the furnace is repaired where necessary, and the furnace is ready to receive another charge.

During the heating the iron becomes more or less oxidised. The oxide falls on to the sand bottom, combines with the silica, forming a silicate of iron, which flows to the bottom of the chimney, and is removed from there from time to time. The slag is called mill furnace slag, or, very often, flue slag or flue cinder. It is a ferrous silicate, containing 40 to 45 per cent of ferrous oxide. The bottom of the re-heating furnace is sometimes made of oxide of iron, whilst fireclay has been used and basic slag has been patented.

The Rolls.—Two or more pairs of rolls are usually employed: The roughing or billeting rolls, in which the pile is first reduced, and the finishing rolls, in which it receives its final form. The rolls vary much in size, 8 in., 10 in., or 12 in. being the usual diameter, but as small as 6 in. are sometimes used for light work, and up to 18 in. Both rolls are driven from the engine, and the distance between the rolls is capable of adjustment by means of screws. The neck of the roll is attached to the driving shaft by means of a short connecting shaft or breaking spindle and coupling boxes ; by this means not only are the rolls and shaft protected from breaking, but they can be worked if they are not strictly in line. The finishing rolls are also connected to the roughing rolls in the same way, so that the two sets work together.

The form of grooves will also vary. The first groove on the roughing roll will be nearly rectangular, so as to grip the pile ; the last will be of the form which the finished bar is to have ; in the case of " merchant bar " this is a flat bar 2 in. to 4 in. wide and ½ in. to 1 in. thick.

In the front of the finishing roll is a stripping plate. This is a plate of iron with projecting teeth which fit into the grooves of the rolls. It is fixed to the framework of the rolls, and its projections rest in the grooves of the lower roll, so that if the bar should stick at all it cannot be carried round by the roll but will be turned outward by the stripping plate. The bar is passed through the first groove. As soon as it is through the workman lifts the end on to the top of the roll, the workman on the other side seizes it with his tongs, and it is brought over ; it is then passed through the second groove, returned over the top, and so on till it has passed through all the grooves. To avoid the labour of returning the bar over the top of the rolls, and the consequent loss of time, two methods have been suggested :—

(1) The rolls may be reversed, so that the bar is passed backwards and forwards. This has become general in steel mills where heavy sections are rolled, but it is rarely used in the iron mill.

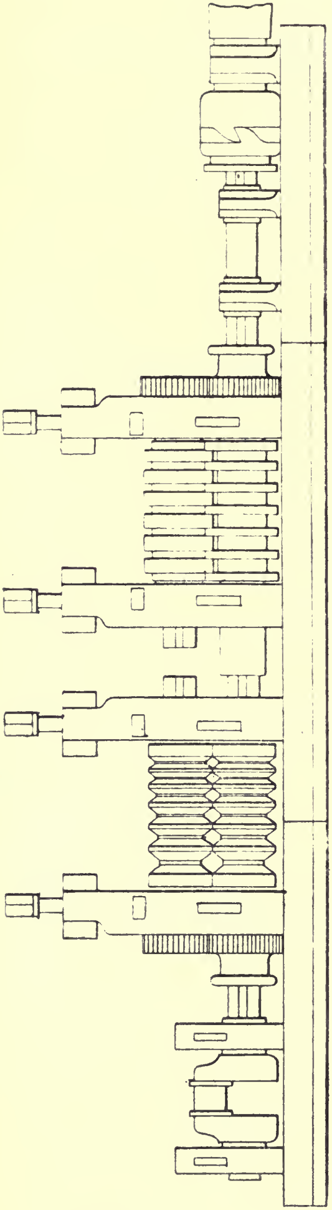

Fig. 105.—Forge Train (Truran)

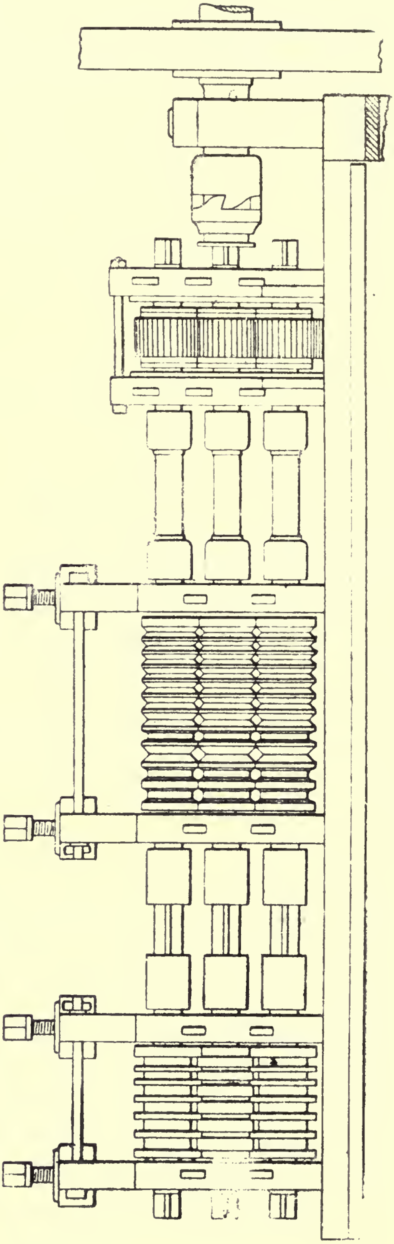

Fig. 106.—Three High Mill Train (Truran).

(2) Three high rolls are used. In this form of roll three rolls are arranged one above the other, instead of two. The centre roll is driven by the engine. The bar is passed in one direction between the middle and bottom roll and then is returned through the next groove between the middle and top roll, and in that way is rolled in both directions of travel. Three high rolls are largely used for light work, but are not suited for heavy sections.

For heavy work which has to be returned, some mechanical arrangement is sometimes used to lift the piece to the top of the roll. This may be in the form of rods suspended from above, worked by levers, or it may be a movable plate, which can be lifted by means of steam power to the level of the top of the roll.

When the bar has passed through the rolls, it is "merchant bar." For "best," the process of cutting up, piling, re-heating, and rolling is repeated, and a second time for "best best," and a third time for "treble best." At least this is the process which is always described, and which was at one time general, but it is very doubtful if it is now carried out at all frequently. Turner states: "Best, best best, or treble best irons are obtained not by frequent heatings, as is sometimes stated, but by the careful selection of all the materials employed and by systematic and frequent tests of the iron during the various stages of manufacture.*

Chemical Changes in the Mill —Though the iron is not melted in the mill, it undergoes considerable change. The amount of intermixed matter is reduced, the slag and phosphide of iron sweat out to some extent, and more is squeezed out during rolling. The atmosphere during the whole of the process is oxidising, and the carbon and silicon are, therefore, somewhat reduced, and the phosphorus is very considerably reduced. There is considerable loss of iron by oxidation.

Other Sections.—Malleable iron is rolled into various sections, and for each a different set of rolls will be required.

Two classes of cast-iron rolls are used. Grain rolls, which are cast in ordinary sand moulds, and are used for roughing rolls and rolls on which sections have to be turned; and chilled rolls, on which a hard surface is produced by casting in a chill. The former are now very largely superseded by cast or forged steel rolls, which, though much more expensive, are more durable, and the latter are used for plates and sheets where a fine surface is required. The mills for various sections do not differ from those used for rolling bar, except that the form of the grooves varies according to the section required.

In the plate mill flat rolls are used, the roughing rolls being grain or steel rolls, and the finishing rolls chilled. The bottom roll is driven and the top roll runs free. As the plate will be reduced

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* "Iron," p. 328.

at each pass, and has not to go through a set of grooves, the distance between the rolls must be capable of adjustment, and they are brought a little nearer each pass. The rolls are often reversing, so that the plate has not to be passed over the top of the rolls, or else a lifting arrangement is used by which the plate is lifted and passed back.

The top roll is always made a little larger than the bottom one, and this causes the end of the plate or bar to turn downwards and avoids any chance of it wrapping round the upper roll. The extension of the plate is almost entirely in the direction of its length. The pile is therefore passed through in one direction till it has become as long as the rolls are wide, then it is sent through in a direction at right angles to that.

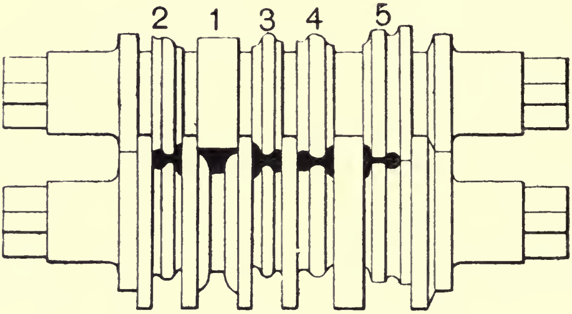

Fig. 107.—16in. Rail Rolls.
(The numbers show the order in which the rail is passed through.)

In rolling bars, rails, and similar articles, the grooves of the finishing rolls are so arranged as to gradually give the bar the required form. Fig. 107 shows the form of the grooves for rolling a rail, and will serve as an illustration.

The subject of rolling will be further dealt with under steel.

PART IV.

CHAPTER XX.

STEEL.

Under the name steel are now included so many varieties of iron that it is impossible to give a good definition of the term. Until the introduction of mild steel, steel was always defined as being iron containing from ·5 per cent to 1·5 per cent of carbon; with only small quantities of other impurities; and which when heated to redness and quenched in water becomes sensibly hard. Now, however, materials known as steel are made containing much less than ·5 per cent of carbon, and which do not sensibly harden on quenching. The name must be taken as it is used, and it may be sufficient, therefore, to define steel as being any form of iron other than malleable iron, containing 2·5 per cent or less of carbon, with only small quantities of other elements.

When any considerable quantity of another metal, such as nickel or manganese, is present, the material is called steel, the name of the other metal being prefixed, *e.g.*, manganese steel, nickel steel. It will be seen, therefore, that a great variety of materials suitable for very many purposes are included under the one name.

Steels may be classified in various ways according to the purpose for which the classification is needed.

The most general classification perhaps is into hard steel and mild steel. Hard steel contains over ·5 per cent of carbon, and becomes hard when quenched; mild steel contains less than ·5 per cent, and is not sensibly hardened when so treated. The two forms pass gradually one into the other, there being no sharp line of demarcation. Percentage of carbon is far the best means of discriminating, since hardness is a property which it is difficult to determine, and there is no accurate method of measuring it. Even when steel is so low in carbon as not to be appreciably hardened by quenching, its structure is modified and its strength increased by such treatment.

Another classification is that based on the use to which the metal is to be put; the high carbon steels being called tool steels because principally used in tool making, and the low carbon steels structural steels, because they are largely used for structural purposes. Steel which has been melted and cast may be called cast steel; that which has been melted in crucibles being crucible cast steel, whilst that which has not been melted, but worked up from plastic masses, may be called weld steel.

A classification according to the process of manufacture is often convenient for purposes of study, but less so for practical purposes, as it is not always possible to say by what method a given sample has been produced.

Such a classification will be—

(1) **Puddled Steel** —Steel made from pig iron in the puddling furnace. It has not been fused, but welded together from pasty masses exactly in the same way as malleable iron, which it closely resembles in structure, the chief difference being in the percentage of carbon. There is every gradation from soft iron through steely iron to steel.

(2) **Cement Steel.**—Made from malleable iron, by heating for a long time with carbon. It has not been fused, and the carbon is not uniformly distributed. When the bars are cut up, piled, and welded, the metal is called shear steel.

(3) **Crucible Cast Steel.**—Steel which has been melted in crucibles and cast. It is usually high in carbon, and is made by melting cement or other steel. It is occasionally made by the direct carbonisation of malleable iron in crucibles.

(4) **Bessemer Steel.**—Steel made by the Bessemer process.

(5) **Siemens Steel.**—Steel made by the open-hearth process in gas-fired Siemens furnaces; sometimes called Siemens-Martin steel; but this name is only appropriate in certain cases.

(6) **Basic Steel.**—Bessemer or Siemens steel made in converters or furnaces, as the case may be, lined with a basic material such as dolomite.

Steels of the 4th, 5th, and 6th classes are almost invariably mild, though the amount of carbon they will contain will depend upon circumstances. They are all cast, but the castings may be afterwards rolled or otherwise worked.

Each variety of steel has its own peculiar qualities depending on its chemical composition and the method of manufacture.

American Classification.—An international committee was appointed in 1876, under the auspices of the American Institution of Mechanical Engineers, and it recommended the following nomenclature:—

(1) That all malleable compounds of iron, with its ordinary ingredients, which are aggregated from pasty masses, or from piles, or from any form of iron not in a fluid state, and which will not sensibly harden and temper, and which generally resemble what is called wrought iron, shall be called *Weld Iron*.

(2) That such compounds when they will from any cause harden and temper, and which resemble what is called puddled steel, shall be called *Weld Steel.*

(3) That all compounds of iron with its ordinary ingredients which have been cast from a fluid state into malleable masses, which will not sensibly harden by being quenched in water while at a red heat, shall be called *Ingot Iron.*

(4) That all such compounds when they will from any cause harden shall be called *Ingot Steel.*[*]

Many attempts have been made to induce manufacturers and others to adopt this system, but without success, and the name steel is now so firmly fixed to the materials made in the Bessemer converter and Siemens furnace which do not harden when quenched that any change is most unlikely.

It will be seen that the four groups correspond very nearly with varieties of iron and steel which are generally recognised, and the actual name used is of very little moment so long as its meaning is distinctly understood. Weld iron is the same as wrought or malleable iron ; weld steel includes puddled steel, cement steel, and shear steel ; ingot iron is the same as mild steel, and ingot steel as crucible cast steel.

Chemical Composition of Steel.—Steel is essentially a compound of iron and carbon, other constituents present being regarded as accidental impurities, so that the nearer it approaches to pure iron and carbon the better. It is often stated that steel is intermediate between cast iron and malleable iron ; this statement, however, is incorrect, or at least needs considerable qualification. Ordinary tool steels, containing, say, 1 per cent of carbon, are intermediate in carbon content between pig iron with, say, 3·5 per cent and malleable iron with, say, ·2 per cent of carbon, but in this respect only, for the steel must be as free from other impurities, such as silicon and phosphorus, which are present in considerable quantity in cast iron, as malleable iron, and mild steel can be and is made to contain as little carbon as malleable iron.

Carbon —Carbon is the essential constituent in steel, the presence of which differentiates the metal from pure iron. The amount may vary from ·1 per cent, or even less, in the very mildest steels, up to 1·5 per cent in the hardest tool steels, or more in very hard steel made for special purposes. The grade of the steel is mainly determined by the quantity of carbon which is present, and its properties depend also on the form in which the carbon is present. The quality depends on the presence or absence of impurities, and on physical structure.

Graphite is never present in steel, except perhaps occasionally in specimens very high in carbon. A variety of uncombined carbon which has not the form of graphite, and is known as graphitic

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[*] Thurston's "Materials of Engineering," vol. ii., page 211.

temper carbon, sometimes separates when high carbon steels are slowly cooled ; but this is never seen in steels containing less than 1 per cent of carbon.

The combined carbon exists in at least two forms : (1) As a definite carbide F_3C disseminated through the metal, whence it is called carbide carbon, and (2) distributed evenly through the mass either in combination with the whole of the iron or in solution in it, the carbon being present chiefly in this form in hardened steel, it is generally called hardening carbon.

When a high carbon steel is slowly cooled it is comparatively soft, and the carbon is present chiefly as carbide. When the steel is quenched from a red heat in water the metal is harder, and most of the carbon is present in the hardening form. When the hardened steel is gently heated, part of the hardening carbon passes into the carbide condition, and the metal is somewhat softened or tempered. The theory of hardening and tempering will be discussed later.

Pure iron is very soft, malleable, and ductile, but has little tenacity. The presence of other elements in general hardens the metal and at the same time increases its tensile strength and diminishes its ductility. Hardness, with its accompanying tensile strength and ductility, are opposite characteristics, and increasing the one usually means a decrease of the other ; but the rate of increase of the one property and of decrease of the other varies with the constituent which produces it, and this, in the case of steel, is mainly carbon. Carbon increases the hardness and strength with less loss of ductility than any other element. "Strength must be bought at a certain cost, and this cost is less in the case of carbon than with any other element."*

By varying the percentage of carbon, steel of varying strength can be produced, and by changing the condition of the carbon from the carbide to the hardening condition, still greater variations can be obtained, whilst the presence of other constituents leads to still other varieties.

The purest iron commercially obtainable has a tensile strength of about 17 tons to the square inch. When the carbon is ·18 per cent the tensile strength is about 30·5 tons, with an elongation of about 22 per cent on an 8 in. test piece ; when the carbon reaches ·22, the tensile strength is about 32·5 tons, with an elongation of about 21 per cent ; with ·25 per cent of carbon, the strength is about 35 tons, and the elongation about 20 per cent ; with ·5 per cent carbon the tensile strength is 45 tons or thereabouts ; and with hardened high carbon steels, a tensile strength of 100 tons may be obtained, the elongation before fracture being in this case inappreciable.

It is obvious that the amount of carbon required will vary with the purpose for which the steel is to be used. For all structural purposes, especially where the metal is subject to shocks, softness and ductility are of chief importance, and brittleness is to be avoided.

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* Campbell's "Structural Steel," page 256.

The carbon is, therefore, low. For rails, strength is required, but, at the same time, the metal must be hard enough to resist abrasion, whilst a lancet must be very hard, so as to take a keen edge, but does not require any great strength, so that for it a very high carbon steel may be used.

The following may be taken as an example of the carbon content of steels for various purposes :—

	Per cent.	
For razors	1·5	carbon.
,, hard files $(1\frac{3}{8})$	1·375	,,
,, turning tools, drills, &c.	1·25	,,
,, large turning tools, dies, &c. $(1\frac{1}{8})$	1·125	,,
,, cold chisels	1	,,
,, sets wood chisels, &c. $(\frac{7}{8})$	·875	,,
,, dies, &c.	·75	,,
,, locomotive tyres	·55 to ·65	,,
,, hard rails	·35 to ·50	,,
,, axles	·25 to ·35	,,
,, springs, &c.	·5	,,
,, bridge work, &c.	·2	,,
,, boiler plate, &c.	·15 to ·3	,,
,, wire rod thin sheets, &c.	·1 to ·125	,,

Silicon.—Silicon is always present in small quantity, and sometimes is added intentionally. Very diverse opinions are held as to the influence of silicon, some metallurgists holding that in small quantities it has little or no effect on the quality of the metal, whilst others say that even in the smallest quantity it is always objectionable. The general effect of silicon seems to be to harden and strengthen the steel, but to a much less extent than carbon. According to some experiments made by Turner, the increased tensile strength due to ·2 per cent of silicon was found to be only about 4,000 lbs. (1·8 tons) per square inch.

In some works, rails are made containing ·5 per cent of silicon which pass all the tests and wear well, and a well-known authority has recently stated that " silicon up to ·30 per cent, with carbon ·30 or ·40 per cent, does not harden steel or make it brittle, and diminishes its strength in such small degree as not to imperil the safety of the rail."* Hard steel suitable for tools not infrequently contains a considerable quantity of silicon without being injuriously affected.

Campbell states that " silicon cannot be classed among the highly injurious elements," and that it is " only reasonable to suppose that small quantities cannot exert a very deleterious influence," and Howe concludes that there is no evidence that silicon in moderate quantities is injurious to a steel. When the amount of silicon is very high, reaching 5 per cent or so, its influence becomes well marked, and the metal becomes hard and brittle. In one case given by Hadfield, a bar containing 5·08 per cent of silicon gave a tensile strength of 46 tons, with an elongation of ·3 per cent in 2 in.

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* Sandberg, Proc. Inst. Mech. Eng., 1890, page 301.

Phosphorus.—This element is universally regarded as being the greatest enemy of the steel maker, and its evil influence is recognised both by the engineer and the metallurgist ; but there is great uncertainty as to its exact influence.

With small quantity up to, say, ·1 per cent, phosphorus increases the tensile strength of the metal, very frequently with but little decrease of extension or of reduction of area before fracture, so that the testing machine may fail to detect the influence of the metal ; but if the metal be subjected to shock—that is, a stress suddenly applied—it will break readily with a comparatively small load. This brittleness under shock is the most marked character of phosphoric steel, and is one which unfits it for almost all uses in the arts.

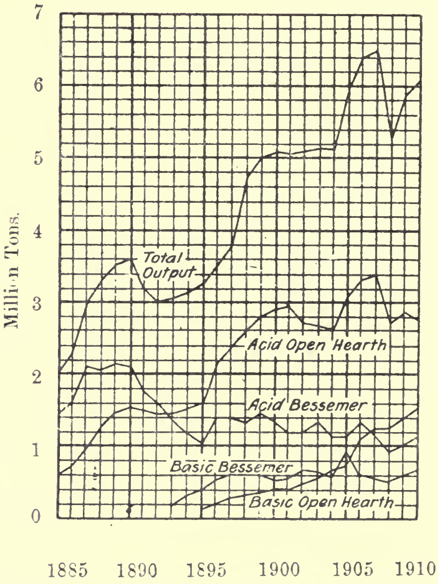

Fig. 108.—British Output of Steel, 1885-1910.

The effect of phosphorus seems to be greater in high carbon than in low carbon steels, so that it is highly objectionable in tool steels. One effect of phosphorus is to produce a coarsely crystalline structure, and no doubt the brittleness is to some extent due to this. It also lowers the maximum temperature to which the metal may be heated in working.

Sulphur.—Sulphur produces red shortness in malleable iron and it has much the same influence in steel. Steel containing sulphur has a coarsely crystalline structure, tends to crack in rolling, and welds badly. The amount of sulphur which is allowable varies with the amount of other elements that may be present. In the presence of manganese a larger quantity is permissible than if that element be absent, whilst with copper only a trace must be present.

Sulphur to the extent of ·08 per cent interferes with the rolling qualities of the metal, and it is better if much less than this is present. Sulphur in the quantities likely to be present in steel seems to have little influence on tensile strength or elongation, though it is said to slightly increase the former.

Manganese.—This element is always added to the melted metal in the manufacture of mild steel, but only a small quantity remains in the steel. It is not disadvantageous, as it to some extent counteracts the influence of sulphur, and causes the structure to be more finely crystalline. It increases the tensile strength of the metal, but greatly increases the tendency to crack when suddenly cooled. Up to 1 per cent it has little injurious effect on mild steels, but in larger quantity it tends to make the metal brittle under shock. In high carbon steels a very much smaller quantity only is allowable.

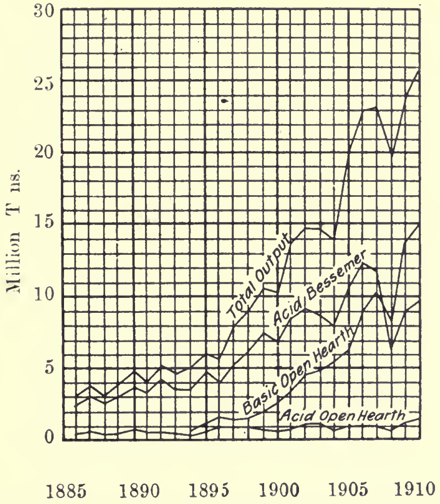

Fig. 109.—United States Output of Steel, 1886-1910.

Copper.—This is rarely present in British steels, but is found in the metal made from ores containing copper. Campbell states that 1 per cent may be present without injuring the steel. provided there be but little sulphur ; but that, if the sulphur be up to ·08 or ·10, the metal will be red short, and that copper also reduces the welding power of the metal, especially if sulphur be present ; but he adds : "In all cases the cold properties seem to be entirely unaffected."

Aluminium.—This metal is often added to the molten steel in the ladle, but only a trace remains in the metal. It seems to have little or no effect on the qualities of the metal until it reaches about ·2 per cent. With ·5 per cent the tensile strength is increased, and elongation and reduction of area are diminished. Some observers state that even a very small quantity of aluminium is injurious.

Arsenic.—This element is rarely present except in minute quantity. With ·10 per cent to ·15 per cent there is no noticeable change in the metal, but with larger quantities the steel is hardened and its ductility is reduced.

Nitrogen.—Much has been written on the presence and influence of nitrogen in steel. It seems to be always present, mainly as dissolved, occluded, or mechanically mixed gas, and to a small extent fixed, and, therefore, probably in combination. The amount usually present, however, seems to have no detrimental effect on the metal.

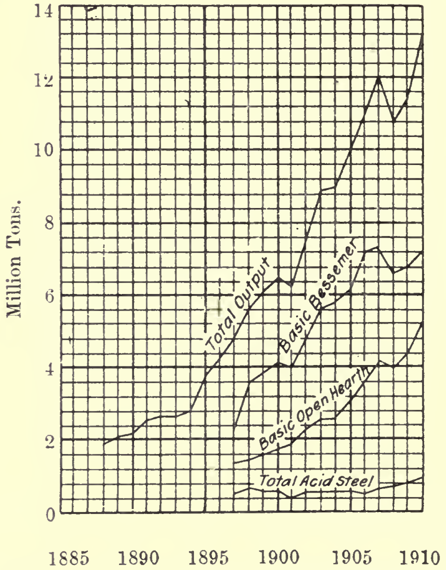

FIG. 110.—German Output of Steel, 1886-1910.

Oxide of Iron.—This is said to be present in mild steels when an insufficient quantity of recarburiser has been added. There is too little evidence available at present to justify a definite statement, but Campbell thinks that it raises the ultimate strength.

Cumulative Influence of Impurities.—Almost all the impurities that can be present in steel act in the same direction, tending to increase the hardness and strength and diminish the ductility. It is, therefore, quite impossible to draw conclusions as to the character of a sample from the consideration of one constituent only, and it is difficult to sum up the action of so many separate factors, and as all have their influence, it is still more difficult to isolate and determine the influence exerted by any particular one.

H. H. Campbell has recently worked out the problem for mild steel more completely than has been previously done, and his results are of the utmost importance.*

His chief conclusions are :—

(1) "The strength of pure iron, as far as can be determined from the strength of steel, is about 38,000 lbs. or 39,000 lbs. (17 tons to 17½ tons) per square inch."

(2) "An increase of ·01 per cent of carbon raises the tensile strength of acid steel about 1,210 lbs. per square inch, and of basic steel about 950 lbs."

(3) "An increase of ·01 per cent of manganese has very little effect on acid steel, unless the carbon content exceeds ·60 per cent, but raises the strength of basic steel about 85 lbs. per square inch."

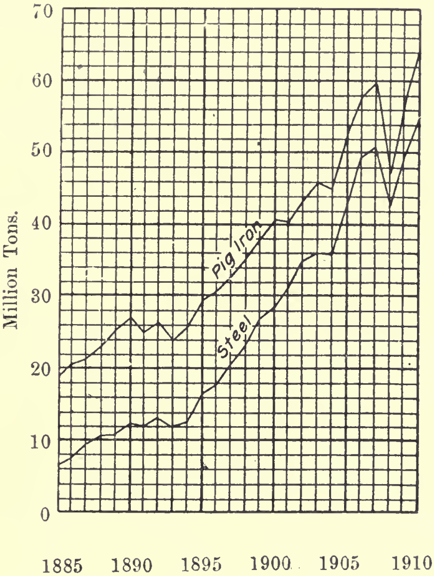

Fig. 111.—World's Production of Pig-iron and Steel, 1885 1910.

(4) "An increase of ·01 per cent of phosphorus raises the tensile strength of acid steel about 890 lbs. per square inch, and basic steel about 1,050 lbs."

(5) "The following formulæ will give the ultimate strength of ordinary open-hearth steel in pounds per square inch, the carbon, manganese, and phosphorus being expressed in units of ·001 per cent, and a value being assigned to R according to the conditions of rolling and the structure of the piece."

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* These are fully given in his work on "Structural Steel," to which reference must be made for further details than are here given.

Formula for Acid Steel.

" Ultimate strength = 38,600 + 121 carbon + 89 phosphorus + R."

Formula for Basic Steel.

" Ultimate strength = 37,430 + 95 carbon + 105 phosphorus + 8·5 manganese + R."

(6) " The metals from which these data were derived were ordinary structural steels, ranging from ·02 per cent to ·35 per cent of carbon, and it is not expected that the formulæ are applicable to higher steels or to special alloys."

(7) " A considerable difference may be found between steels which apparently are of the same composition, and which, as far as known, have been made under the same conditions."

(8) " In the case of acid steel, an increase in manganese above ·60 per cent will raise the tensile strength above the amount indicated by the formula, the increase being quite marked when a content of ·80 per cent is exceeded."

(9) " In steels containing ·30 per cent to ·50 per cent of carbon the value of the metalloid is fully as great as much lower steels, while the presence of silicon in such metal in proportions greater than ·15 per cent seems to enhance the strengthening effect of carbon."

Since all the foreign constituents in steel act in the same direction as carbon, it is evident that the freer the steel is from such ingredients the more carbon will be required to produce a definite amount of hardness.

The properties of steel are largely modified by the structure, which is dependent on heat and mechanical treatment as well as on chemical composition. This will be fully discussed later.

METHODS OF STEEL MAKING.

Steel can be made by several distinct methods.

(1) Directly from the ore.

(2) From malleable iron.

  α By heating to welding temperature with carbon (cementation).

  β By fusion with carbon.

(3) From pig iron.

  α By partial decarburisation. Puddled steel, Bessemer steel, by the original process.

  β By complete decarburisation and subsequent addition of carbon. Bessemer and Siemens steels.

CHAPTER XXI.

PRODUCTION OF STEEL DIRECT FROM THE ORE AND FROM MALLEABLE IRON.

PRODUCTION DIRECT FROM THE ORE.

Direct processes are not now in use. In the Catalan forge and similar furnaces steel was no doubt often produced, for if the iron was left long in contact with carbon, that element would be taken up and steel would result. It would, however, be impossible to produce metal of a uniform quality by such a process. Patents have been taken out for the direct production of steel by heating iron ore with charcoal or other carbonaceous matter in crucibles, and whilst, undoubtedly, steel can be made in this way, the results are so uncertain that they have never become practicable.

PRODUCTION FROM MALLEABLE IRON.

When malleable iron, either in the form of sponge or bar, is heated with carbon, that element is taken up and steel is produced.

The carburisation of bar iron is the process by which all steel was for a long time made, and is still the process by which much of the high carbon or tool steel is made. The process may be conducted in such a way as to yield solid bar steel, *i.e.*, without fusion of the product as in the cementation process still largely used, or to yield cast steel as in the manufacture of Wootz in India.

THE CEMENTATION PROCESS.

This process has been in use in Sheffield for considerably over a century, but its origin is unknown. Percy states that "it was well described by Reaumar in 1722 in his admirable treatise on the 'Art of Converting Bar Iron into Steel,'" and the furnaces he describes are essentially the same as those still in use in Sheffield.

Principle.—The principle on which the process is based is simply that if bar iron be heated for a long time to welding temperature with carbon, the carbon gradually travels into the bar, and thus the metal becomes carburised.

The Process.—The vessels in which the conversion takes place are called converting pots. They are of stone, about 4 ft. deep, 4 ft. wide, and 12 ft. long, or long enough to contain the bars to be cemented. They are usually made "of slabs of sandstone, obtained in the neighbourhood of Sheffield, which possesses the property of not cracking when heated slowly to a high temperature, and allowed to cool slowly. The slabs are united together with a mortar made of ground fireclay." Two of these pots are built up, one each side of a fireplace, and are supported on bricks so that the flame from the fire can pass freely under and round them, and thus heat them uniformly, and they are covered with an arched roof of brickwork, through which pass flues to carry away the products of combustion. At one end of the pots is a hole, by which trial bars can be withdrawn, so that the progress of the operation can be tested. The whole is covered with a brick stack.

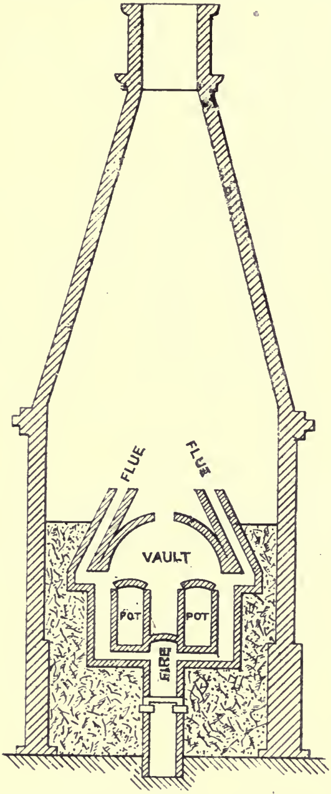

Fig. 112.—Section of Steel Converting Furnace.

Charcoal is broken up and carefully riddled through a sieve of about two to four holes to the inch to separate the dust, and a layer of the small pieces is spread on the bottom of each pot to the depth of about half an inch. On this is laid a layer of the bars to be converted, which are usually about 3 in. wide and ½ in. or so in thickness, placed a little apart, so that there may be a layer of charcoal between them. On this is put another layer of charcoal, then another layer of bars, and so on till the pot is full, each pot holding up to 30 tons of iron. The pots must be made airtight, or the carbon would burn away and the iron become oxidised. In Sheffield the covering material is "wheel swarf," a mixture of finely-divided steel with siliceous sand, the mud which accumulates in the troughs of the Sheffield grinding wheels. This is spread over the top of the pot. As the temperature rises the metal partially oxidises, the oxide combines with the silica, forming a very difficultly fusible silicate, which frits or binds the whole into a solid mass.

The fire is lighted and the temperature brought up to full redness, or about welding temperature. This occupies about two days, and the temperature is steadily maintained at this point for from seven to nine days, according to circumstances. The more carbon it is intended that the iron should take up the longer will the process take. When the carburisation has gone sufficiently far—this being judged by the condition of the trial bars which are withdrawn for examination—the fire is withdrawn and the pots are let cool slowly, this occupying another week, when the pots are opened and the charge is withdrawn, the bars being broken subsequently and the fracture examined. The whole process occupies about three weeks, so that about 15 or 16 charges can be worked in the same furnace each year, and each pair of pots may be used from 20 to 40 times before they have to be replaced.

The Products.—The charcoal has been partially consumed, a good deal of fine powder is produced, and the remainder is apparently unchanged. It is sifted and used again.

Fig. 113.—Steel Converting Furnaces.

The bar iron has undergone several changes :

(1) It has increased in weight by about one per cent or so.

(2) The bars, which when placed in the pots were quite smooth, have become rough, and the surface is dotted with blisters, whence it is called "blister steel." These may vary in size from that of a pea up to 1 in. in diameter. Small, uniformly distributed blisters are held to indicate a good, and large, irregularly distributed blisters an inferior steel.

(3) The appearance of the fracture has changed. Before the operation commenced the fracture was that of malleable iron, bright and crystalline; when it is finished the bar is wholly or partially converted into steel, and as the change goes on from outside inwards the conversion may, or may not, go right through. In the latter case the centre of the bar remains iron. The core of iron is called the "sap," and as the crystals are not as brilliant as in ordinary iron "the sap is said to be 'killed,' and no longer looks raw or stares."

The grades of steel usually made are :

No. 1.	Spring heat	½	per cent carbon.
,, 2.	Country heat	⅝	,, ,,
,, 3.	Single shear heat	¾	,, ,,
,, 4.	Double shear heat	1	,, ,,
,, 5.	Steel-through heat	1¼	,, ,,
,, 6.	Melting heat	1½	,, ,,

or, as given by Mr. Flather in a paper read before the N.S.I. in 1901 :—

Die temper	·7	per cent carbon.
Safe ,,	·85	,, ,,
Chisel ,,	1·00	,, ,,
Large turning tool temper	1·15	,, ,,
Turning tool ,,	1·25	,, ,,
Saw file ,,	1·35	,, ,,
Razor ,,	1·50	,, ,,

Prof. Arnold states*: "Cemented bars are usually classed into six grades (Nos. 1, 2, 3, 4, 5, and 6), and glazed or doubly-converted bar which might be called No. 7," but that since the introduction of mild steel No. 1 is not made. These are distinguished by the depth to which the conversion has gone or the amount of sap which is left.

In No. 1 only the outer skin "is converted into steel; in No. 2 the crystals of steel have become more distinct, and the sap is more 'killed.' 'In single shear heat the fracture shows more steel on the outside and less iron in the centre, until in double shear heat the fracture shows about equal proportion of iron and steel,'" and "in a steel-through heat, as its name implies, all trace of iron in the fracture has been lost, but the crystals of steel are small. A short time longer in the furnace will make the steel a melting heat, the crystals will be large, and in exceptional cases the facets will reach across the bar."†

The line of demarcation between the steel and the sap should not be sharp, but the one should pass gradually into the other. A sharp line of demarcation indicates that the process has been carried on too rapidly, "and the bars of steel so converted are said to be 'flushed.'"

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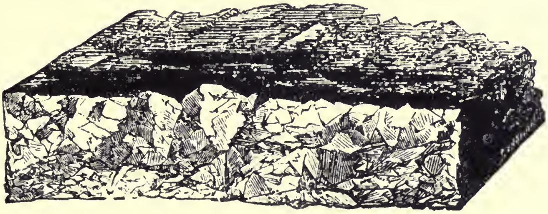
*I. and S. I., 1898. † Seebohm.

The dangers of accident to the metal are several. "Sometimes the pots crack; air is admitted to the furnace, the charcoal is burnt, and in bad cases even the iron is oxidised." Bars which have thus missed conversion are technically said to be "aired," and even when very slightly affected may easily be discovered in consequence of their having lost the tendency to become rusty. If the furnace be rasied to too high a heat, the surface of the bars will melt, and when they are drawn it will appear glazed. There are even instances handed down by tradition in Sheffield of unskilful converters who had heated the furnace under their care to such a degree that the whole mass of iron and charcoal had become fused together, and the end of the furnace had to be taken out to remove the contents."*

Fracture of Blister Steel.—Shear Heat.

Fracture of Blister Steel.—Spring Heat.



Fracture of Blister Steel.—Melting Heat.

Fig. 114—Fracture of Blister Steel.

Theory of the Process.—There are two changes to be accounted for: (1) The transmission of the carbon into the metal, and (2) the formation of the blisters. (1) As neither the carbon nor the metal have been melted it looks as if the solid carbon must

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* Seebohm.

have travelled into the solid metal. Whilst undoubtedly, under certain circumstances, solids can diffuse one into the other at high temperatures, such action is always slow—and the cementation of the iron can be accounted for in another way. The iron, it must be remembered, is not embedded in solid carbon. The charcoal being in small pieces, there are abundant air spaces, and even solid charcoal consists largely of spaces, so that the iron is really surrounded by air and charcoal. As the temperature rises the carbon will combine with the oxygen of the air, forming in presence of excess of carbon, and at a high temperature carbon monoxide $C + O = CO$. At high temperatures iron is porous to carbon monoxide, so that diffusion will at once begin, the carbon monoxide distributing itself through the metal. As soon as it comes in contact with the iron it is—partially at any rate—decomposed. carbon being deposited, and carbon dioxide formed. $2\,CO = CO_2 + C$. The carbon dioxide will then diffuse, and that which comes out of the iron into contact with the carbon will be at once reconverted into carbon monoxide, which will be ready to start the process over again. Thus the carbon may be transferred from the outside to the iron, not by solid diffusion, but by chemical change and gaseous diffusion. The outer skin of the metal thus becomes carburised first, and the action goes on gradually inwards. At any point where the carburisation is not complete there will be a double action, a stream of carbon monoxide diffusing inwards tending to deposit carbon, and a stream of carbon dioxide diffusing outward and tending to take up carbon, so that when there is equilibrium. the two will balance and carbon will neither be deposited or removed. As the action goes on this neutral zone will move gradually inward till the bar is converted through. At welding temperature the carbon enters into combination with the iron, thus converting the metal into steel and altering its whole structure.

Prof. Arnold has recently made a microscopic study of the cementation process, the results of which throw much light on the way in which the changes take place. He took a bar of Swedish iron and converted portions of it to the different grades, the mean percentage of carbon in the cemented samples and the structure being—

Bar iron ..	·05.	
No. 2 bar ..	·45	fairly uniform throughout.
,, 3 ,, ..	1·13	three distinct layers.
,, 4 ,, ..	1·33	three ,, ,,
,, 5 ,, ..	1·60	two ,, ,,
,, 6 ,, ..	1·80	practically uniform.
Glazed bar ..	1·70	fairly uniform.

The carbon percentage gradually increases from the outside of the bar to the centre, though not always uniformly, and it sometimes happens that, owing to slight "airing," the outer layers contain less carbon than those a little below. The mass of the iron is, of course, originally pure ferrite, which gradually becomes converted into the carbide, Fe_3C (cementite), which ultimately becomes arranged in regular layers with the ferrite, forming pearlite, and an "attenuated carbide or eutectic alloy corresponding to the formula $Fe_{24}C$." The steel area gradually grows inward, and ultimately, when No. 6 bar is reached, the carbon is almost uniform throughout the bar, the structure consisting of masses of pearlite enveloped in somewhat dark membranes of cementite.

Prof. Arnold seems to think that carbides are first formed, and that these diffuse or interpenetrate into the metal. He sums up his results :—

"1. That the diffusion of carbon in the process of cementation presents two distinct varieties of interpenetration.

(*a*) The interpenetration of the substance corresponding with the formula $Fe_{24}C$ and pure iron.

(*b*) The interpenetration of the normal carbide Fe_3C and the subcarbide $Fe_{24}C$.

2. That the interpenetration of $Fe_{24}C$ and iron is more rapid and takes place at a lower temperature than the interpenetration of $Fe_{24}C$ and Fe_3C.

3. (*a*) That the interpenetration of $Fe_{24}C$ begins at A_r2 (about 750 deg. Cen.), and is coincident with the evolution *in vacuo* of gases from the iron.

(*b*) That the interpenetration of $Fe_{24}C$ and Fe_3C does not take place till a temperature of about 950 deg. Cen. has been reached.

The above results seem to indicate that it would be possible to convert iron up to the saturation point (·9 per cent carbon) at a temperature of, say, 800 deg. Cen., but that it is not possible to produce supersaturated high number bars unless the temperature of the chest be kept (as is the case in practice) at about 950 deg. Cen."*

The Blisters.—The blisters on the surface are hollow, and are, therefore, presumably formed by the pressure of enclosed gas ; they are only at the surface, and there are no corresponding cavities in the body of the metal. The blisters are undoubtedly due to the presence of minute specks of solid impurities, mainly oxide of iron, in the metal ; for if a metal such as mild steel, which has been melted, be converted, no blisters are formed, whilst, as has been already pointed out, such particles are always abundant in malleable iron. If the iron has been well worked so that the particles are broken up and are uniformly diffused, the blisters will be small and evenly distributed ; but, if it has not been well worked, the particles will be larger and less evenly disseminated and the blisters will be fewer and larger. The action may be as follows : Assuming the existence of a speck of oxide or silicate of iron in the mass of metal, carbon is deposited in contact with it, the oxide of iron is reduced and carbon monoxide is evolved. As the gas will occupy an enormous volume

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* I. and S. I., 1898.

compared with that of the solids from which it is formed, it will exert a very great pressure, but as the mass of metal is too strong to yield the gas can only exist under pressure till it slowly diffuses away. If, however, the same action takes place near the surface the thickness of metal will be insufficient to resist the pressure, and a blister will be formed. Mr. Hogg* states that he has frequently examined the interior of the blisters under a low degree of magnification, and has almost always found globules of slag or glassy material. The gas may, therefore, be evolved, not by the reduction of ferric oxide to metal, but by the reduction of a portion of the oxide existing in a basic silicate. Whether this is the exact method of their production or not, it seems certain : (1) That the blisters are due to the evolution of gas. It is evident that the gas must be evolved in the metal, no diffusion being able to produce blisters ; and (2) that evolution of the gas is determined by the presence of intermixed particles of iron oxide or similar impurity.

Shear Steel.—The blister steel thus obtained is to a large extent converted into shear steel. The process is thus described by Dr. Percy :—

" Bars of blister steel are broken into pieces about 10 in. long, and drawn out at a red heat under the hammer to the width of about 1½ in. and the thickness of about ½ in. Several bars thus obtained are piled on one another, and the end of the pile is firmly wedged into an iron hoop with a handle attached to it. The free end of the pile is raised to a welding heat in a hollow coke fire, during the process being dusted over with finely powdered clay, welded under the hammer, and reduced to 2 in. square. The hoop is now detached from the other end of the bar, and this end is treated in exactly the same manner as the first end. In this state it is termed ' single shear steel.' It may be broken into two equal parts, which may again be welded together and drawn out to any required dimensions to form ' double shear steel.' The dusting with clay is intended to prevent superficial oxidation, and consequent decarburisation as far as practicable."†

" The name (shear steel) was given it because it was the kind used for the blades of shears formerly employed for cropping woollen cloths."‡

CRUCIBLE CAST STEEL.

For a long time the only cast steel was that made directly by the fusion of iron with charcoal. Shear steel is, from the method used for its production, necessarily more or less heterogeneous, and a more homogeneous metal was urgently needed, but casting was attended with considerable difficulties. These were overcome by Benjamin Huntsman, of Sheffield. Like most great metallurgical inventors, he was not connected with the trade ; he was, in fact, a

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* I. and S. I., 1896, page 323.

† Metallurgy of Iron and Steel, page 859.

‡ The Useful Metals and their Alloys, page 345.

watchmaker, and the poor quality of the springs obtainable seems to have led him to turn his attention to the production of steel. His experiments were made at Handsworth, near Sheffield, and the exact date when he attained success is not known, but about 1770 he removed the business to Attercliffe. His steel soon acquired a very high reputation. The process as at present carried out in Sheffield differs very little from that used by Huntsman, and consists of melting the steel in crucibles and pouring it into moulds.

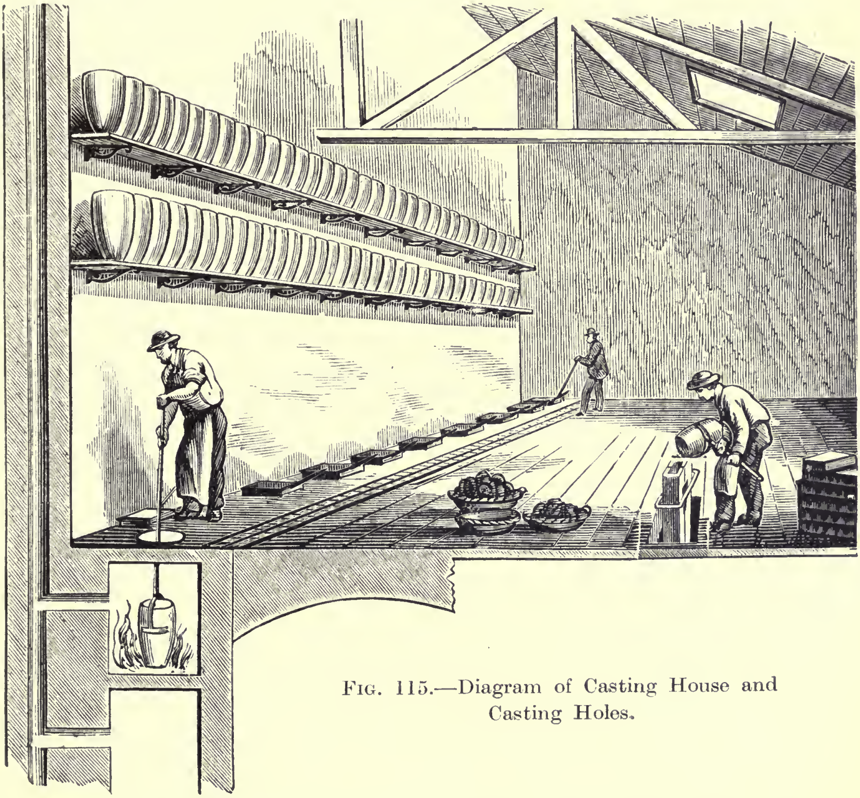

Fig. 115.—Diagram of Casting House and Casting Holes.

The Furnace.—The furnaces almost universally used are coke-fed crucible furnaces, or melting holes, those used in Sheffield being made to hold two pots. They are oval chambers, 26 in. by 19 in., and 3 ft. deep from the top to the bars. They are lined either with firebrick set in fireclay or with ganister rammed round a core. As the pots, which have to be lifted, are heavy, the floor of the melting house is made level with the top of the furnaces, the ashpits, &c., being underneath, and access being provided to them by means of a cellar. In the older works each furnace had its own chimney; now they usually all unite with one main flue, the draught being regulated by dampers or, more simply, by inserting a brick in the flue. Four-pot holes have been tried, but abandoned, and in America anthracite-fed furnaces are sometimes used, 30 in. broad and 3 ft. 7 in. deep, worked with closed ashpits and a blower.

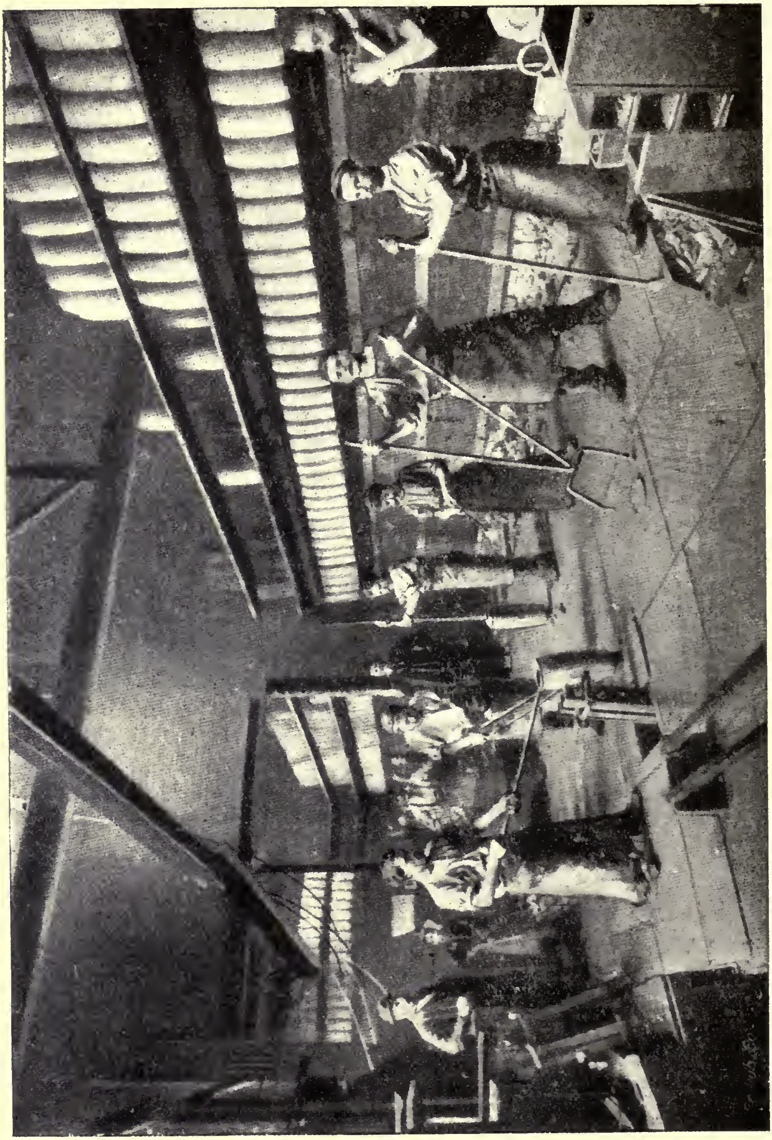

FIG. 116.—Crucible Furnace Department at the Works of Messrs. Thos. Firth and Sons Ltd., Sheffield.

Gas-fired furnaces have been tried. Indeed, steel melting in crucibles was one of the first purposes for which Siemens used his regenerative furnace. A furnace arranged for this purpose is shown in Fig. 117. The principle will be fully dealt with under the Siemens steel process. The gas furnace uses much less fuel than the coke furnace, but it has not come largely into use.

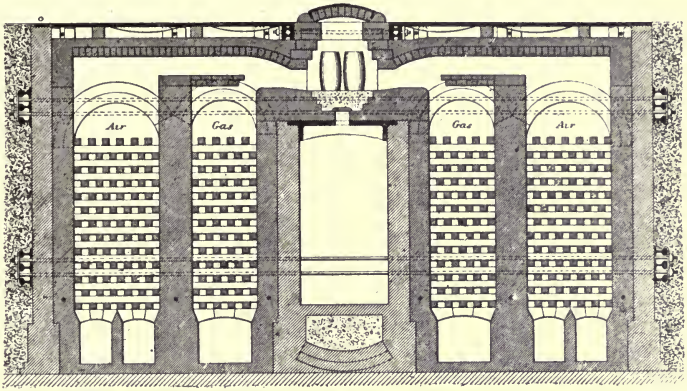

Fig. 117.—Siemens Crucible-steel Furnace.

The Crucibles.—Either clay or graphite crucibles may be used, but in this country the former are still almost universal. They are made in the works, and each maker has his own favourite clay mixture. The crucibles may be made by hand or machine, but the former method is almost always used.

Hand-made pots are made in cast-iron moulds, the interior of which has the form which is to be given to the outside of the crucibles. It is open top and bottom, the interior is turned and polished, and it is provided with two handles for lifting. A plug of hard wood—lignum-vitæ, or similar—turned to the form which is to be given to the interior of the pot, and provided with a projecting pin at the bottom and a head at the top, on which it can be hammered, is used as a core. The bottom of the mould is closed by a loose plug of iron just large enough not to drop out, and in the centre of this is a hole to receive the projecting pin of the plug or core.

Various mixtures of clay are used. Mr. Seebohm says a mixture of Burton and Stannington clay, to which is sometimes added a little Stourbridge clay, and, if the pots are required to stand a great heat, some china clay from Devonshire ; a small quantity of ground coke and old pots is also added. Dr. Percy gives a mixture used at one works as being—

Derbyshire clay from Edensor	15 lbs.
Stanniugton clay	7 lbs.
Old ground pot	2 lbs.
Ground cinders	1 lb.
	25 lbs.

The clay is thoroughly mixed and tempered by treading with the bare feet.

The pot mould is well oiled, placed upon a solid support, and the necessary amount of clay, made up into a ball, is put in. The plug, also well oiled, is then put down, and driven in by blows from a mallet, the projecting point keeping it central. The clay rises round the plug, and the excess is cut off round the top of the mould with a knife. The core is then taken out, the top of the pot narrowed a little by running a tool round between the clay and the mould, and the pot is forced out by gently pushing the iron plug at the bottom of the mould, and is set aside to dry. Lids are made of the same clay as the pots. The hole in the bottom of the pot is not stopped.

The pots hold about 50 lbs. of metal. They are used three times, the charges being 50 lbs., 44 lbs., and 38 lbs., the reason for the variation being that the pot is corroded most just at the surface of the metal, and if this were at the same point always the pot would be cut through so far that it would be weakened, and would very likely give way when it was lifted from the furnace.

The pots are dried in the melting house for 30 or 40 days, and are heated to redness, or annealed for some hours just before use, in an annealing furnace.

The Melting.—The fire in the melting hole being low, two pots, with covers, are put in upon fireclay stands or bricks, and a fire is made up with coke. When the pots are white-hot—if hand-made pots are being used—a little sand is thrown in, which frits the pot to the stand, and thus closes the hole at the bottom, and the metal is put in.

"The bar steel is first carefully selected of the exact temper required, all flushed or aired pieces are rejected, and, after it has been broken up into small pieces and carefully weighed, it is put into the pot" through an iron funnel called a charger. The lid is carefully adjusted, and the melting hole is filled up with coke. The operation consists of two stages—melting and killing.

Melting.—The coke burns away very rapidly, so that in about an hour the first fire will have burned off; the coke is poked down, and more is added. When it is judged that the charge is melted, the lid is removed and the charge is examined, the greatest care being taken that no coke falls in. The regulation of the temperature is also very important, and this can be judged by the appearance of the metal. As the operation goes on, the fire is made up from time to time. When the melting is complete, which will take from two or three hours, the charge looks like slowly-boiling porridge, and bright specks, probably of metallic iron, may be seen on the upper surface of the slag.*

If the metal were poured now it would yield unsound castings full of blowholes, and, to prevent this, the steel is kept melted some time longer, till it is "killed" or "dead melted."

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* Howe "Metallurgy of Steel," page 304.

If the killing be too prolonged the metal teems "dead," pours very quietly, and yields solid, but hard and brittle ingots, wanting in tensile strength. "It is very doubtful whether moderate over killing, say, of 15 to 20 minutes more than is actually necessary, produces an appreciable effect."*

The time taken for the killing varies very much. Howe gives from 30 to 60 minutes as being the most usual time. "In general, the hotter the furnace the shorter the killing may be. It is the nearly, if not quite, universal belief of steel makers that the better the steel, *i.e.*, the freer from phosphorus, &c., the longer killing does it need."†

Three or four heats are worked in each furnace per day.

When anthracite is the fuel used the pots do not rest on supports but are set high up in the fuel, which slowly burns down, carrying the pots with it, and the fire is not disturbed during the process.

Teeming.—The puller-out protects his arms and legs with sacking soaked in water, takes the lid off the pot, lifts the pot with a "lifting-out tongs," which grip the middle of the crucible, skims off the slag, and at once pours the metal into the mould. The stream of molten metal must not be allowed to touch the side of the mould, or it may melt it. The pot is examined, and, if sound, returned at once to the furnace. Graphite pots are often allowed to cool before being examined for re-use.

If large castings are to be made, several or many pots of steel may be required, and the teeming of the second must be commenced before that of the first is finished, so that there may be no break in the pouring; and this, of course, necessitates that all the pots shall be dead melted at the same time, or all the metal may be poured into a ladle and thence delivered to the mould.

The moulds for small ingots are usually made in two halves, held together by rings and keys. Before use they are smoked by burning resin, coal tar, or similar substance.

Crucible steel casting depends largely on the individual judgment of the "puller-out," and "one of the principal reasons why the industry has been to such a remarkable extent localised in Sheffield is the importance to this branch of the trade of being able to select from a large class of more or less experienced workmen the few exceptional men in whom sound judgment, technical skill, and steady habits are combined."‡

Loss, &c.—The loss of metal is very small, 2 per cent or less (according to Howe), and rather less with graphite than with clay crucibles.

Physics.—Many attempts have been made to improve the quality of the steel by the addition of physics. "It has ever been the darling dream of the Sheffield steel maker to discover some

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* Howe "Metallurgy of Steel," page 305.

† ,, ,, ,, ,, 305.

‡ Seebohm.

substance—some philosopher's stone—which will transmute *common* cast steel into *best* cast steel. The various substances used in the melting of cast steel, and supposed to have a chemical effect upon the material melted, are known by the technical name of 'physic.'

"The most generally used of these is peroxide of manganese, mixed with a little ground charcoal. Common salt, rock salt, sal-ammoniac, chlorate of potash, prussiate of potash, and even ground fluor spar and broken glass form ingredients of the physic used by some steel makers."*

Chemistry of the Process.—Though the process is essentially one of melting, chemical changes also take place. There will always be some oxide of iron on the metal, and there is air in the pot the oxygen of which will form oxide of iron; and this will attack the silica of the pot forming silicate. At first the silicate may be basic, and thus have a purifying influence by acting as an oxygen carrier, but as the action goes on it becomes more and more acid, and its action may cease, or at any rate become less marked.

The metal, too, is in contact with the clay, from whence it may derive silicon; and carbonaceous matter, either coke or graphite, from which it may take carbon; indeed, if it did not, the carbon would be reduced by melting. The composition of the metal may therefore be changed somewhat. Unless the temperature be very high the silicon will be more ready to oxidise out than the carbon, but the extent of oxidation will depend on the proportions in which the elements are present. If the carbon be fairly high the silicon will be less removed than if it be lower. The presence of manganese also may tend to prevent the removal of silicon, by oxidising first, and thus tending to use up all the available oxygen. The result of the melting is almost always to increase the percentage of carbon and silicon present, and, unless manganese be added, to reduce the manganese. The amount of sulphur also increases slightly either from pyrites in the clay or from the furnace gases.

The nature of the change which takes place in "killing" has been much discussed. The freshly-melted metal teems "fiery," and yields an unsound casting, the unsoundness being due to the evolution of gas during cooling. The killed metal teems quietly, and yields sound castings.

It has been suggested that the killing may be due to the evolution of gas. This is not likely. The escape of gas has not been noted, and the gas in solution is given off when the metal cools, not when it is kept melted. Howe says: "Killing probably acts chiefly through enabling the metal to absorb silicon from the walls of the crucibles, thus increasing its solvent power for gas, and thus enabling it to retain in solution during solidification the gas which it retains when molten. The common belief is that killing expels the gas which is present, so that less remains to escape during solidification. But, in the first place, we find that silicon is absorbed rapidly during the killing, and we have already seen that silicon seems to

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* Seebohm.

prevent blowholes by increasing the metal's solvent power for gas. In the second place, when the conditions are such that the metal cannot absorb silicon, holding the metal molten this way does not kill it, *i.e.*, does not cause it to solidify without blowholes."*

If the killing be too prolonged, too much silicon is taken up, and this element hardens the steel.

The reader desiring fuller information, should refer to Howe's "Metallurgy of Steel," where he will find an immense mass of experimental data. The following tables† will indicate the effect of killing. The crucibles used were made of 30 per cent clay, 50 per cent burnt clay, and 20 per cent coke:—

	C.		Si.		Mn.		S.		P.	
	%	%	%	%	%	%	%	%	%	%
The charge contained	·23	..	·12	..	·74	..	·03	..	·223	..
Immediately after complete fusion.	·38	..	·10	..	·36	..	·04	..	·223	..
Loss or gain.	..	+ ·15	..	– ·02	..	·38	..	+ ·01	..	0
45 minutes after fusion	·44	..	·12	..	..	..	·04	..	·224	..
Loss or gain.	..	+ ·06	..	+ ·02	..	..	..	0	..	+ ·001
90 minutes after fusion	·50	..	·25	..	..	..	·046	..	·224	..
Loss or gain.	..	+ ·06	..	+ ·13	..	..	..	+ ·006	..	0
135 minutes after fusion .	·53	..	·30	..	·38	..	·051	..	·224	..
Loss or gain.	...	+ ·03	..	+ ·05	..	+ ·02	..	+ ·005	..	0
Total loss or gain	..	+ ·30	..	+ ·18	..	+ ·36	..	+ ·021	..	+ ·001

TREATMENT OF THE INGOT.

The size of the ingot cast will, of course, depend on the purpose for which it is to be used. About 3 in. square is a common size.

When the ingot is cold the ends are broken off, as they are apt to be unsound, and the melter judges the quality of the "cast" from the fracture.

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* "Steel," page 304.

† Howe, "Steel," page 312.

Wash Welding.—The ingot is heated to welding temperature, and the surface is covered with a flux to protect it from oxidation, fire clay, borax, or fine sand being usually used, and is at once worked down under the hammer into bars. If bars larger than $\frac{5}{8}$ in. are required, they may be completed at one hammering. If not, the ingot is hammered to billets about $2\frac{1}{2}$ in. × $1\frac{1}{2}$ in. The ends of these are broken off, the fracture is examined, and the billets are re-heated and rolled down to the size required.

The exact temperature of working is very important as high carbon steels are only malleable through a short range of temperature.

Cold Drawing—The metal having been rolled into rods, or strips, these are pickled in acid and then in lime-water, to remove the traces of acid, and are heated to about 400 deg. Cen., to expel occluded hydrogen, and are then drawn down cold. As the working hardens the metal, repeated annealing is necessary.

Manufacture of Steel in Crucibles by Carburisation of Malleable Iron.

Steel has been made in India and elsewhere by this process for a very long time, and though now almost extinct, it is still carried on in one or two districts.

Wootz.—The steel known as Wootz, which was at one time largely imported from India for the manufacture of various cutting tools, was made by this process. The method of manufacture has been described by several observers, and, while the details of work no doubt varied considerably in different districts, the principle was always the same.

The process at as present carried on in the Trichonopoly district was described in the *Indian Engineer*.* Small pieces of wrought-iron, together with a few pieces of wood and some green leaves, are enclosed in a crucible, 5 in. long by 2 in. diameter at the top, made of a mixture of red earth and paddy-husk charcoal ; a cover is luted on, and the pots are heated in a small charcoal furnace till the iron is melted, which is ascertained by shaking the crucible. The pots are allowed to cool, and are then broken, when a knob of steel is found in each.

The furnace is an inverted cone of earth, 2 ft. in diameter and the same in depth ; the apex of the cone opens below into an ashpit, and air is supplied by two men working skin bellows. Each furnace holds 25 crucibles, and the process takes about $1\frac{1}{2}$ hours. The crucibles are not very refractory, and can only be used once. The iron used is a crude wrought iron. The steel can be remelted and poured, and is then cast into ingots of suitable size, usually weighing either 8 oz. or $10\frac{3}{4}$ oz., and these ingots are re-heated and hammered. For an 8 oz. ingot about 10 oz. of iron and $\frac{3}{4}$ oz. of wood are used. The outupt of India is at present about 28,000 lbs. annually.

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* J. I. and S. I., 1889.—1—p. 339.

As the process is described by Dr. Buchanan (1807), the wood is said to be that of *cassia auriculata* and the leaves those of a species of *convolvulus* or *ipomœa*.*

Prof. Wedding gives the following analysis of a sample of Indian Wootz (No. 1), and No. 2 is an analysis by Henry, given in Dr. Percy's "Iron."†

	1.		2.
Carbon (comb.)	·33	....	1·333
,, (uncomb.)	—	....	·312
Silicon	·08	....	·045
Sulphur	·01	....	·181
Arsenic	—	....	·037
Copper	·01	....	—
Chromium	·07	....	—
Iron (diff.)	99·50	....	98·092
	100·00	....	100·00

As might be expected, the composition of a metal made in this way will vary very much.

Prof. Wedding says that the structure of his sample was very interesting. It showed hollows containing some carbon and some slag, and also bright, worm-like streaks of hard metal, probably high carbon steel which had become fused during the treatment, and two other varieties of metal were also distinctly discernible. Part of the silicon in the analyses is probably due to intermixed slag.

Mushet's Steel.—In 1800, David Mushet took out a patent for a process of a similar character. It consisted in fusing bar or scrap iron, or rich pure iron ore, in crucibles with the proper proportions of carbonaceous matter, and, as pointed out by Dr. Percy, the process is identical with that used by the Hindoos for the manufacture of Wootz.

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* Percy's "Iron," page 775.

† Page 775.

CHAPTER XXII.

METHODS OF PREPARING STEEL BY THE PARTIAL DECARBURISATION OF PIG IRON.

It is frequently stated that steel is intermediate between pig iron and malleable iron, and, though this statement is manifestly incorrect, it has led to many methods of steel making which have proved failures, or, at any rate, have been found to be only available under a very limited set of conditions.

The carbon content of steel is almost invariably between that of pig iron and malleable iron, but some steels made by modern processes are lower in carbon than some malleable irons. An average steel, containing from ·5 to 1·5 per cent carbon, is certainly between malleable iron with ·2 and pig iron with 2·5 per cent, and, therefore, if pig iron contained only iron and carbon, it might be practicable to convert it into steel by partial decarburisation, though, even then, there might be difficulty in obtaining metal of perfectly definite carbon content. Pig iron is, however, not a pure carbide, but always contains considerable quantities of other impurities, so that, as a rule, such a method is impracticable. If, however, a pig iron be selected containing but small quantities of other impurities, such as silicon and phosphorus, and the process be so conducted that these are sufficiently removed before the carbon is unduly reduced, such a method may be practicable. The only pig iron really suitable for such a purpose is Swedish cold blast iron, which often contains not over 1 per cent of silicon and only traces of phosphorus, sulphur, and other deleterious impurities ; but fair steel has been made from other qualities of pig under suitable conditions.

The cementation process is so costly that, prior to the introduction of the modern mild steel processes, there were great inducements to discover other methods. Of the many partial-decarburisation processes that have been suggested only one or two need be mentioned.

Puddled Steel.—A consideration of the method of producing malleable iron by puddling will at once suggest the possibility of making steel by a similar process, for, if the process were stopped at an intermediate point, a steel would result the character of which would depend on the nature of the pig iron used, and the point at which the process was stopped.

Puddled steel seems to have been made in Carynthia about 1835, and was introduced into this country about 1858. For a time the process was used to a considerable extent at the Ebbw

Vale Works, and the best description of it is that of Mr. Parry, of that works,* which is largely quoted by Dr. Percy in his description of the process.

The pig iron used at Ebbw Vale was the same as that used for making malleable iron, and the ordinary puddling furnaces were used.

"The usual charge is from 4 cwt. to 4½ cwt. of good bright grey or low dark grey pig iron, which is melted at a pretty strong heat, after which the temperature must be reduced so as to retain the molten metal of the consistency of thin cream. While in this state it should be diligently stirred with a rabble, and well mixed with the cinder previously introduced, and which need not exceed the quantity commonly used in puddling iron. Boiling takes place owing to the escape of carbonic oxide, produced by the combustion of the carbon of the molten metal at the expense of the oxygen of the oxide of iron in the cinder. If the heat be too high, and the metal, in consequence, extremely liquid, the mixed cinder and metal immediately separate from each other after the operation of rabbling and decarburisation. This proceeds slowly compared with what occurs when the cinder and metal are rabbled in a plastic or less liquid state. If, on the other hand, the temperature be too low and the metal, in consequence, too stiff, the cinder cannot be equally intermixed, and the steel will not be homogeneous. In a short time the effervescence from being sluggish becomes very vigorous, and, if a portion of the metal be withdrawn from the furnace at this stage, its fracture, when cold, will be silvery white, the whole of the carbon being in the combined state. The temperature of the furnace may now be raised, but not so high as in puddling iron, and continued until incipient solidification occurs, which will be indicated as usual by the appearance of floating granules. It must then be reduced to about a full yellow heat, and the process of balling and finishing the charge may be proceeded with in the ordinary manner. If the temperature during the last stage be kept too high, either iron, or steel containing too little carbon, will be obtained."†

It will be seen that the metal does not "come to nature," because, owing to the removal of the carbon, it becomes infusible at the highest temperature attainable, as in puddling iron, but the temperature must be so regulated that the metal will solidify with the right amount of carbon. The success of the operation depends therefore almost entirely on the proper management of the temperature, and this requires a large amount of skill and experience. The harder the steel, the lower must this finishing temperature be, and the shorter the boil therefore the greater the difficulty in successful working.

The slag must be kept very fusible, or, owing to the lower temperature of working, it may be difficult to separate it from the

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* Proceedings of South Wales Institute of Engineers, 1863.

† Percy, "Metallurgy of Iron," page 794.

metal; indeed, for this reason puddled steel usually contains more intermixed impurities than malleable iron. As the process is shorter, the slags tend to be silicious and infusible, and, therefore, basic fusible slags must be added to the charge. Mr. Parry suggested the use of borax, but this would be very expensive.

As remarked above, determining the end of the process must depend almost entirely on the personal skill and judgment of the workman, there being no definite change to mark it, and it is therefore difficult, if not impossible, to produce metal, charge after charge, of uniform composition.

Ordinary pig iron, not too high in silicon, was usually used at Ebbw Vale. It will be remembered that in puddling the silicon is removed in the early stages of the process more rapidly than the carbon. The harder the steel to be made the lower must be the silicon in the pig iron. The phosphorus will be only partially removed, so the amount present in the pig must not be too high, and sulphur must be absent. The presence of manganese is very advantageous, since it forms a very fusible slag and facilitates the removal of silicon and also of sulphur. Percy states that speigeleisen (with not less than 4 per cent of manganese) answered admirably.

Parry gives the following analysis of a pig iron and a puddled steel made from it * :—

	Pig.	Steel.
Carbon	2·680	0·501
Silicon	2·212	0·106
Sulphur	0·125	0·002
Phosphorus	0·426	0·096
Manganese	1·230	0·144
Iron (difference)	93·327	99·151
	100·00	100·00

The slags are almost identical with those produced in puddling malleable iron.

Greenwood states that the puddling furnace used for making puddled steel has a smaller bed than that used for malleable iron, and as the other parts are the same size the ratio of the area of the grate to that of the hearth is larger, and also that the temperature is kept higher during the melting stage than in puddling iron.

Puddled steel is not now made.

Hearth Processes.—Obviously the decarburisation might be carried on in a hearth as well as in a reverberatory puddling furnace, and hearths were used for the preparation of steel before the introduction of puddling. The hearths used were the same as those used in the manufacture of malleable iron, which have been already described, and were always charcoal fed. The process also was almost identical with that of making malleable iron, except that it

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* Percy's "Metallurgy of Iron and Steel," page 795.

was so adjusted that the necessary amount of carbon was left in the metal. The details of the processes differed in different districts, the best known forms being the Styrian and the Carynthian. These processes are probably now extinct. The great difficulty with them, as with puddling, was the production of metal of uniform quality.

The Uchatius Process.—This process was patented in 1855. It consists in partially decarburising pig iron by fusion with oxide of iron in crucibles. The pig iron was granulated by being run into water, and the granulated metal was mixed with about 20 per cent of washed pulverised spathic iron ore and 4 per cent of fireclay, and fused in clay crucibles.

The oxide of iron oxidised the silicon and carbon out of the pig iron, and the metal thus reduced increased the quantity of steel obtained, the increase of weight being, according to Percy, about 6 per cent. Spathic ore was recommended because it contained manganese, and the clay was added as a flux.

The process never came into use, partly, no doubt, because of the difficulty of securing uniformity and partly because the introduction of the Siemens regenerative furnace made melting in crucibles unnecessary.

The Heaton Process.—The difficulty in the ordinary decarburisation processes was to hit the exact end of the process, and, to overcome this, many inventors were led to the use of chemical oxidising agents, by which they thought they could secure a definite amount of oxidation and no more. The most important of these processes was that of Mr. Heaton. It was not successful in its original form, but within the last few years attempts have been made to revive it, the steel or iron made being afterwards finished in an open-hearth steel furnace. The attempt, however, does not seem likely to be attended with any degree of success.

The oxidising agent used was sodium nitrate (soda nitre). The requisite quantity of this was put in a ladle, which formed the bottom of a cupola-like furnace, and covered with a perforated plate of cast iron. The molten pig to be treated was then run on, the heat of the charge melted the iron cover, and when the molten iron came in contact with the nitre, a vigorous reaction took place, by which the iron was, to a large extent, decarburised. The resulting metal not being liquid enough to tap, the ladle-like bottom of the cupola was drawn away, and its contents emptied on to the floor. The metal, after solidification, was broken up and re-melted in crucibles, or, according to the modern form of the process, in a Siemens steel furnace. The objections to the process, in its first form, were the cost and the difficulty of obtaining a uniform product; the second difficulty is now of little importance, as the composition can be adjusted when the open hearth furnace is used, but the coat and trouble are so great as probably to render the process unworkable.

Decarburisation by Cementation.—A patent was granted to Samuel Lucas in 1804 for making steel by this method. Bars of cast iron were heated with oxide of iron (ironstone ore) or other suitable material for five or six days, and the resulting bars, which had become partially decarburised, were melted in crucibles for use. It will be seen that this process is identical with that used in making malleable castings.

Decarburisation by Blowing Air through Cast Iron.—In the Bessemer process cast iron is decarburised by blowing air through the molten metal. In the ordinary form of the process the carbon and silicon are completely removed, and the necessary amount of carbon for the steel is subsequently added in a suitable form. In the original process, however, which is still carried on on a large scale in Sweden, the process is not continued to the end, but is stopped so as to leave the necessary amount of carbon in the metal.

In order that this process may succeed, the purest pig iron only can be used. The Swedish pig, which is preferred, contains about 1 per cent of silicon, 2 to 4 per cent of manganese, 4 per cent of carbon, and very little sulphur or phosphorus. Steel containing from ·25 to 1·5 per cent of carbon is regularly made in large quantities. It is usually cast into large ingots, which are subsequently re-melted for use. It is impossible to make a steel by this process milder than about ·25 per cent carbon, as when the carbon is reduced below this, oxygen is absorbed, and the metal becomes rotten.

The plant used, and the details of working, will be more fully described when the principles of the Bessemer process have been discussed.

CHAPTER XXIII.

THE BESSEMER PROCESS.

The removal of the impurities from pig iron in the puddling and similar processes, for the production of malleable iron and steel, is brought about by the oxygen of the air, the oxide of iron in the slag acting as an oxygen carrier. The resulting metal is obtained in a pasty condition, and necessarily, therefore, contains intermixed foreign material. In the early fifties it struck Mr. Henry Bessemer that a better result could be obtained by blowing air through molten pig iron, the metal being kept in a liquid condition to the end of the process, thus ensuring homogeneity and the absence of intermixed foreign matter, and at the same time bringing about the required result more quickly.

Bessemer's first patent was taken out in 1855 (October 13th, No. 2,321), and this was rapidly followed by others as modifications and improvements of the process were devised. The process was first made public in a paper read by Bessemer before the British Association at its meeting at Cheltenham on August 13th, 1856.*

After years of untiring industry, patience, and skill, and the overcoming of enormous practical difficulties, and great prejudice and opposition, the process was made thoroughly practical, and was first carried out on a manufacturing scale at the works which Bessemer started in Sheffield.

The process, as worked by Bessemer at Sheffield for the first two years, was for the production of tool and similar high carbon steel by the partial decarburisation of Swedish pig iron. When the method of making very mild steel by the complete decarburisation of pig iron, and subsequent recarburisation by means of speigeleisen or ferro-manganese, was perfected, the demand for mild steel became so great that the older process was abandoned, and has never been resumed in this country, though it is still worked in Sweden.

The details of the process vary very much in different districts. It will, perhaps, therefore, be best to describe a simple form of it, and then to describe the modifications that have been suggested, the details of the plant used, and give an account of the historical development of the process.

The Principle.—The principle of the process is very simple. Molten pig iron is run into a suitable vessel, and a rapid stream of air is blown through it. Oxidation takes place very rapidly, oxidis-

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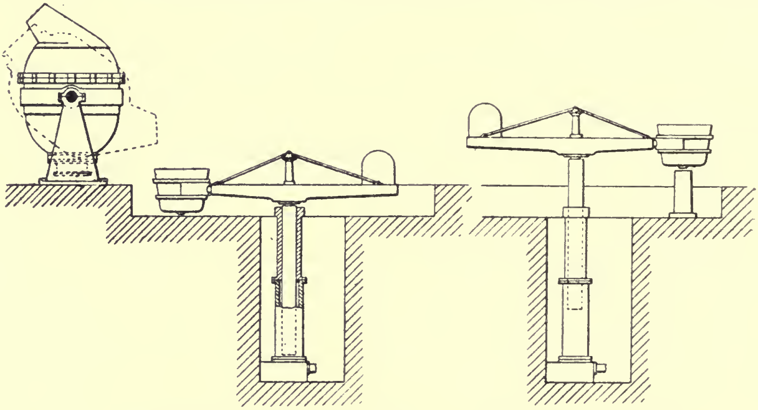
* The paper was judged of sufficient importance to be printed in "The Times" next day, and to be reprinted in the "Engineer," but it does not appear in the "Reports of the British Association."

able impurities are burnt out, the carbon and silicon are removed, and sufficient heat is evolved to keep the metal liquid, even after complete decarburisation, so that it can be poured directly into moulds. In his first experiments, Bessemer—not realising the enormous amount of heat evolved in the process—heated the vessel containing the iron externally, but this was soon found to be quite unnecessary.

Brief Outline of its Process.—The apparatus in which the decarburisation takes place is called the converter, or, in America, the vessel. The usual form is something like that shown in Figs. 118 and 119. It consists of a vessel of sheet steel, usually made in three parts, held together when in use by suitable catches, and is lined with ganister or some other very refractory material. The bottom of the lowest portion is an iron plate, through which openings are left for the insertion of the tuyeres, which are clay cylinders perforated with a considerable number of holes, and beneath this is the air chest, into which the air is blown. The top portion of the converter is usually bent over so that the mouth is not horizontal, to reduce, as far as possible, the loss by projection. The middle



Converting Vessel, Casting Ladle and Crane.

Casting Steel into Ingots.

FIG. 118.

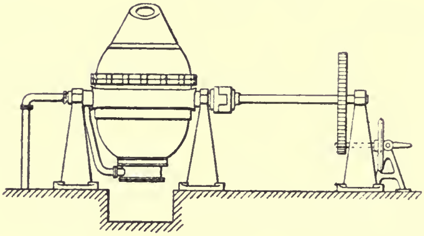


FIG. 119.—Front Elevation of Converting Vessel.

portion is nearly cylindrical, and round it passes a strong iron band —the trunnion band,—to which the trunnions, on which the converter rotates, are attached. To the one trunnion is attached turning mechanism by which the converter can be turned completely over. An air main passes up one of the supports, through the other trunnion and by means of a pipe to the air chest, the opening being so arranged that air can pass into the converter whilst it is rotating through 90 deg., *i.e.*, from a vertical to a horizontal position.

A cupola for melting the pig iron is provided in some suitable position. A ladle, capable of holding the whole of the charge, is carried on a rotating platform—the ladle crane—which can be lowered so as to bring the ladle under the converter or raised over the moulds. The ladle has a tap hole at the bottom, closed by a plug, which can be operated from outside, so that the metal can be run directly into the moulds. The moulds, which may be of any convenient size, according to the size of ingots required, are arranged in an arc of a circle of which the support of the ladle crane is the centre, and are usually sunk so that the tops of the moulds are about the level of the working floor. They are thus in the casting pit. Cranes for lifting the ingots, moulds, &c., are provided. The converter is operated from a platform, or pulpit, from which the process can be watched.

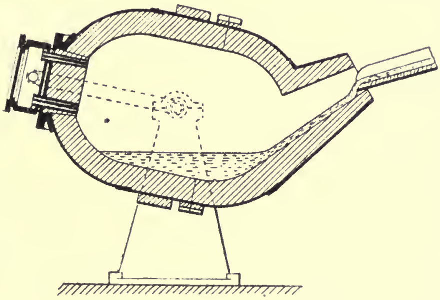


FIG. 120.—Filling.

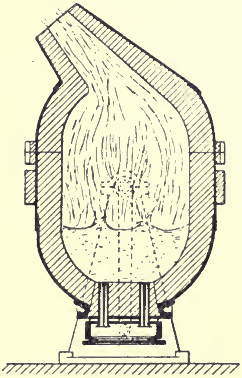


FIG. 121.—Blowing.

Brief Description of a Blow.—The converter is brought into a horizontal position (Fig. 120), and the charge of molten iron, usually five to ten tons, is run in. The converter is so shaped that when in this position the metal is quite clear of the tuyere openings, or it might run into them and solidify. The blast is then turned on, the air, of course, passing over the metal, and the converter is turned up (Fig. 121). As the metal flows over the tuyeres from which the air is coming, the air, forcing its way through the thin sheet of metal, breaks it up and causes the vigorous ejection of a shower of sparks. As the full head of metal comes over the tuyeres the rush of air through it can be distinctly heard, and the ejection of sparks continues. At first there is little, if any, flame, only a stream of hot gas and showers of sparks coming from the mouth of the converter. In a few minutes a small but decided flame makes its appearance, which is only slightly luminous, and has a yellowish-red colour. This stage lasts from four to six minutes. The flame is mainly due to the combustion of carbon-monoxide formed from the carbon in the iron. The temperature now rapidly rises, and the boil begins. The flame increases in size and brilliancy, and for a time is excessively unsteady, both as to size and brightness: then it becomes bright and dense. At the same time showers of sparks and fragments of burning iron are ejected. This stage lasts six or eight minutes. The intensity of the action then begins to diminish, there are fewer sparks, the flame becomes bluish-violet in colour, less luminous, and more transparent, and diminishes in volume. At about 20 minutes from the start the flame suddenly becomes much smaller, or "drops," and the operation is over. All the carbon and silicon are removed, and if the blow were continued the iron would take up oxygen, and the charge would be spoilt. The converter is, therefore, rapidly turned over into a horizontal position. If the metal were now poured it would be brittle or rotten, and quite unfit for use. A quantity of speigeleisen or ferro-manganese, the amount varying with the nature of the steel required, is shovelled in, and then the contents of the converter are poured into the ladle which has been put ready to receive it (see Fig. 122). The ladle is moved away, the converter is turned mouth down so that some refractory slag which has not poured with the rest may be removed, the interior is examined, repaired if necessary, and the converter is turned up ready for another charge. Thus, in about 20 minutes, 10 tons of pig iron will have been converted into mild steel.

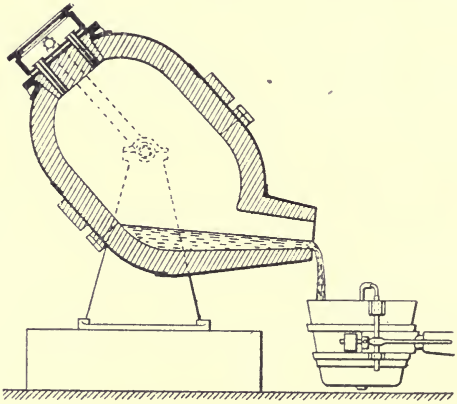


Fig. 122.—Pouring.

The ladle is brought over the moulds, and the metal is run into them till it is all out of the ladle, and then the slag is tipped out to be subsequently removed. As the ladle is moved away, sand is thrown on the top of the hot metal in the moulds, and the moulds are closed or "stopped" with an iron plate.

As soon as the metal has set sufficiently the ingots are stripped—that is, the moulds are lifted away by means of a crane. The red-hot ingots are lifted out, and either left to cool or placed at once in the soaking furnace, and the moulds are replaced ready for the next charge.

Bessemer's Description.—The first published description of a blow, that given by Bessemer in a paper read before the Institution of Civil Engineers in 1859, may be of interest. He describes the converter being turned up, and says: "The process is thus in an instant brought into full activity, and small though powerful jets of air spring upward through the fluid mass. The air, expanding in volume, divides itself into globules or bursts violently upward, carrying with it some hundredweight of fluid metal which again falls into the boiling mass below. Every part of the apparatus trembles under the violent agitation thus produced. A roaring flame rushes from the mouth of the vessel, and as the process advances it changes from violet colour to orange and, finally, to a voluminous white flame. The sparks, which at first were large like those of ordinary foundry iron, change to small hissing points, and these gradually give way to soft floating specks of bluish light as the state of malleable iron is approached. There is no eruption of cinder as in the early experiments, although it is formed during the process. The improved shape of the converter causes it to be retained, and it not only acts beneficially on the metal but helps to confine the heat, which during the process has rapidly risen from the comparatively low temperature of melted pig iron to one vastly greater than the highest known welding heats by which malleable iron only becomes sufficiently soft to be shaped by the blows of a hammer; but here it becomes perfectly fluid, and even rises much above its melting point, so as to admit of its being poured from the converter into a founder's ladle, and from thence to be transferred to several successive moulds."

CHAPTER XXIV.

THE CHEMISTRY OF THE BESSEMER PROCESS.

The chemical reactions which take place in the Bessemer process closely resemble those of the puddling process, and consist, essentially, in the removal of oxidisable impurities together with a certain quantity of the iron by means of the oxygen of the air.

The nature of the changes will be best studied, in the first instance, by a series of analyses of the metal at different stages of the blow. The first example is of a blow at the Dowlais Works, the figures being given by Snelus :—

	Pig Iron.	End of First Stage, 4 mins.	After 9 mins. Blow.	End of Blow.	Steel Ingot.
Graphitic carbon	2·070	..	..	..	..
Combined ,, ...	1·200	2·170	1·550	0·097	0·566
Silicon	1·952	0·790	0·635	0·020	0·030
Sulphur	0·014	Trace	Trace	Trace	Trace
Phosphorus	0·048	0·051	0·064	0·067	0·055
Manganese	0·086	Trace	Trace	Trace	Trace
Copper	..	..	..	..	0·039

Another example, from the treatment of a highly-manganiferous pig in Styria, given by Prof. Kupelwieser in "Bell's Principles : The Manufacture of Iron and Steel," shows a similar set of phenomena* :—

	Pig Iron.	1st Period. Metal after Slaging.	2nd Period. End of Ebullition.	3rd Period. End of Blow.
Graphitic carbon	3·100	..	..	..
Combined ,, ...	·750	2·465	·949	0·087
Silicon	1·960	0·443	0·112	0·028
Sulphur	0·018	Trace	Trace	Trace
Phosphorus	0·040	0·040	0·045	0·045
Manganese	3·460	1·645	0·429	0·113
Copper	0·085	0·091	0·095	0·120
	9·493	4·684	1·630	·393
Iron	90·507	95·316	98·370	99·607
	100·000	100·000	100·000	100·000

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* Page 391.

The oxidised materials pass into the slag. Analysis of the slag is, therefore, also of importance, as indicating the way in which the oxidation takes place. The following analyses of slags by Snelus will show the progressive slag formation :—

	End of First Stage.	End of Boil.	End of Blow before addition of Spiegel.	After addition of Spiegel.	Siliceous residue in Converter.
Silica	46·78	51·75	46·75	47·27	72·25
Alumina	4·65	2·98	2·80	3·45	2·43
Ferrous oxide ...	6·78	5·58	16·86	15·63	20·65
Manganous oxide .	37·00	37·90	32·23	31·89	2·95
Lime	2·98	1·76	1·19	1·23	1·04
Magnesia	1·53	0·45	0·52	0·61	0·13
Alkalies	Trace	Trace	Trace	Trace	Trace
Sulphur	0·04	Trace	Trace	Trace	Trace
Phosphorus	0·03	0·01	0·01	0·01	Trace

Prof. Kupelwieser gives the slags corresponding to the charge of manganiferous iron as being :—

	1st Period.	2nd Period.	3rd Period.
Silica	46·78	51·75	46·75
Alumina	4·65	2·98	2·80
Lime	2·98	1·76	1·19
Magnesia	1·53	0·45	0·52
Alkalies	Trace	Trace	Trace
Sulphur	0·04	Trace	Trace
Phosphorus	0·03	0·02	0·01
Manganous oxide	37·00	37·90	32·23
Ferrous oxide	6·78	5·50	16·86

Mr. F. Julian gives a series of analyses stated rather differently—the metal and slag being given together—relating to a modern American blow; the blow being, as is usual in American practice, much shorter than in English practice—10 minutes, in place of 20 minutes or more.

	Pig Iron.	Time of Blowing.					After addition of Spiegel.
		2 min. 0 sec.	3 min. 20 sec.	6 min. 30 sec.	8 min. 8 sec.	9 min. 10 sec.	
Carbon	2·98	2·94	2·71	1·72	0·53	0·04	0·45
Silica	0·94	0·63	0·33	0·03	0·03	0·03	0·038
Sulphur	0·00	0·06	0·06	0·06	0·06	0·06	0·059
Phosphorus	0·10	0·104	0·106	0·106	0·107	0·108	0·109
Manganese	0·43	0·09	0·04	0·03	0·01	0·01	1·15
Silica	..	42·40	50·26	62·54	63·50	..	62·20
Alumina	..	5·63	5·13	4·06	3·01	..	2·76
Ferrous oxide ..	..	40·29	34·24	21·26	21·39	..	17·44
Ferric oxide ...	..	4·31	0·96	1·93	2·63	..	2·90
Manganous oxide	..	6·54	7·90	8·79	8·88	..	13·72
Lime	..	1·22	0·91	0·88	0·90	..	0·87
Magnesia.......	..	0·36	0·34	0·34	0·36	..	0·29
Phosphorus	..	0·008	0·008	0·010	0·014	..	0·010
Sulphur	..	0·009	0·009	0·014	0·008	..	0·011
Flame		Silicon flame.	Brightening.	Moderate Carbon flame.	Full Carbon flame.	Flame drops.	

History of the Metal.—From these figures it is easy to learn—approximately, at any rate—the way in which the metalloids are removed during the blow.

The pig iron is of complex composition, the various metalloids being in combination with either the iron or the manganese, and, by thermal considerations, based on the law of greatest heat evolution, it is possible to ascertain approximately how they are distributed. The carbon will probably be divided between the manganese and iron—the quantities varying with the amount of carbon and the amount of manganese—forming carbides $Mn\,C_2$ and $Fe_3\,C$; the silicon will be divided between the manganese and iron as $Mn_7\,Si_2$ and $Fe\,Si$; the phosphorus will be entirely with the iron as ferrous phosphide $Fe_3\,P$; and the sulphur will be either ferrous sulphide $Fe\,S$ or manganous sulphide $Mn\,S$. It is possible that these compounds may not be those actually present, but there may exist others which are more stable at very high temperatures.

The air is blown through the molten metal, it does not come at once into contact with the disseminated impurities, but, in presence of the large excess of iron, will form oxide $Fe_3\,O_4$, which will then be reduced by the easily-reducible constituents. The action is, therefore, indirect, exactly as in puddling.

The series of reactions is undoubtedly very complex, and as yet they have not been completely made out.

Taking only the ultimate results, the reactions are somewhat as follows: Manganese and iron are at once oxidised, probably to manganous oxide and magnetic oxide of iron or ferrous oxide. However easily the carbon and silicon may be oxidised in comparison with the iron, the mass of the iron is so great that the air must come in contact with it, and at that temperature it will be rapidly oxidised. The oxides thus formed come in contact with the silicon and carbon, and the oxide of iron is reduced, and silica is formed thus:

$$Fe_3\,O_4 + 2\,Si = 3\,Fe + 2\,Si\,O_2.$$

The silica thus formed at once combines with the manganese oxide, forming manganese silicate,

$$Mn_2\,Si\,O_4. \quad (2\,Mn\,O,\,Si\,O_2).$$

When the manganese has thus been converted into silicate, some of the iron is retained as oxide, forming silicate of iron,

$$Fe_3\,O_4 + Si = Fe_2\,Si\,O_4\,(2\,Fe\,O,\,Si\,O_2) + Fe\,;$$

or, perhaps,

$$Fe_3\,O_4 + 2\,Si = 3\,Fe + 2\,Si\,O_2.$$

The carbon is also attacked. Whilst the temperature is low the reaction is, probably,

$$Fe_3\,O_4 + 2\,C = 3\,Fe + 2\,C\,O_2,$$

but, as it rises to the temperature at which carbon dioxide is decomposed, the reaction becomes

$$Fe_3\,O_4 + 4\,C = 3\,Fe + 4\,C\,O.$$

The actual reactions are, as already remarked, much more complex. The silicon, carbon, &c., are not present as free elements, but as compounds of iron and manganese, and these have to be broken up. It is hardly necessary to say that there is no direct method of ascertaining the exact sequence of changes which take place in the converter. During the blow there is a mixture of metal silicides, carbides, oxides, &c., at a very high temperature, and many sets of reactions may be going on at once, some of which we may be able to trace, but to others of which we may have absolutely no clue. The aid of thermal chemistry has been called in, it being assumed that the reactions always take place in such a way as to evolve the largest amount of heat. Whilst this is a safe guiding principle in many cases, it is not always so in cases where reactions take place at a very high temperature and in presence of a very large excess of one substance.

As far as can be made out, the probable course of the reactions is somewhat as follows: The manganese silicide $Mn_7 Si_2$ is first oxidised, the oxygen being supplied perhaps to some extent directly, but mainly from oxide of iron,

$$Mn_7 Si_2 + 11 O = 7 Mn O + 2 Si O_2,$$

manganese oxide and silica then combining to form manganese silicate as above. Manganese carbide may be attacked by oxide of iron, thus:

$$Fe_3 O_4 + Mn C_2 + 4 O = Mn O + 3 Fe O + 2 C O_2,$$

or the carbide of manganese may even reduce silica, thus:

$$Si O_2 + 2 Mn C_2 + 8 O + Fe = 2 Mn O + 4 C O_2 + Fe Si.$$

At the same time the iron carbide may be decomposed by oxide of iron. These and many other reactions may take place.

For our purpose, however, the way in which the constituents are removed during the blow is of much more importance than the exact changes which take place.

Carbon.—The removal of carbon commences immediately the air enters the iron, and the rate of removal increases very rapidly as the process goes on. When the flame drops the carbon is reduced to about ·1 per cent. There is rarely more, except in cases where it is intentionally left for the purpose of making a high carbon steel, and it cannot with certainty be reduced much lower.

Silicon.—The removal of silicon begins at once, and is very rapid in the earlier parts of the blow, and, unless the initial silicon be very high or the temperature of the blow too high, the removal of the silicon is complete. With ordinary Bessemer pig and the method of blowing usually used, the residual silicon is about 0·1 per cent or less. Silicon is best removed at a moderate temperature. At very high temperatures the affinity of oxygen for silicon falls in comparison to its affinity for carbon, and carbon may even decompose silica, liberating silicon. If the temperature of the blow be too high there is therefore always a risk that silicon may be left. When the blow is too hot the metal is often cooled by turning down the converter and adding cold scrap.

Manganese.—Manganese is removed rapidly. Indeed, it is the first of the foreign constituents to oxidise, and in highly manganiferous iron it may be oxidised before there is enough silica formed to produce a slag with the oxide. The presence of manganese may cause the blow to be prolonged, but in all cases it is ultimately completely removed.

Sulphur.—The sulphur is not sensibly reduced during the blow.

Phosphorus.—The phosphorus is not reduced during the blow, and as other constituents are removed, and the total weight of metal decreases, the percentage of phosphorus increases. Ferrous phosphide is not decomposed, and the phosphorus in the manganese phosphide passes over to the iron. It is often stated that under the conditions of the blow silica would decompose iron phosphate, forming silicate, and liberating phosphoric anhydride, which would then be decomposed by the iron, and the phosphorus thus again pass into the metal. This, however, does not seem to be the case, but rather the phosphide of iron is not oxidised under the conditions of the blow.

Iron.—Iron is oxidised to some extent very early in the blow; indeed, probably from the very first. The total loss of iron by oxidation is from 5 to 10 per cent, though the amount varies very much.

Oxygen.—The molten metal is in intimate contact with oxygen, and oxide of iron is therefore rapidly formed. When the oxidisable constituents are all removed, the oxide of iron will dissolve in the metal and make it brittle or "rotten," and if it were cast in this condition it would go to pieces under the hammer. This, indeed, was one of the greatest difficulties which had to be faced in the early days of the process, and it was overcome by Mushet's invention of the use of manganese. When the blow is over, manganese in the form of spiegeleisen or ferro-manganese is added. The manganese at once decomposes the oxide of iron in the metal, forming oxide of manganese, which passes into the slag. Some oxygen is, no doubt, always left, even though an excess of manganese remains in the iron.

Recarburising.—The metal at the end of the blow is too low in carbon for most purposes. It is impossible to stop the process so as to leave a definite amount of carbon in the steel, except in very special cases, for (1) there is no indication of when to stop, except the drop of the flame, which indicates complete removal: and (2) if the blow were stopped sooner, other impurities injurious to the metal might be left. Any carbon required must, therefore, be subsequently added. This is always done by the addition of spiegeleisen or ferro-manganese, which are simply varieties of pig iron very rich in manganese. The amount of the manganese alloy to be added is calculated so as to give the required amount of carbon, and it must at the same time contain enough manganese to remove the oxygen. If the amount of manganese were too low, either oxygen would be left in the metal or carbon would be oxidised. It is obvious, therefore, that the richer the alloy is in manganese compared with its carbon content, the smaller will be the amount of carbon it will be possible to add for a given amount of manganese, and the milder steel will it be possible to make.

The order in which the impurities are removed can be diagrammatically shown in various ways. Fig. 123 shows the removal of the impurities on the method used by Sir Lowthian Bell, the percentage of each impurity removed being given by the ordinates. Fig. 124 shows the actual amounts removed in the blow, the analyses of which are given above. Fig. 125 shows the removals in the Styrian blow, and Fig. 126 that in the American blow.

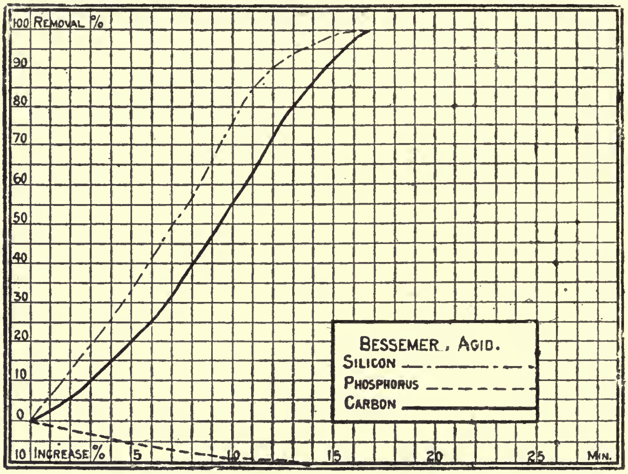

FIG. 123.—Bell's Curves, illustrating the removal of impurities in an ordinary Bessemer blow.

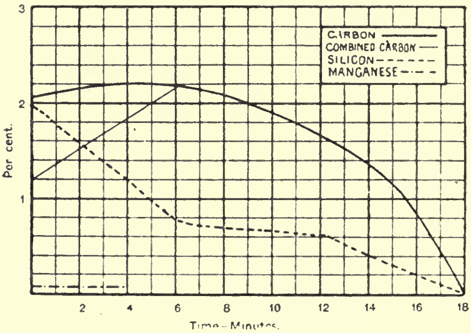

FIG. 124.—Removal of impurities in an ordinary Bessemer blow.

History of the Slag.—The history of the slag follows from that of the metal. The silicon is oxidised to silica, and at the same time metal is oxidised forming oxide, which combines with this to form a slag. Silica may also be taken from the lining of the converter, as also are small quantities of alumina, lime, &c. The result of these changes is the production of a slag which may vary between the bisilicate R O, Si O_2, and the monosilicate, 2 R O, Si O_2 types, the latter being, apparently, the most stable type of silicate at high temperatures. The proportion of the various bases will vary. At first manganese oxide predominates largely, but as the blow goes on the proportion of iron oxide increases rapidly. The amount of manganese present in the slag will, of course, depend on the amount present in the iron, as it will all pass into the slag ; and the amount of iron in the slag will also depend somewhat on the quantity of manganese and on the quantity of silicon. If the silicon in the iron be low the slag may be somewhat more basic, and may also contain intermixed ferric oxide, and no doubt, if the blow were continued after the drop of the flame, considerable quantities of ferric oxide or magnetic oxide would be produced. Only traces of sulphur and phosphorus pass into the slag.

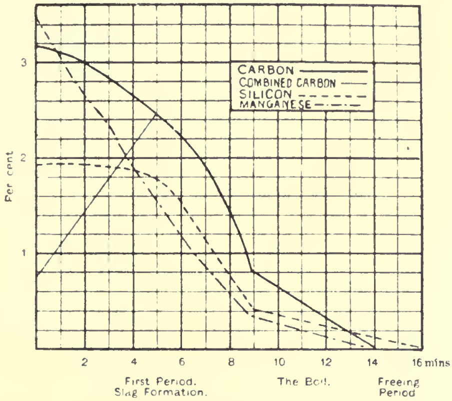

FIG. 125.—Blow of Manganiferous Pig Iron.

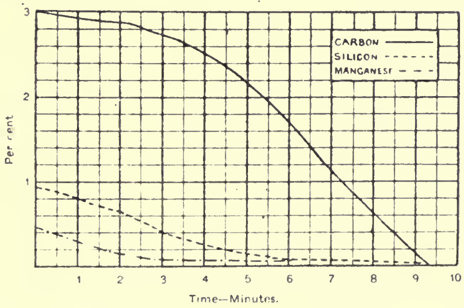

FIG. 126.—American Blow.

Slag Test.—In cases where the blow is not to be continued till the drop of the flame, it has been suggested to take samples of the slag on an iron rod, and to judge the progress of the blow by the appearance of the slag. "The slag presents a peculiar brownish tint so long as the metal retains a considerable amount of carbon, whilst it becomes totally black with the lustre characteristic of the presence of ferrous silicate immediately the whole of the carbon is removed from the metal in the converter, and the various intermediate percentages of carbon are indicated by corresponding tints of the slag; thus, 0·75 per cent of carbon in the charge is indicated by a lemon-yellow coloured slag, which changes to orange as the carbon falls to 0·60 per cent, becoming light brown with a content of 0·45 per cent, while 0·30 per cent of carbon is indicated by a dark brown colour, and 0·15 per cent by a bluish-black slag."*

This test seems now to have been abandoned. It is not reliable, as the colour of the slag must depend to some extent on the initial composition of the metal, and, perhaps, on other causes: and, further, the passage from one tint to another is so gradual that the exact point could not be determined.

History of the Gases.—The gas blown in is air, carrying, of course, a small quantity of moisture, the amount depending on the condition of the atmosphere.

The following analyses, by Snelus, of the gases from a converter will indicate their general character:—

	Time after Commencement of Blow.					
	2 min.	4 min.	6 min.	10 min.	12 min.	14 min.
Carbon dioxide . . .	10·71	8·59	8·20	3·58	2·30	1·34
,, monoxide .	. .	3·95	4·52	19·59	29·30	31·11
Oxygen	0·92	. .	. .	. .	. .	. .
Hydrogen	88·37	0·88	2·00	2·00	2·16	2·00
Nitrogen		86·58	85·28	74·83	66·24	66·55

As the air rushes into the iron, oxidation begins. The temperature being low, some of the carbon is oxidised, forming carbon dioxide, but most of the oxygen is retained, forming solid oxides. As the blow goes on, and the temperature rises, the amount of carbon dioxide decreases, and ultimately disappears as the temperature reaches its dissociation point; at the same time the amount of oxygen retained in the slag and metal falls, so that near the end

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* Greenwood, "Steel and Iron," page 485.

of the blow almost the whole of the oxygen leaves the converter as carbon monoxide. The steam carried into the converter by the air is completely decomposed, so that the percentage of hydrogen remains almost constant. It must be remembered that some gas remains in solution in the metal.

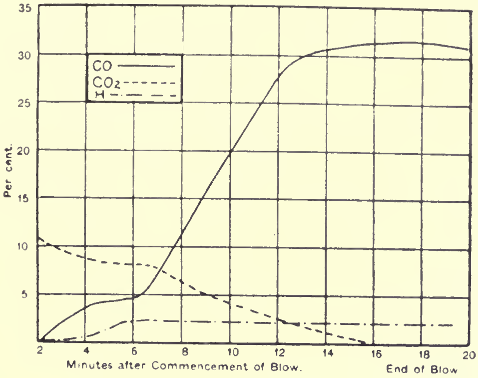

FIG. 127.—Converter Gases.

The composition of the gas at different stages is shown in Fig. 127.

Temperature of the Flame.—The temperature of the Bessemer flame has been given on the authority of M. Watts as being above the melting point of gold (1,045 deg. Cen.) and below that of platinum. Le Chatelier measured the temperature of the flame with his pyrometer, and found it to be :

Flame at the	"boil"	1,330 deg. Cen.
,, ,,	finish	1,580 deg. Cen.

Hartley, from spectroscopic considerations, comes to the conclusion that it must be hotter than the oxy-hydrogen flame.

The temperature of the flame is not, necessarily, the same as that of the interior of the converter, as the gases are combustible and burn ; and the heat therefore is partly brought from the converter, and partly produced by the combustion of the gas at the mouth, the former being the more important.

The luminosity of the flame is due, largely, to the combustion of the metallic vapours, &c., which are raised to a very high temperature by the burning carbon monoxide.

Spectroscopic Examination of the Flame.—It might be expected that a spectroscopic examination of the flame would give valuable information as to what is going on in the converter. This is the case, and in some districts the spectroscope is used to determine the end of the blow.

The spectrum of the converter flame has been studied by Roscoe, Marshall Watts, and others, and lately by Hartley.

The following is a brief account of the appearance of the flame through the spectroscope :—

At first, when the converter is turned up, the spectrum is faint and continuous. As the flame increases (four minutes or so) the yellow lines of sodium make their appearance : at first flashing out and disappearing, then becoming steady. As the temperature rises, other lines gradually make their appearance, till the spectrum becomes very complex, the most noteworthy lines being the bright green, so-called, manganese (really carbon) lines. During the fining stage the spectrum grows fainter, and when the blow is over the green lines suddenly disappear. As the temperature rises, lines also make their appearance in the ultra-violet, which, though invisible, can be photographed.

Snelus gives the following tabular statement :—

	Spectrum Observation shows.	Eye shows.	Analyses of Gas shows.
First Stage—4 min.	Faint, continuous spectrum ; Na lines appear in flashes.	No actual flame ; abundance of sparks.	Carbon dioxide evolved little or no carbon monoxide.
4 to 8 min.	Na. K. Li. lines appear ; towards the close occasional flashes of the carbon lines.	Quantity of sparks decreasing.	Carbon dioxide still given off ; carbon monoxide increasing ; temperature rising, and causing the volatilisation of the alkali metals.
Second Stage— 8 to 10 min.	Bright carbon lines in red, blue, and green fields.	Flame dense and bright; very few sparks.	Carbon monoxide evolved in quantity burning with high temperature at mouth of converter.
10 to 14 min.	Bright green carbon lines more distinct.	Dense flame.	Carbon monoxide in large quantity ; little carbon dioxide.
14 min. to end	Carbon lines bright till end, when they disappear.	Flame diminishing; then drops.	Carbon monoxide evolved till end.

Greenwood describes a blow* :—

Time from Commencing Blow.	Appearance of Flame to Eye.	Appearance by Spectrum.
4 minutes ..	Very small flame with sparks of metal	Faint, continuous spectrum.
5 ,, ..	Flame pale, but increasing in size	Continuous spectrum with two yellow sodium lines flashing across it.
6 ,, ..	Large, unsteady flame	Sodium lines, steady and fixed.
8 ,, ..	Flame larger and brighter ...	Yellow sodium lines, with lines also in the red and violet bands, appear.
10 ,, ..	Boil commenced, accompanied by bright, dense flame	Spectrum as the last, but with additional lines appearing in the red, with carbon lines in the green, and blue and other manganese lines also in the green.
15 ,, ..	Flame becomes larger and more transparent	Spectrum more distinct and the lines better defined.
20 ,, ..	Less luminous and diminishing volume of flame.......	Spectrum as before, but fading in intensity.
24 ,, ..	Flame drops	Green lines in the carbon and manganese lines disappear.

The substances that may come off from the converter in the gases are thus classified by Hartley, according to the nature of the spectra they give.

Gases.—Hydrocarbons show the band spectrum, which is well known ; also the spectrum of water vapour lines. Carbon monoxide was proved to give nothing beyond a continuous spectrum when perfectly uncontaminated by any other material, such as dust in the air.

Metals and Non-metallic Elements.—The following characteristic flame spectra are emitted at high temperatures :—

1. Line spectra, lithium, thallium, nickel cobalt.
2. Banded spectra, antimony, bismuth, gold, tin, sulphur, selenium.

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* "Iron and Steel," page 491.

3. Banded spectra with lines, copper, iron, manganese, tellurium, lead, and silica.
4. More or less continuous spectra with lines, sodium, potassium, magnesium, chromium, cadmium.
5. A continuous spectrum, solid carbon.

Compounds.—The alkaline earths, carbonates and sulphates, emit beautiful spectra of bands with lines. The oxides of the heavy metals, such as iron, manganese, and chromium, also behave in a similar manner. The bands of magnesium oxide and manganese are quite remarkable. Phosphoric anhydride emits a spectrum of a continuous band of rays with what appear to be very faint lines overlapping it. These are probably feeble indications of the edges of bands in the spectrum.*

The lines observed during the blow are :—

During the first period, "slag formation."	Lines of the alkali metals, *sodium*, *potassium*, and *lithium*, are seen on a *continuous spectrum of carbon monoxide.*
During the second period, "the boil."	Bands of manganese are prominent overlying the *continuous spectrum of carbon monoxide.* There are lines of *carbon*, *manganese*, *and iron*, also those of the *alkali metals.*
During the third period, "fining stage."	The spectrum is the same as the foregoing, but the lines of *iron* are not so strong and not quite so well defined. Some of the short lines disappear. The lines of the alkali metals are visible.

At the outset, therefore, the spectrum is the continuous one of carbon monoxide. As traces of alkalies from the ganister lining pass into the slag, these show their characteristic spectra. As the temperature rises—the atmosphere now being powerfully reducing—iron and manganese volatilise and, coming into the flame, give their characteristic spectra and burn, with the carbon monoxide, in the air, sometimes, if the quantity of manganese is very large, producing clouds of brown vapour. Even when there is little manganese, so that it all passes from the metal to the slag very early in the process, the flame still gives its spectrum of manganese, it evidently being reduced from the slag. So the spectrum of manganese is obtained when an old converter is heated up with coke. At the end of the blow the lines disappear, owing to the cessation of the escape of carbon monoxide and the fall in temperature.

Temperature of Flame from Spectroscopic Observation.—As the temperature rises the tendency is for the spectrum of any gaseous substance to become more complex, the number of lines increasing, and the spectrum becoming banded. Also, the increase of lines is often considerable in the ultra-violet, the lines then are not visible to the eye, but are capable of being photographed.

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* "Thermo-chemistry of the Bessemer Process," page 33.

If, therefore, two spectra from the same substance are of different degrees of complexity, and one shows more lines in the ultra-violet, the inference is that that one is at the higher temperature.

Prof. Hartley says : "Judging by the number of lines and bands belonging to iron and manganese which have been photographed in the spectrum of the Bessemer flame, the temperature must in any case nearly approach that of the oxyhydrogen flame, even if it does not very generally exceed it."

The parallel columns below show the number of lines observed in the spectra of the respective substances under different conditions :—

BESSEMER FLAME.	CARBON MONOXIDE BURNT WITH OXYGEN.
CO spectrum, 8 lines and edges of bands. Exposure 1½ to 3 min.	CO spectrum, 16 lines and edges of bands. Exposure 60 min.
Mn spectrum, 73 lines and edges of bands. Exposure ½ to 3 min.	Mn spectrum, pure metal, 103 lines and edges of bands.
Fe spectrum, 92 lines. Exposure ½ to 3 min.	Fe spectrum. 92 lines. Exposure from 15 to 30 min.

"The temperature is to be judged by iron lines, because there is a smaller difference in the proportions of this metal present in the two cases than in the case of carbonic oxide and manganese. It is a striking fact that the Bessemer flame required a much shorter exposure than the oxyhydrogen blowpipe flame, but the volume of the flame is much larger ; on the other hand, however, it is not so close to the instrument. These facts, however, do not influence the number of lines in the spectra, which are readily photographed. In fact, nothing but an approximately equal temperature could give a similarity of spectra, particularly in the ultra-violet region."*

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* "J. I. and S. I.," 1895, 2, page 118.

CHAPTER XXV.

THERMAL CONDITIONS OF THE BESSEMER BLOW.

In his early experiments Bessemer heated the vessel containing the iron by means of an external fire ; but he soon found that this was unnecessary, as the heat evolved by the chemical changes which took place during the blow was quite sufficient to keep the metal melted even when completely decarburised, and therefore in the condition of carbonless iron.

General Statement of the Sources of Heat.—It is not difficult to see the sources of heat, and why such a high temperature can be attained.

Assume the pig iron used and the steel produced to have the following composition :—

	Pig Iron.	Steel.
Carbon	3·70	·10
Silicon	2·50	·10
Sulphur	·05	·05
Phosphorus	·05	·06
Manganese	1·00	Nil

It will be seen that the conversion of the iron into steel has been produced by the removal of the easily oxidisable constituents. In each 100 lbs. of iron charged into the converter there is 2·4 lbs. of silicon to be oxidised to silica. Each pound of silicon being so oxidised evolves about 7,830 units, so that the 2·4 lbs. will evolve 18,792 units, there is also 3·6 lbs. of carbon to be burnt, and, assuming that two-thirds of this is burnt to carbon monoxide and one-third to carbon dioxide, the amount of heat evolved will be

$$(1·2 \times 8{,}080) + (2·4 \times 2{,}400) = 9{,}696 + 5{,}760 = 15{,}456 \text{ units.}$$

The 1 lb. of manganese will give about 1,724 units, and, assuming three per cent of iron to be oxidised, this will give 1,582 × 3 = 4,746 units. Summing up, there will be

From	2·4 lbs. of	silicon	oxidised to	$Si O_2$	18,794
,,	1·2 ,,	carbon	,, ,,	$C O_2$	9,696
,,	2·4 ,,	,,	,, ,,	$C O$	5,760
,,	1 ,,	manganese	,, ,,	$Mn O$	1,724
,,	3 ,,	iron	,, ,,	$Fe_3 O_4$	4,746
				Units of heat..........	39,118

For each 100 lbs. of crude iron.

One pound of good coal gives about 8,000 units of heat, so that the heat evolved in the converter will be equal to that given by the combustion of 4·9 lbs. of coal for each 100 lbs. of iron, or 1,090 lbs.—

a little over 9 cwt. for a charge of 10 tons of iron. Imagine 9 cwt. of coal to be burnt in a small enclosed place like a converter in 20 minutes, and it will not seem strange that a very high temperature should be produced.

Sir Lowthian Bell's Estimate.*—Sir Lowthian Bell gives a more detailed statement of a special case. He says: "We will assume an average consumption of 112·5 units of pig to be needed per 100 of ingots, the pig consisting of 105 units of hematite pig and 7½ units of spiegel."

The composition of the materials employed and steel made may be taken as follows:—

	Hematite Pig.	Spiegel.	Steel.
Carbon	4·000	4·500	·450
Silicon	2·500	·750	·100
Sulphur	·025	. .	·020
Phosphorus	·060	. .	·060
Manganese	·500	18·000	1·110
Iron	92·915	76·750	98·260

Hence the elements in 112·5 units would be:—

	Pig Iron.	Spiegel.	Steel.	Disappeared during Blow.
Carbon	4·200	·337	·450	4·088
Silicon	2·625	·056	·100	2·581
Sulphur	·026	. .	·020	·006
Phosphorus	·063	. .	·060	·003
Manganese	·525	1·350	1·110	·765
Iron	97·561	5·752	98·260	5·057
	105·000	7·500	100·000	12·500

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* "Principles of the Manufacture of Iron and Steel," page 421.

The heat evolved is computed to be as follows :—

Carbon	4·088	×	4,150	=	16,965·2
Silicon	2·581	×	7,830	=	20,209·2
Sulphur	·006		—		—
Phosphorus	·003	×	5,868	=	17·6
Manganese	·765	×	1,724	=	1,318·8
Iron	5·057	×	1,582	=	8,000·1
					46,510·9 units.

For each 100 parts of steel made.

The slag from the oxidised materials should weigh 11·52 units, equal therefore to about 2·3 cwt. per ton of iron.

More Recent Estimates.—The estimate of heat evolution given above is based on the assumption either that the elements oxidised are in the free condition in the iron or that they are present in such forms that the algebraic sum of their heats of formation is nil. The first assumption is certainly not true, for the elements are in combination, and the second is extremely unlikely ; the estimate may therefore be either too high or too low, according as the sum of the heats of formation of these compounds is positive or negative. As stated above, the elements are present in combination with iron and manganese, the probable forms being $Mn_7 Si_2$, $Mn S$, $Mn C_2$, $Fe_3 C$, $Fe Si$, $Fe_3 P$. The heat of formation of these bodies is therefore important, and it has been recently investigated by Troost, Hautefeuille, Pourcel, and others.

Ferrous Carbide seems to be formed with the absorption of heat, though the amount of heat absorbed is small. This explains the readiness with which the carbide breaks up with separation of graphite on cooling a mass of iron.

Manganese Carbide, $Mn C_2$, is formed with a very considerable evolution of heat, the heat of formation of a gramme molecule being 116,000 Cen. units, or 2,109 units for each gramme of manganese. Manganese carbide is an excessively stable body.

Iron Silicide is also formed with a small absorption of heat.

Manganese Silicide is formed with a considerable evolution of heat ; it, therefore, is a very stable body.

The following table gives the heat of formation of the various compounds, as far as they have at present been approximately determined, as given by Prof. Ponthiere.

	Heat Units per gramme molecule.	Heat units for one gramme of the Metal.
Manganese carbide	116,000	2,109
,, phosphide	72,300	1,314
,, sulphide	54,800	998
,, silicide	52,500	955
Ferrous phosphide	43,300	773

These amounts must, therefore, be deducted from the heats of combustion of the elements. The heats of combustion of the compounds, as far as they have been determined, are :—

	Per gramme atom.	Per gramme of Metal.
Manganese sulphide, $Mn\ S$	164,200	3,000
,, silicide, $Mn_7\ Si_2$	157,200	2,859
Ferrous phosphide, $Fe_3\ P$	129,900	2,302
Iron carbide, $Fe_3\ C$—		
C to $C\ O_2$	101,500	1,812
C to $C\ O$	78,800	1,386
Ferrous sulphide, $Fe\ S$	138,200	2,468
Ferrous silicide	288,200	5,146

The following table is given by Prof. Hartley* :—

	Heat of Formation per gramme atom of Metal assumed to be one-fifth when not proved.	Heat of Combustion of the Free Elements per gramme atom of Metal.	Heat of Combustion per gramme atom of Metal.
Manganese Carbide, $Mn\ C$ —			
C to $C\ O_2$	116,000	290,200	174,200
C to $C\ O$	116,000	153,800	37,800
Manganese Phosphide, $Mn_3\ P_2$	72,300	216,800	144,500
,, Sulphide, $Mn\ S$	54,600	164,200	109,400
,, Silicide, $Mn_7\ Si_2$	52,500	157,600	105,100
Ferrous Silicide, $Fe\ Si$	Negligible	288,200	288,200
,, Sulphide, $Fe\ S$	Negligible	138,200	138,200
,, Phosphide, $Fe_3\ P$	45,300	129,900	86,600
Ferrous Carbide, $Fe_3\ C$—			
C to $C\ O_2$	Negligible	101,500	101,500
C to $C\ O$	Negligible	77,700	77,700
Manganese Carbide—			
If the carbon is burnt to $C\ O_2$	290,200	116,000	174,200
If the carbon is burnt to $C\ O$	158,000	116,000	37,000

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* In the original table the quantities are given in calories (1 kilo. 1 deg. Cen.), in this table they are given in gramme units (1 gr. 1 deg. Cen.).

It is obvious that the heat evolution in a Bessemer blow will be less than that obtained by calculation from the free elements, and that the actual amount can only be determined if we know the way in which the various constituents are united.

Take as an example a pig iron containing

Carbon	3·5
Silicon	2·5
Sulphur	·05
Phosphorus	·05
Manganese	1·00
Iron	92·90

such a pig as would be very suitable for the Bessemer process.

Assuming that the whole of the constituents to be present in the free state and to be burnt out, the heat evolution would be :—

Carbon, burnt to carbon monoxide	3·5	× 2,450 =	8,575
Carbon monoxide from one-third of the carbon burnt to carbon dioxide	1·67	× 5,630 =	9,402
Silicon burnt to silica	2·5	× 7,830 =	19,575
Manganese burnt to manganese oxide	1·0	× 1,724 =	1,724
Iron burnt to oxide	5	× 1,250 =	6,250
Total units of heat evolved per 100 lbs. of iron if the elements were free			45,526

How are the elements combined in the pig iron ? The sulphur and phosphorus will probably be combined with the iron, but the quantity present is so small that the heat values are negligible.

The manganese will be present both as carbide and silicide, and it may be assumed that two-thirds of it is combined with the carbon as carbide $Mn\,C_2$, and the other one-third with silicon as silicide $Mn_7\,Si_2$. So that

$$Mn : C_2 : 55 : : 24 : : \cdot 667 : x \therefore x = \cdot 291 \text{ C.}$$

$$Mn_7 : Si_2 : : 385 : : 56 : : \cdot 333 : : z \therefore z = \cdot 048 \text{ Si.}$$

The rest of the carbon is combined with iron as iron carbide $Fe_3\,C$, so that the amount of the carbon in this carbide will be 3·5 − ·299 = 3·201, and the amount of iron in combination with this will be

$$C : Fe_3 : : 12 : : 168 : : 3\cdot 209 : x \therefore x = 44\cdot 906 \text{ Fe.}$$

The amount of iron present as silicide will be

$$Si : Fe : 28 : 56 : : 2\cdot 452 : z \therefore z = 4\cdot 904 \text{ Fe.}$$

So that the composition of the pig iron will be

			per cent.
Iron carbide	Iron Carbon	44·926 3·209	= 48·135
Iron silicide	Iron Silicon	4·904 2·452	= 7·356
Manganese carbide	Manganese Carbon	·667 ·291	= ·958
Manganese silicide	Manganese Silicon	·333 ·048	= 381
Iron Sulphide	Iron Sulphur	·044 ·050	= ·074
Iron phosphide	Iron Phosphus	·270 ·050	= ·320

It is now easy to calculate the heat of oxidation of the metal. Take, first, the manganese compounds. The heat of combustion of manganese carbide is given as 37,800 units per gramme atom of the metal, that is $\frac{37,800}{55}$ for each gramme of, the metal = 687, the carbon being burnt to carbon monoxide.

The heat of combustion of the manganese silicide is given as 105,100 per gramme atom $= \frac{105,100}{55} =$ 1,909 per gramme. Since the heats of formation of the carbide and silicide of iron are so small as to be negligible, we can take the heat due to these as being the same as that given by the free elements, and the sulphide and phosphide can also be neglected.

The heat of combustion will therefore be

Manganese carbide	·667	× 687	=	458
Manganese silicide	·381	× 1,909	=	727
Silicon in iron silicide	2·452	× 7,830	=	19,199
Carbon in iron carbide (to C O)	3·209	× 2,450	=	7,862
One-third of the total carbon burnt from C O to C O_2				9,402
Iron burnt to oxide				7,150
Total heat units				44,798

It is therefore evident that except in cases where there are present large quantities of manganese compounds or phosphide or sulphide of iron, the result obtained by considering the elements as being free is near enough for all practical purposes.

Order of Oxidation.—Whilst the total amount of heat evolved is independent of the order in which oxidation takes place, the fluctuations in temperature will depend entirely on this. As soon as oxidation begins the graphitic carbon passes into the combined form, but this has little thermal effect. Then the manganese silicides and carbides and the iron silicide oxidise, and, as these evolve a large quantity of heat, the temperature rises very rapidly, and may readily become too high.

Heat of Recarburisation.—When the spiegeleisen or ferro-manganese is added there is a considerable rise of temperature. The iron contains magnetic oxide, and the manganese reduces this at once to ferrous oxide, which, with the manganese oxide formed, passes into the slag. The reaction given is $2\ Fe_3\ O_4 + Mn\ C_2 + 7\ Si\ O_2 + Fe = Mn\ O, Si\ O_2 + 6\ Fe\ O, Si\ O_2 + Fe\ C_2$. This reaction is exothermic, being equal to $96{,}200 + x + 6\ x^1$ units, where x and x^1 are the unknown heats of formation of manganese and iron silicates per gramme atom.

Expenditure of Heat.—The sources of expenditure of heat are: (1) Heat carried out in the gases. This will, of course, depend on the heat generated in the converter, and will be all the heat not otherwise disposed of. (2) Heat carried out by the hot metal and slag. (3) Heat lost by radiation during or between the blows. The quicker the blows follow one another, so that the shorter the time the converter stands empty, the less loss of heat will there be from this source.

If the constituents of the iron are such that the heat of combustion is not very high, loss of heat must be avoided as far as possible. By very quick working, so as to avoid loss, by radiation pig iron, containing 1 per cent of silicon, is blown in America.

Sources of Heat.—The sources of heat in the converter are: (1) Heat carried in the molten pig iron. (2) Heat carried in the air. (3) Heat produced by the chemical reactions in the converter as above.

The general balance sheet for an acid Bessemer blow of 10 tons of hot metal of the composition mentioned on page 274 would work out as follows :—

Income.	C. Th. U.	Per cent.
Heat carried in by molten iron	5,000,000	33
Heat derived from converter warm blast and slag formation	1,000,000	7
Heat evolved by oxidation :		
Si to $Si\ O_2$	3,900,000	26
C to $C\ O$	1,725,000	24
C to $C\ O_2$	1,880,000	
Mn to $Mn\ O$	345,000	10
Fe to $Fe\ O$	1,150,000	
	15,000,000	100
Expenditure.		
Heat carried out in molten steel	7,000,000	46
,, ,, ,, slag	1,500,000	10
,, ,, by gases	3,500,000	23
,, lost by radiation and conduction.	2,800,000	20
,, lost by decomposition of moisture....................	200,000	1
	15,000,000	100

CHAPTER XXVI.

WORKING THE BESSEMER PROCESS.

Having discussed the theory of the Bessemer process, we are now in a position to discuss various points in connection with the working.

Selection of a Pig.—The pig iron must be carefully selected. Since neither sulphur nor phosphorus are removed during the blow, a pig must be chosen free from these impurities. Such pig is now largely made, and is known as Bessemer pig, because it is suitable for the Bessemer process, or as hæmatite pig, because it is usually made from hæmatite ores. For the usual British system of working it should contain about 2·5 per cent of silicon, not much more and not much less, whilst, when the American system is practised, 1·5 per cent of silicon, or even less, is sufficient. Silicon is necessary because it is the principal source of heat in the early part of the blow, and, if it be too low, the blow is apt to be "cold." The disadvantages of too much silicon are: (1) The silicon leaves the converter as silicate of iron, and, therefore, the more silicon the larger will be the amount of iron carried away in the slag. (2) If the silicon is too high the blow may become too hot, and when this happens the carbon is burnt out more rapidly than the silicon, and enough silicon may be left to seriously impair the quality of the steel. When the blow seems to be becoming too hot, it is usually cooled by the addition of cold scrap. (3) Though, undoubtedly, the removal of silicon is more rapid than that of carbon during the early part of the blow, and as a rule the silicon is all removed before the carbon is gone, this is not necessarily always the case, and if the initial silicon is very high some may be left in the residual steel.

The amount of carbon is immaterial provided it be about 1 per cent higher than the silicon.

For these reasons the range of composition allowable in a pig for the Bessemer process is comparatively small, and, therefore, the pig must be most carefully made, and when purchased the composition is always specified. The composition of a good Bessemer pig may be taken as being :—

	Per cent.	
Carbon	3·5	
Silicon	2·5	Not more than 3 nor less than 2.
Sulphur	·025	
Phosphorus	·05	
Manganese	1·00	

Manganese is only objectionable because it delays the process, being oxidised out during the early stages of the blow.

Time of Blow.—The time of the actual blow depends on the length of time occupied in the removal of the impurities by oxidation, and this in its turn depends on the composition of the pig and the amount of air which is blown in. If, therefore, it is desired to shorten the blow, a pig must be used which is low in silicon, and, therefore, which can be purified rapidly. Air must be sent in as rapidly as is consistent with its regular distribution through the charge. Pig iron high in silicon, therefore, requires a long, and pig iron low in silicon a short, blow. With a pig iron very low in silicon, there is but little heat evolution in the early stage of the blow, and, therefore, means must be taken to keep up the temperature of the charge.

As stated above, the sources of heat in the converter are: (1) That carried in by the pig iron; (2) that produced by the chemical action; and (3) that carried in by the air. The sources of loss are: (1) Heat carried out in the gases; (2) heat carried out in the liquid products; (3) heat lost by radiation.

The only sources of income that can be increased are (1) and (3), and up to the present little gain has been found to accrue from the use of heated air. The only source of loss that can be reduced without danger is (3), so that, obviously, if short blows are to be used, the pig iron must be sent to the converter at as high a temperature as possible, and the process must be so worked as to avoid loss of heat by radiation.

Speed of Working.—The speed of working—that is, the number of blows that can be worked in an hour—is, of course, limited by the time taken for each blow; but it also depends very much on the arrangement of the plant, for, obviously, if the blowing is to go on regularly without hitch or delay, not only must the steel be made, but it must be removed with sufficient rapidity. In the ordinary British plant two converters are used together at opposite sides of a circular pit, and the operations will be: (1) No. 1 converter is blown, and the steel is poured into the ladle; (2) No. 2 converter is charged, and the blow started; (3) the steel from No. 1 is run into the moulds, the slag emptied out, and the ladle made ready for the next charge; (4) the ingot moulds are lifted away as soon as the metal has solidified, and (5) the ingots themselves are lifted out, and either put aside to cool or transferred at once to the soaking furnace, and (6) the moulds are replaced for the next charge; (7) No. 1 converter is made ready for the next charge. These operations are not consecutive, as, for instance, 2, 3, and 7 will be going on at once. It is obvious that if any operation takes so long that the plant in use is not clear of the steel from converter No. 1 before that from No. 2 is ready, it will cause a block and interfere with the smooth working.

The following arrangement of the times of the various processes is mainly that given by Howe, whose work on steel should be consulted for further details.

The actual time of the blow Howe calls (1) "blowing time" (B.T.). It is the time occupied by the blow from the time the metal is in the converter till it is ready to be poured. It is determined by the conditions given above, and of course regulates the maximum number of charges that can be blown in a given time. In this country it averages about 20 minutes, in America about 10 or 12 minutes, and sometimes even less. "At Homestead sixty-one 5-ton heats have been made in eight hours, or at the rate of 7·87 minutes per heat,"* and greater speed than this has been attained in some cases.

When two converters are kept going the actual time per blow will be this blowing time.

(2) The fresh metal cannot be run into the converter immediately the charge is out. The pasty slag has to be removed, the interior of the converter examined, and repairs made and tuyeres replaced if necessary. The time thus occupied, Howe calls "vessel time" (V.T.), and this will be much increased when a bottom has to be changed, or a serious repair made. In ordinary working V.T. is much less than B.T., so that with a pair of converters the working can be made continuous.

The time needed is given by Howe as being :—

	Mins.	Secs.
Recarburising	0	25
Pouring into ladle	0	45
Emptying slag and turning back	0	25
Receiving iron and examining tuyeres	1	50
	3	25

the minimum observed time being stated to be 2 minutes 57 seconds. The working in this country is nothing like as quick as this, but the time occupied is always much less than the blowing time. Obviously, if the converter cannot receive the new charge as soon as it is ready for it, it will be losing heat, thus necessitating more heat to bring the temperature up again to working point. With a 20-minutes' blow, the converter may have to stand 15 minutes or more cooling. When a bottom has to be changed, the time occupied is much longer. Howe mentions one case, however, in which this was done in 14½ minutes, the vessel time, including changing the bottom, being only 17½ minutes.

(3) The time occupied by the casting crane in receiving and casting its charge is called by Howe "ladle time."

Howe gives the following details for rapid work :—

	Mins.	Secs.
Receiving the molten steel	0	45
Swinging to the moulds	0	28
Teeming 10 tons in eight ingots	5	30
Changing or repairing ladles	1	0
Swinging back to vessel	0	13
	7	56

the shortest time on record being 7 minutes 11 seconds.

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* Howe, "Steel," page 321.

The figures given assume very rapid working and the casting of large ingots. For small ingots the time would be much increased.

It is obvious that the ladle time approaches very near the blowing time, and therefore, to prevent delay in very rapid work, two casting ladles and cranes must be used. With the British method of working the one crane is quite able to keep up with the work of two converters.

(4) The time from the teeming of the metal into the moulds to the teeming into the next set in the same place is the "mould time." It will include the time of actual teeming, the time during which the metal is solidifying sufficiently to allow of the removal of the moulds, the removal of the moulds, the lifting away of the ingots, and the replacing of the moulds. The time occupied will depend largely on the number of moulds to be moved, for it takes almost the same time to lift a small mould or ingot as a large one.

Howe gives the time required in rapid working as being :—

	Mins.	Secs.
Teeming 10 tons in eight ingots	5	30
Last ingot must stay in mould	10	20
Stripping last ingot	0	27
Lifting last four ingots	1	50
Replacing last four moulds............	1	40
	19	47

The length of time which the ingot must stay in the mould varies much. Howe states that in some cases 8 minutes was sufficient. It depends on the size of the ingot and on the temperature of casting. With 20-minute blows one set of moulds might therefore just do, but two or more are invariably used, and for rapid working (8 to 10 minute blows) three or four sets must be provided.

(5) The crane is occupied in lifting the moulds and ingots, and this time is called "crane time" (C.T.).

Howe gives the time required as being :—

	Mins.	Secs.
Lifting and removing eight moulds	3	30
Lifting eight ingots and placing on cars..	3	30
Setting eight moulds................	3	10
	10	10

or about 1¼ minutes per ingot.

One crane can therefore do the work with 20-minute blows, but for quicker blowing at least two will be required.

Supply of Metal.—It is of the utmost importance that the metal should be supplied to the converter of uniform composition, and under uniform conditions. The pig is usually melted in a cupola, whence it is tapped into a ladle and thence poured into the converter. Casting the iron from the furnace into pig moulds, and then re-melting it, obviously entails waste of labour and fuel, and to obviate this the metal is frequently supplied direct from the blast furnace to the converter. The metal is then tapped into a ladle, and this is drawn to the converter house. Whilst the use of direct metal has undoubted advantages, it is attended with difficulties. It does not always happen that metal is ready for tapping from the blast furnace when the converter needs it, or that the converter is ready for it when the furnace needs tapping. Again, the composition of the iron from a blast furnace often varies considerably in composition from tap to tap, and when the metal is used "direct" there is no chance of sampling and selecting it. This difficulty is, to a large extent, overcome by the use of a metal mixer. The iron from the several furnaces is tapped into this, and distributed from it to the ladles.

The following figures will illustrate the effects of the metal mixer in securing uniformity of the metal at Barrow :—

"During a period of 83 working shifts, 52,000 tons of molten iron were sent to the mixer, from which 1,294 samples were taken, with results as follows : Silicon, daily average, 2·39 per cent ; the highest average for any day being 2·80 per cent, and the lowest 1·95 per cent ; variation, ·85 per cent only. The highest silicon in any one sample was 4·75 per cent, and the lowest ·82 per cent, a variation of 3·95 per cent. The greatest variation in any day was 3·39 per cent, the highest and lowest on that day being 4·31 per cent and ·92 per cent respectively.

"During the period, 999 samples were taken from the mixer for analysis, giving an average daily of 2·30 per cent of silicon, the highest being 2·75, and the lowest 1·85 per cent, showing a variation of ·90 per cent. The greatest variation in any day was 1·75 per cent ; the highest on that day being 2·98, and the lowest 1·23 per cent. The highest silicon in any one sample was 3·29, and the lowest 1·18 per cent ; a variation of 2·11 per cent ; the cause of this great variation being the taking out of the metal from the mixer faster than it was being put in."*

Addition of Recarburiser.—In the early days of Bessemer working, the spiegeleisen or ferro-manganese to be used was always melted in a small cupola and run into the converter in the liquid condition. This is now very rarely done except in making steel high in carbon, the heat of the charge being quite sufficient to melt the material added, and the oxidation of the manganese always causes a considerable rise of temperature. Ferro-manganese is now generally used. This is broken up into small pieces, and shovelled either into the converter just before pouring, or into the metal as it flows from the converter into the ladle. At one time it was customary to add the ferro-manganese to the converter and then turn up and blow for a few seconds. The object of this was to ensure a thorough admixture of the ferro-manganese with the iron. It is now given up, as it was found to be quite unnecessary, and also to render the ultimate composition of the metal uncertain.

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* E. Windsor-Richards, "J. W. of S. I. and S. I." vol. vi., page 20.

CHAPTER XXVII.

BESSEMER PLANT.

The plant required for any steel making process will always be of two kinds—that special to the process, and that which is required equally for other processes. In connection with the Bessemer process only the former will be described here, a consideration of the latter being postponed until other processes of steel-making have been dealt with.

The special plant needed for the Bessemer process generally consists of: The cupola, in which the pig iron is melted; and the converter in which the blow takes place; with the various accessories connected with it.

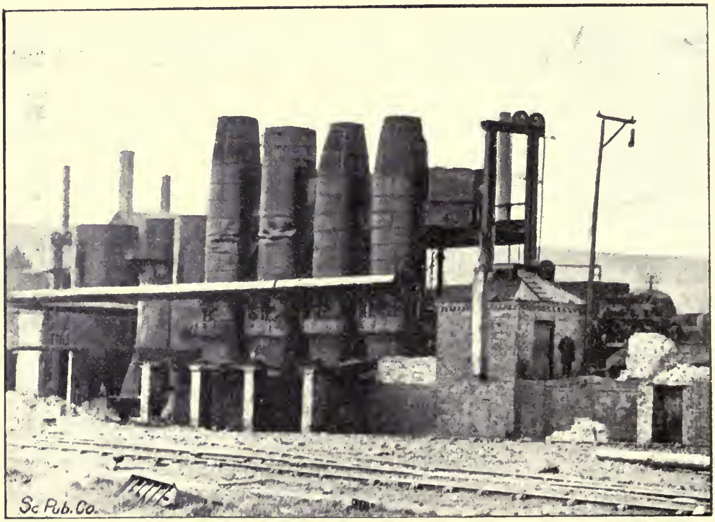

FIG. 128.—Iron Melting Cupolas for a Bessemer Plant.

The Cupola.—The cupola used does not differ from that used in the foundry. When so placed that the metal is run directly into the converter by a shoot, the tap hole may be near the ground level; but when, as is usually the case in modern plant, the metal is run into a ladle, the tap hole must be high enough to allow of ready tapping. The arrangement is shown in Fig. 128, which represents a row of cupolas for a Bessemer plant.

When the metal is to be tapped direct to the converter the cupolas have to be placed on the charging platforms, a position in many ways inconvenient; when ladles are used they can be put in any convenient position.

The metal may be transferred from the ladle to the converter in several ways. Howe mentions three :—

> (1) "It may be run on a track on the general level, be raised to the level of the vessels by a hoist or the jib of a crane standing between or beside them, and there be tipped by gearing attached to the trunnions.
>
> (2) "It may be run on an elevated track at about the level of the vessel's trunnions. From this track it pours the metal into the vessel, being tipped by gearing attached to its trunnions. If the vessels stand side by side, this track may run either before or behind them; if opposite each other, as in the British plan, the track should run between them.
>
> (3) "It may be carried by a crane to the vessel's mouth, and, while suspended aloft by its own trunnions, be tipped so as to empty its molten iron into the vessel by lifting its bottom with a chain."*

The first-named method is but little used, as it has many inconveniences, and requires much more labour than either of the others.

The second is more general, either the ladle on its track is lifted by a hoist or it is usually run up an inclined plane, being hauled either by an engine or by a rope, or, in some cases, by an endless chain. The track is usually brought to the converter level at some distance from the converters, so as to avoid obstructing the work going on below.

The iron should always be weighed into the ladle, so as to ensure the converter receiving its right charge. The usual method is to let the ladle receive its metal on a weighing machine, so that the flow of metal can be stopped when enough has been run; or a larger quantity may be run in, the excess being afterwards discharged. In many works no weighing machine is used; but the amount is judged by its height in the ladle.

When "direct metal" is used the cupola is, of course, not needed, its place being taken by a metal mixer. The ladle conveying the direct metal may be dealt with by any of the methods given for cupola metal; but the second is almost always used.

The Converter or Vessel.—This is the essential part of the apparatus. Its form and size have undergone many modifications, but are now fairly well settled into two or three types.

The air may be blown in at the bottom of the converter, or it may be sent in at the side, below the level of the metal. Converters are, therefore, either bottom blown or side blown.

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* "Steel," page 319.

The metal may be removed from the converter by tilting and pouring, as already described, or the converter may remain fixed, the metal being tapped out from a tap hole. Converters may be therefore either tilting or fixed.

The external form of the shell may narrow considerably towards the top and bottom, the whole having a curved contour, or the sides may be cylindrical; the body is therefore either curved or straight. The mouth of the converter may be horizontal when the converter is up, *i.e.*, it is parallel to the bottom and concentric with it, or it may be turned over to one side as in the example already given; it is then eccentric. The converter already described is a bottom blown, tilting, curved shell, eccentric converter. All converters, except some used for small charges, are bottom blown and tilting; they have usually a straight shell, but they may be eccentric or concentric.

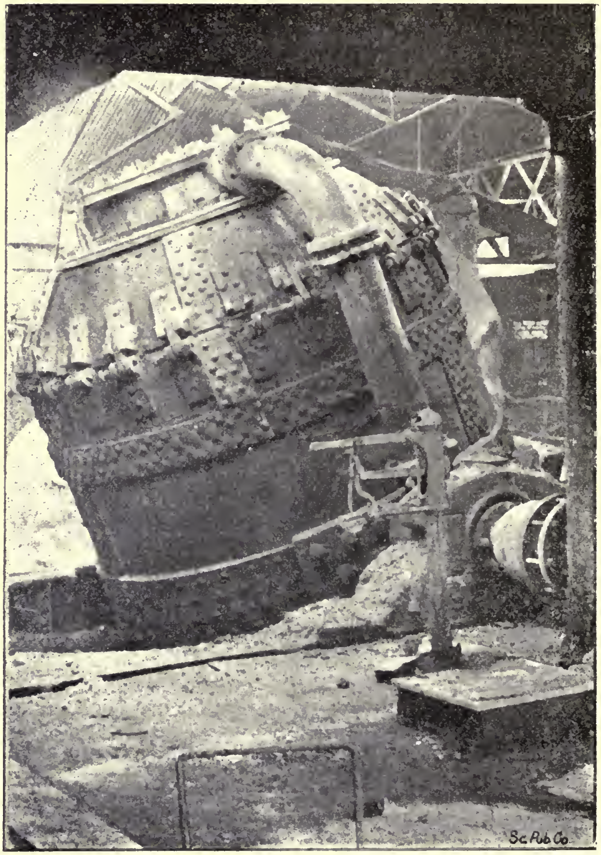

FIG. 129.—Bessemer Converter (Bottom up).

The Converter Shell.—This is of sheet iron or steel, ¾ in. to 1 in. thick. It is always made in three parts—the body, the hood, and the bottom—which are made separately, and are separately removable, and are held together by catches and keys when in use. The plates of which the converter is made are strongly riveted together, as will be seen from the illustrations. (Figs. 129 and 130).

The body of the converter is now usually made cylindrical. To it is bolted the strong trunnion ring which carries the trunnions. The trunnions are hollow steel cylinders, one of which conducts the blast to the pipe or goose-neck, by means of which it is carried to the bottom of the converter. The pipe may be attached to the body of the converter, or separate from it. To the other trunnion is attached the turning gear. The trunnion ring itself may be either a heavy casting or a heavy flanged wrought-iron or steel plate, and is now very generally so fixed as to leave an air space between it and the converter body, the body being attached to it by stout brackets.

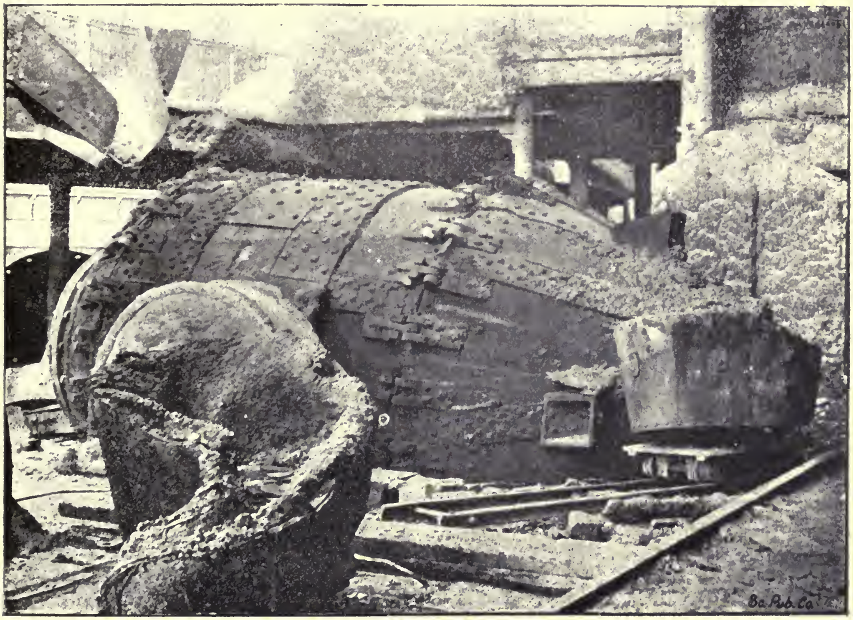

Fig. 130.—Bessemer Converter (and Shoot in position for receiving charge).

The removal and replacing of a body which is attached to the trunnions is a tedious process, and may involve long delay, as the converter body, with its trunnions and fittings, must be lifted away by means of a powerful crane. To overcome this difficulty, Mr. Holley has designed a removable shell (shown in Fig. 131), so arranged that the body can be quickly lifted out of the trunnion ring and replaced. The trunnions are attached to a trunnion ring which is quite independent of the body of the converter, and is of such size that the latter passes easily within it, and it is bored with a series of vertical holes about 1 in. in diameter. The converter shell is provided with a series of strong iron brackets, long enough to rest on the upper side of the trunnion ring, and with a series of holes corresponding to those in the latter. When the shell is in position, right way up, bolts are put through the openings and firmly keyed up; the weight of the converter is thus carried by the iron brackets resting on the trunnion ring, and when it is inverted the weight is hung on the bolts passing through the ring. To keep the converter in place and prevent stress, a series of strong screws are passed horizontally through the ring and screwed up against the converter body. When the converter is to be removed, it is turned bottom upward, a truck, with an hydraulic lifting table, is run underneath, and the table is raised till it supports the weight of the converter. The screws are then slackened, the keys withdrawn, the bolts taken out, and, the table being lowered till the converter is clear of the trunnion ring, the truck is drawn away, and another, bearing the new body, takes its place.

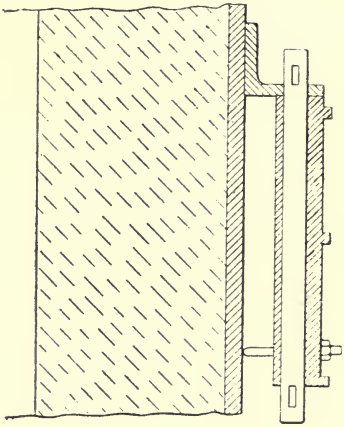

Fig. 131.—Holley Removable Shell.

The Hood.—The hood is also of iron or steel plate, but it may be thinner than the body of the converter. It is lifted into place by means of a crane and keyed in position.

The Bottom.—This is, perhaps, the most important part of the converter. At anyrate, it is that portion which wears out most rapidly, and which, therefore, requires most frequent renewal. The upper portion is made of iron or steel, like the body, and the lower portion, or bottom plate, is a circular iron plate, perforated for the passage of the tuyeres by which the air is to be admitted.

Below this is the cylindrical air chest; this is closed at the bottom by an iron plate or cover, and as the tuyeres may need renewal and repair frequently, and it is very important that such repairs should be done quickly, this plate must be easily removable. The sides of the air chest are provided with a series of pins, and the cover has corresponding holes, so that the plate can be put on and keyed up, and to release it the keys have only to be driven out and the plate forced off.

In many modern American plants the bottom plate is made double, or a false plate is used, so that there is an air space between the converter bottom and the air chest. Should any leakage occur the metal finds its way out, and can be immediately detected, and the leakage can be repaired.

The Converter Lining.—With the removable shell all parts of the converter are lined in the repair shop, but with other forms, whilst the hood and bottom are lined in the shop, the body must be lined in position.

In this country the lining material is almost always ganister, a sandstone containing just enough argillaceous matter to make it become plastic when wetted, and to bind well on drying. Speaking of American practice, Howe says: "The vessel linings are usually 'monolithic,' a mass of clay and quartz rammed solidly together and thoroughly dried. Some vessels, however, are lined with blocks of stone, which give good results; but, as far as my experience goes, do not last so long as the monolithic lining. The monolithic lining is usually made of a mixture of from 50 to 60 per cent of coarsely-crushed quartz, in pieces whose largest dimension is not over 2 in., and from 17 to 25 per cent of finely-pulverised fat fireclay, the remainder consisting of some finely-ground siliceous material, such as old bricks, fire sand, or loam sand."

The linings are put in in various ways. The usual method is to put into the portion to be lined (bottom, middle, or hood as the case may be) a core the shape which the interior is to have, and then to ram the refractory material, mixed with enough water to make it plastic, round it. Another method, which is much quicker, and which is said to give equally satisfactory results, is to mix the plastic material very thoroughly with water, and knead it well, as in crucible making. "It is then cut up into lumps, which a man standing within the vessel throws against its sides; he then smooths and pats them into shape with a wooden mallet. A 10-ton vessel has been lined in the same general way in seven hours."* Silica bricks and other materials have also been used for converter linings.

The lining of the bottom is of very great importance. Dummies the form and size of the tuyeres are placed through the holes in the bottom plate, and the material is well rammed round them. The material may be a clay silica mixture, as above, or ganister. Tiles or bricks may be inserted in the clay to strengthen it, or the bottom may be made of bricks set in the least possible quantity of clay. The bottom is then thoroughly dried for from 12 to 48 hours, either by running into a drying stove on the carriage on which it was brought for repair, or by putting it under a hood and burning gas above it. When the bottom is dry the dummies are taken out and the tuyeres inserted, being held in their place by buttons fixed on the underside of the bottom plate. The bottom is put on a truck, which is run under the converter and the bottom is lifted into place.

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* Howe, "Steel," page 351.

Joint Between the Body and the Bottom.—The making of a tight joint between the body and the bottom has always been a matter of difficulty. The joint between the hood and the body need not be tight, as only gas can escape; but if that between the bottom and the body be not tight, metal will be forced out. In the early forms of plant, the joint was made by running in a liquid slurry of clay and water, through the mouth of the converter, and trusting to its finding its way into the crevice. Holley suggested a method of external plugging (Fig. 132), which has largely come into use. The inner edge only of the lining comes into contact, a space being left at the outside between the shells of the body and the bottom, and this space is plugged with clay.

Howe states that in America "the joint is made by spreading on the upper side of the bottom a ring (or 'noodle') of ball-stuff, covering this with a little graphite, and squeezing the bottom tightly against the shell lining by means of the bottom-jack. The graphite preserves a good parting, so that the bottom, when worn out, may be removed without tearing away the lining of the shell, indeed leaving it so smooth that a sound joint is easily made with the next bottom. The powerful bottom-jacks in some recently-built works exert a pressure of about 2,000 lbs. per foot on the joint, which, thus made, never leaks. In some works, which have neither bottom-jacks nor hydraulic bottom cars, in the vessel is inserted a ring of ball-stuff, set on the edge of the shell lining, the bottom placed on this by means of a crane, and keyed tightly. Even this uncompressed joint serves admirably."*

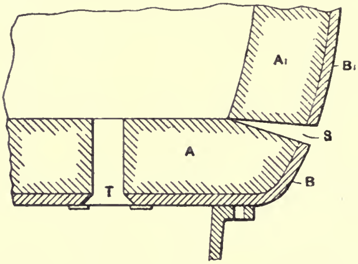

Fig. 132.—Holley Bottom Joint.

A Bottom Lining; B Bottom Casing; A_1 Body Lining; B_1 Body Casing; S Space into which lining material is rammed; T Tuyere.

Repairs.—The lining of the converter requires constant attention. Owing to the scouring action of the slag, it is cut away in places, the wear often being very irregular; and in other places infusible accretions or skulls may form. If these latter cannot be melted out they have to be cut away. Thin places are repaired by the addition of balls of clay, only that which is absolutely essential being done between blows, more important repairs being left till the converter is standing.

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* "Steel," page 350.

The wear is greatest on the bottom, as this is cut away more or less regularly. The minimum thickness to which the bottom can be used varies, but about 6 in. is a good average; often, however, it is allowed to wear thinner. The wear is judged by the appearance from the mouth, and when necessary it can be measured by taking off the cover plate of the air chest, when the converter is over, and measuring the length of the tuyere openings with a wire or rod.

It sometimes happens that a tuyere wears more rapidly than the rest of the bottom, or it may give way during the blow and allow the metal to escape.

The converter is turned down, the cover plate removed, and the holes stopped with clay, or the tuyere taken out, as may be judged best. The tuyere being removed, the tuyere opening may be stopped with clay, or a new tuyere, preferably a little smaller than the old one, may be surrounded with plastic clay and pushed into position.

In the case of eccentric converters, the wear on the underside of the hood where the blast strikes is very rapid.

Size and Form of Converters.—The converters are now almost all built with straight shells, and are about equally divided between eccentric and concentric. In the earlier days the capacity was usually about five tons; now it is more usually 10, and, in some cases, 15 tons. A modern 10-ton converter will be 7 ft. 6 in. to 8 ft. diam. inside the lining. The lining will be about 12 in. thick, and the outside casing $\frac{3}{4}$ in. or 1 in., so that the external diameter will be about 10 ft. The body portion of the shell will be about 9 ft. high, the height being of little importance, except that there must be space when the converter is over for the metal to rest clear of the tuyere holes. The hood will be 5 ft. or 6 ft. high, and the bottom portion, the bottom being flush with the surface, 12 in. to 18 in. deep.

Figs. 133, 134, and 135 show modern American converters from Howe's "Metallurgy of Steel," and Fig. 136 a modern English converter for a 15-ton plant.

The Tuyeres.—The number of tuyeres varies considerably, usually being between 6 and 20. The number of holes in each is from 7 to 12, and they are from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. diameter.

The total area of the tuyere openings varies from ·75 to 6 square inches for each ton of metal contained in the converter, the largest area being used in America, and the smallest in Germany; whilst in England the area is about midway between the extremes—say, 3 in. Obviously—the air pressure remaining the same—the amount of air which is given will be proportional to the area of the tuyere openings.

Turning Mechanism.—The turning mechanism is usually a steel pinion attached to the trunnion, gearing into a horizontal or vertical rack and operated by means of a hydraulic cylinder. The amount of rotation which is needed will vary according to the arrangement of the converters from 180 deg., or thereabouts, to 360 deg. Other methods of rotating might be used.

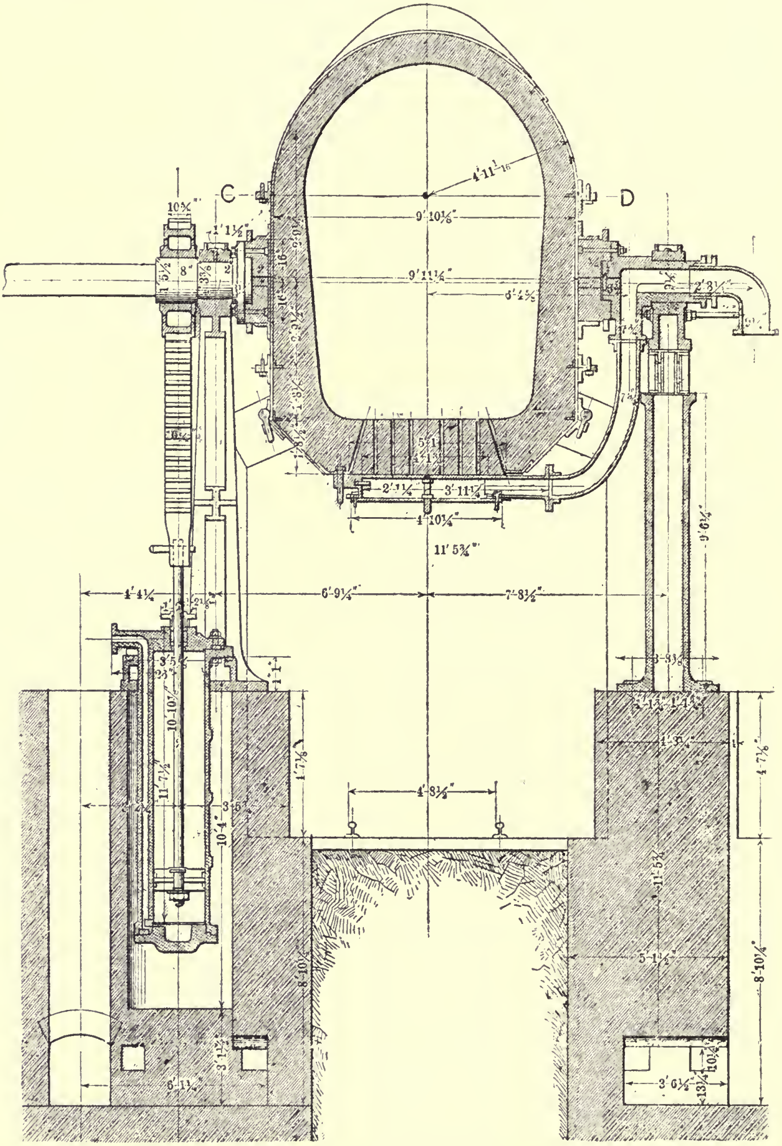

FIG. 133.—American 15 ton Converter. Cross Section. (Howe.)

Blowing Engine.—The engine used is always of the direct-acting horizontal type, and is driven at a much higher speed than in the case of blast-furnace blowing engines, the quantity of air required being less, but the pressure much greater. Each ton of iron will require somewhere about ·58 ton, or 1,340 lbs. of air, which

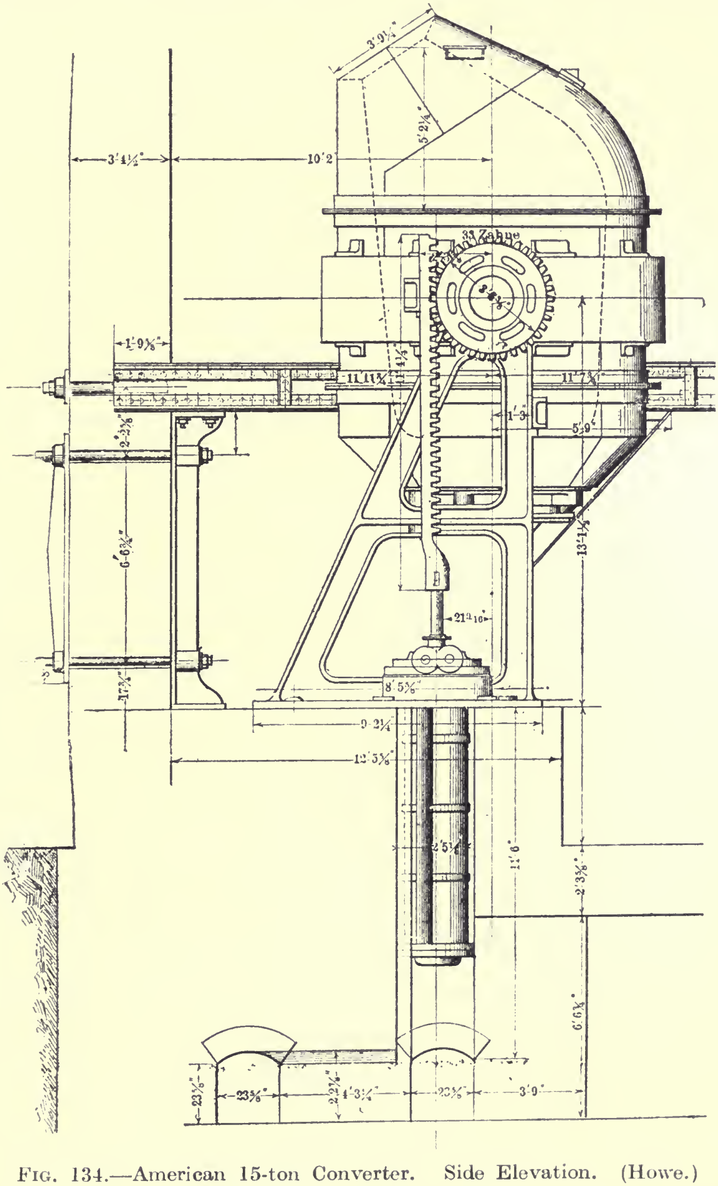

Fig. 134.—American 15-ton Converter. Side Elevation. (Howe.)

will occupy about 16,560 cubic feet (N T P): or, for a 20-minutes' blow, 828 cubic feet per minute, as the time of blow depends on the amount of impurities to be removed and the amount of air given, with a constant air supply, it will depend on the amount of substance to be oxidised. This is the usual condition of working. With iron of uniform quality the rate of blowing can be modified by varying the quantity of air.

The air must be supplied at a pressure sufficient to enable it to force its way easily through the metal. The depth of metal in the converter is usually about 1 ft., and this will exert a pressure of about $3\frac{1}{2}$ lbs. to 4 lbs. per square inch. The air is usually given at a much greater pressure than this, the engine being arranged to give any pressure required from 10 lbs. to 25 lbs. per square inch.

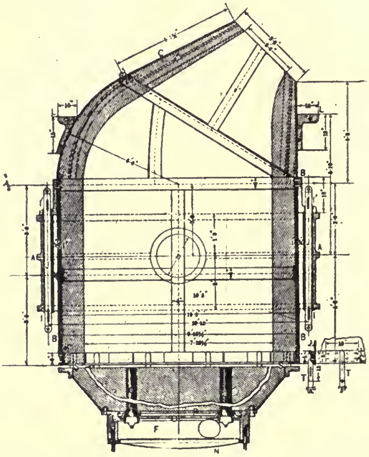

Fig. 135.—10-ton Converter with Removable Shell.

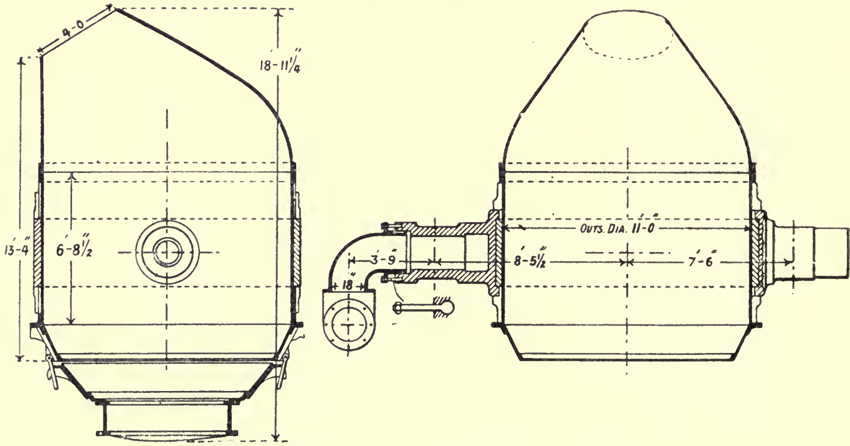

Fig. 136.—English 15-ton Converter.

The engines are usually worked in pairs, so as to keep the blast as uniform as possible.

Durability of the Converters.—The converter linings wear out with greater or less rapidity.

Bottom : This wears out much more rapidly than any other part of the lining, and its life depends very much on the conditions of working. Howe says : " Heavy blast pressure, short and cool heats, small tuyere holes, small depth of metal above the tuyeres, as well as proper materials, careful ramming, and, above all, very thorough baking, all lengthen the life of the bottom. The heavy blast pressure, small tuyere holes, and small depths of metal probably lengthen the life of the bottom by lessening the intimacy of contact of the tuyeres (and it is they that cut out before the surrounding bottom) with the bath of metal, which in the neighbourhood of the tuyere ends is highly charged with iron oxide—a powerful flux for the siliceous tuyeres. The smaller the tuyere holes the more rapidly will the blast emerge from them, and the more will it lift the metal from them."

" The direct effect of heavy blast pressure is probably to corrode the ends of the tuyeres, but this effect is outweighed by the holding of the metal away from the tuyere ends."

The durability of bottoms therefore varies much, but will usually be from 10 to 20 heats, and occasionally more.

The Body : The life of the body lining will depend very much on its composition and the care with which it has been made. Howe gives a table*, to which all interested should refer, showing the durability of various linings. The body linings lasted from 4 to 12 months (in one case 18 months), and something over 3,000 blows.

Arrangement of Works.—The arrangement of the plant is a matter of great importance, especially in a process like the Bessemer, where rapid work is essential to success. The arrangement will be largely determined by the position assigned to the converters, as on it depends the possible arrangements of the casting pit, &c. There are, in general, two methods of arrangement : (1) The British system, in which the converters are arranged in pairs, each pair having its own casting pit ; and (2) the American arrangement, in which the converters are arranged in a line.

The arrangement of a typical British plant is shown in Fig. 137. The two converters are placed on the circumference of a circle with their mouths pointing in opposite directions, and so arranged that when they are tipped for pouring the mouth comes over the ladle. The casting crane is centred in the middle of the casting pit, and moves over the moulds and under the mouth of the converter. The casting pit will be about 30 ft. diameter, and will be available for moulds for about 200 deg., more or less, according to the position of the converters. The casting pit is usually sunk below the floor level to a depth of 2 ft. 6 in. or so, so that the tops of the moulds in use will be near the level of the floor. In some works the converters

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* " Metallurgy of Steel," page 351.

are placed so high that there is no need to lower the crane to receive the metal, and this arrangement has many advantages. The casting pit is also often made much shallower.

In the older plant, cupolas for melting the iron, and smaller ones for the spiegeleisen, were placed on a platform at the rear of the pit. As already remarked, the use of the latter is now abandoned, and the former are placed in any convenient spot, the metal being brought up in a ladle. The cranes for lifting the ingots and moulds will be conveniently placed on each side of the pit, and must be of such size that the arm will reach over any part of the pit. In some cases one large crane, with a jib about 20 ft. long is placed opposite the pit at a point equidistant from the converters. This is only practicable when the working is slow and only a comparatively small angle of the casting pit is used. Rails are laid, on which trucks can run to carry away the ingots and moulds (unless the former are transferred by the crane to the soaking furnace), and the ladles when repairs are needed.

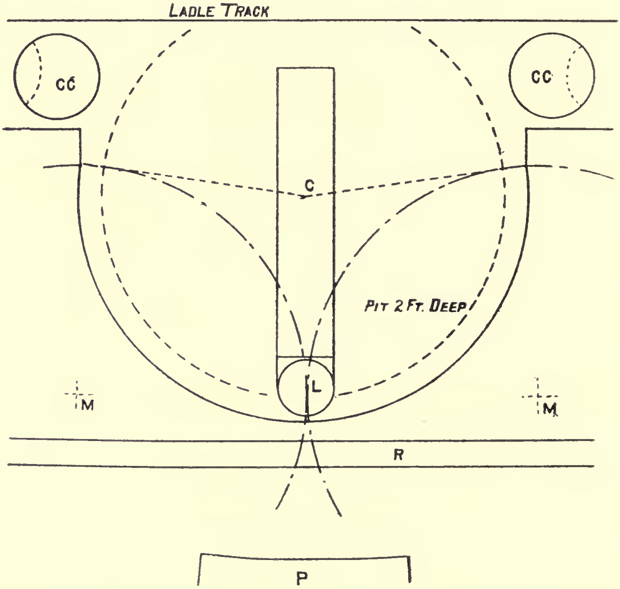

Fig. 137.—Plan of British Bessemer Plant.

CC, Converters ; C, Ladle Crane ; L, Ladle ; P, Pulpit ; M, Ingot Cranes ; R, Rail Track.

The repair shop for the converters must be conveniently placed, and either a crane or rails must be provided for carrying the converter.

The whole of the movements of the plant, except those of the ladle crane, are controlled by the foreman, who occupies an elevated platform (the pulpit) so placed that he can command a view of the converters and cranes. The ladle crane is worked by a man on it, he being usually sheltered by a little sheet-iron shed.

In many modern plants the converters are placed side by side. This arrangement (Fig. 138) has many advantages. The converters are more easily charged, as they tip over towards the platform; an additional converter can easily be put in, so as to keep the work going if one should be incapacitated, and a larger angle of the casting pit can be utilised, thus enabling a smaller pit to be used, or the work to be done more rapidly. It has, however, the disadvantage that the converters blow over the platform on which the men work, or over the casting pit; and if they are concentric converters and blow upwards, both the pit and the platform are likely to be spattered with slag and metal.

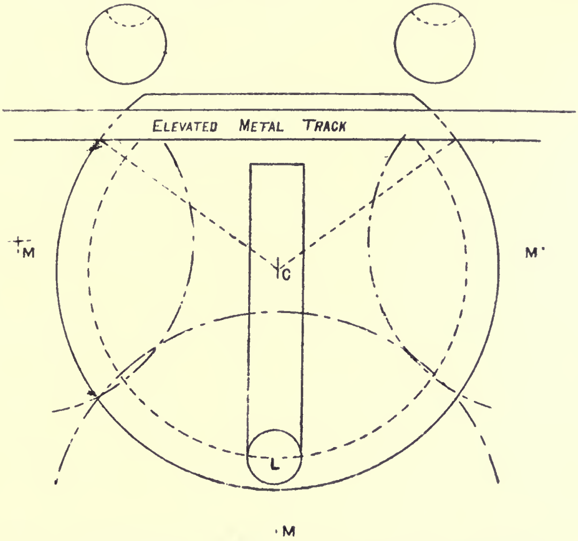

FIG. 138.—Plan of Modern British Bessemer Plant.
C, Ladle Crane; L, Ladle; M, Ingot Cranes.

The casting pit is sometimes placed at some distance from the converters. The metal is then received into the ladle, and this is transferred by a crane or otherwise to the casting crane in the pit; and where rapid working is required, and the accommodation of one casting pit is not sufficient, several may be used. Several converters may be placed round the circumference of the ladle pit, their axes all pointing radially to the centre.

In the modern American plant the converters are almost always arranged in a row, pointing backwards, away from the casting pit. Three converters may readily be worked with two casting pits (Fig. 139) and ladle cranes, the centre converter being served by both pits and the end ones by one pit each; or, better, auxiliary pits are used, to which the ladle can be lifted by a crane.

Longitudinal casting pits are sometimes used. These may be in a line, or they may radiate from a centre. The crane is dispensed with altogether, the ladle being carried on a truck, which is hauled by an engine or a chain along the pits. With the straight pit any required length can be given, and a much larger space can therefore be covered with the moulds.

In some works the pit is dispensed with altogether, the moulds not being put on the floor, but on trucks, so that they can be drawn away immediately they are filled. This plan seems to offer many advantages.

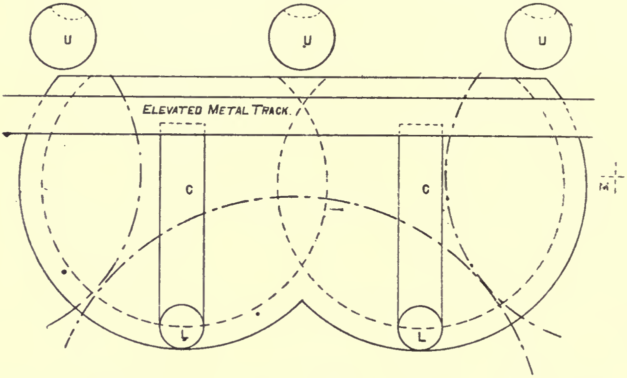

FIG. 139.—Plan of Bessemer Plant with Two Casting Pits.
U, Converters; C, Ladle Cranes; L, Ladles; M, Ingot Cranes.

In the older works the various necessary parts—cupolas, repair shops, &c.—were much crowded together. The modern tendency is to separate them much more widely and give much more room, and therefore to make much larger use of tracks and locomotive engines.

CHAPTER XXVIII.

THE BASIC BESSEMER PROCESS.

THEORY.

The Bessemer process soon proved a great success, and the make of steel by it increased enormously in a few years. Its use was, however, limited by the necessity of a very pure iron free from phosphorus and sulphur, and as the British ores, with the single exception of those of Cumberland and North Lancashire, were unsuitable for the production of such an iron, ores had to be imported in large quantities from Spain and other localities. Attention was soon turned to the conditions of the blow, and especially to those which prevented the removal of the phosphorus, and it was seen that the non-elimination of the phosphorus was due to the acid, *i.e.*, siliceous, nature of the converter lining used, and that the difficulty might be overcome if, in place of the siliceous ganister, a basic material could be found suitable for lining the converters.

Lencauchez is said to have been the first to propose the use of a basic lining, and others followed, but their experiments were not successful. "Gruner, also, who in 1875, in his work on metallurgy, recommended the addition of clay to calcined dolomite, failed of success."*

In 1872 Snelus took out a patent (No. 908) for a basic lining consisting of a mixture of lime and magnesia with a small quantity of clay and oxide of iron; but, though his experiments promised success, they were never brought to a practical issue.†

The nature of the problem was seen and appreciated by Mr. Sidney Gilchrist Thomas. He set himself to solve it, and in the practical solution of the problem he was ably seconded by his cousin, Mr. Percy C. Gilchrist, who was chemist at the Blaenavon Iron Works, and who was therefore able to make experiments with a small converter at the works. Several materials for a basic lining were patented and tried. The first patent covered the use of lime, or similar material, with water-glass—*i.e.*, a soluble alkaline silicate; and on October 5th, 1878, a second patent (5,869) was taken out for the use of magnesian limestone containing suitable amounts of silica and alumina. The material was to be calcined, crushed, and moulded into bricks, or, if a suitable magnesian limestone could not be obtained, mixtures of other substances could be substituted. With these materials the process at once became a practical success.

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* Wedding, "The Basic Bessemer Process," page 29.

† See "J.I. and S.I.," vol. i., 1879.

With a basic lined converter and iron containing phosphorus the blow is modified. It is like that with a ganister-lined converter until the point is reached when the flame drops; but at this point, whilst the carbon and silicon are removed even more completely than in the acid blow, the phosphorus is only slightly reduced. In order to remove this element the blow must be continued a short time longer (the after blow), and as there is no clear external indication of the exact point at which the phosphorus is all removed this must be determined by turning down the converter, and taking and testing samples of the metal.

CHEMISTRY OF THE PROCESS.

The chemistry of the process is, as far as the early stages are concerned, almost exactly the same as that of the acid process, the necessity for the after blow being the principal difference.

The following figures will give an idea of the way in which the impurities are removed. The pig iron given is, however, lower in phosphorus than that now generally used for this process :—

METAL.

Minutes after commencement of Blow.	0	3	6	9	12	14½	16½
Carbon	3·5	3·6	3·40	2·40	·09	·075	·00
Silicon	1·7	·8	·28	·05	·01	·00	·00
Sulphur	·05	·05	·05	·05	·05	·05	·05
Phosphorus	1·50	1·60	1·63	1·43	1·42	1·20	·08

SLAGS.

Silica	32·60	42·60	36·00	35·60	33·00	15·60
Phosphoric acid	·60	·15	1·60	2·61	5·66	15·06
	33·20	42·75	37·60	38·21	38·66	30·66
Oxide of iron	7·62	2·57	5·91	6·17	7·89	13·43
Difference Lime, Magnesia, Alumina, Oxide of magnesia	59·18	54·68	56·49	55·62	53·45	55·91
	100·00	100·00	100·00	100·00	100·00	100·00

It will be seen that as far as the metal is concerned there is but little removal of phosphorus till the end of the blow, in this case 14½ minutes, but that the removal is very rapid during the after blow, the last two minutes, and that owing to this prolongation of the blow the removal of carbon and silicon is more complete than in the acid process, but there is no further removal of the sulphur.

EXAMPLE OF REMOVAL OF IMPURITIES. (WEDDING.)

		1	2	3	4	5	6	7	8	9	10
	Pig.	2 min. 46 sec.	5 min. 21 sec.	8 min. 5 sec.	10 min. 45 sec.	13 min. 28 sec.	15 min. 13 sec.	19 min. 14 sec.	19 min. 31 sec.	19 min. 49 sec.	Steel.
Carbon	3·21	3·30	3·12	2·47	1·49	·75	·05	·02	·02	..	·26
Silicon	1·22	·72	·15	·007	·012	·005	·008	·005	·005	·004	·01
Phosphorus ..	2·185	2·148	2·224	2·157	2·096	2·053	1·910	·230	·139	·087	·142
Sulphur	·080	·047	·051	·049	·051	·051	·055	·060	·055	·056	·045
Manganese ...	1·03	·71	·50	·18	·16	·14	·01	·01	..	..	·48
Nickel	·08	·07	·06	·07	·07	·07	·07	·06	·07	·03	·06
Copper	·02	·02	·02	·02	·02	·03	·02	·02	·03	·03	·03

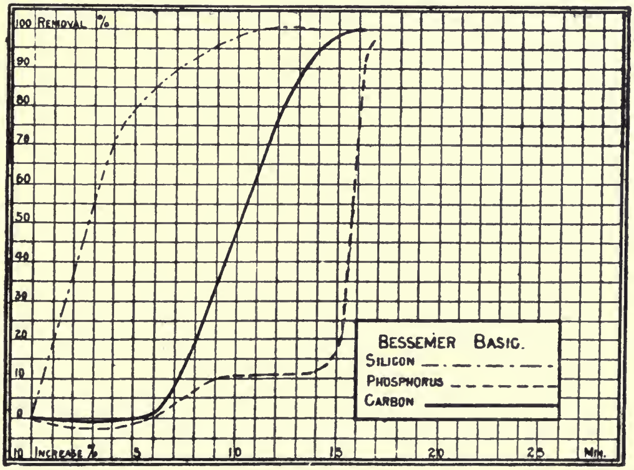


FIG. 140.—Sir L. Bell's curve of the removal of impurities during a basic blow.

The way in which the removal takes place is shown diagrammatically in Fig. 140 from Sir Lowthian Bell's "Principles of the Manufacture of Iron and Steel," drawn on the same principle as the curves previously given. From the analyses of the slag it will be seen that the silicon oxidises rapidly, and passes into the slag. Oxide of iron is slagged from the commencement, but the quantity increases towards the end of the blow.

Fig. 141 is a diagrammatic representation of the removal in another basic blow, the lines giving the actual percentage of the various constituents present at each minute of the blow—the blow in this case being continued a minute or two after the addition of the ferro-manganese.

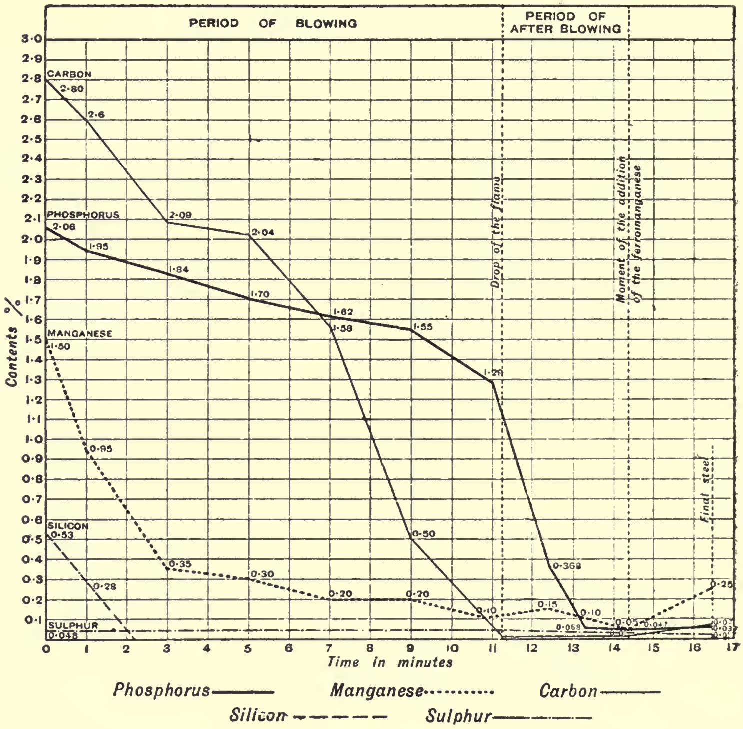


FIG. 141.—Removal of impurities during a basic blow.

The chemistry of the process needs little comment, the figures and diagrams being sufficient to explain exactly what takes place. The phosphorus is almost certainly present in the pig iron as ferrous phosphide Fe_3P, and this is not acted on till the carbon and silicon are almost removed, and then only in the presence of a very basic slag. The slag must therefore be kept basic by the addition of lime. Gruner gives 36 per cent of silica in the slag as being enough to prevent phosphorus removal, and Thomas and Gilchrist fix 20 per cent as being the maximum allowable in a basic slag.

The loss of iron is larger than in the acid process, considerable oxidation necessarily taking place during the after blow, this being indicated by the dense brown fumes which escape from the converter during this period. The amount of slag produced is large, owing to the large quantity of lime added, and the phosphorus is present in this as a calcium phosphate. This slag must be poured off as completely as possible before the addition of the recarburiser, because the ferro-manganese contains carbon and silicon, and these would reduce some of the phosphorus and send it back into the steel. Even when the greatest care has been used, some slag is always left, and there is therefore slightly more phosphorus in the finished steel than there is in the metal at the end of the blow.

THERMO-CHEMISTRY OF THE BLOW.

Since the chemical reactions are, on the whole, much the same as those of the acid process, the thermo-chemical phenomena must be very similar.

Taking a case from Sir Lowthian Bell's "Principles of the Manufacture of Iron and Steel" (page 420), exactly similar to that already given for the acid process :—

COMPOSITION OF MATERIALS.

	Pig Iron.	Steel Scrap.	Spiegel.	Steel Produced.
Carbon	2·83	·234	4·01	·234
Silicon	·66	..	·67	..
Sulphur	·29	·073	..	·073
Phosphorus	1·28	·022	·21	·022
Manganese	·52	·522	11·25	·522
Iron	94·42	99·149	83·86	99·149
	100·00	100·00	100·00	100·00

The pig iron and scrap were used in the proportion of 100 : 13, and 113 parts, together with the spiegel, were required to produce 100 parts of steel, so that the quantities of materials used were :—

		Carbon	Silicon	Sulph.	Phos.	Mang.	Iron.
Pig Iron	100	2·830	·660	·290	1·280	·520	94·420
Steel	13	·030	..	·009	·003	·068	12·890
Spiegel	10	·401	·067	..	·021	1·125	8·386
	123	3·261	·727	·299	1·304	1·713	115·696
Steel made	100	·234	..	·073	·022	·522	99·149
Loss, *i.e.*, materials oxidised	23	3·027	·727	·226	1·282	1·191	16·547

The loss in blowing was 19 per cent—*i.e.*, for 100 parts of material added 81 parts of steel were obtained.

The heat evolved can easily be calculated :—

Carbon 3·027 × 4150 = 12562 heat units.
Silicon ·727 × 7830 = 5692·4 ,,
Sulphur ·226 × Nil. = Nil. ,,
Phosphorus 1·282 × 5868 = 7522·7 ,,
Manganese 1·191 × 1724 = 2053·2 ,,
Iron 16·547 × 1582 = 26177·3 ,,

23·000 41458·1 ,,

In these figures the elements are assumed to give the same amount of heat on combustion that they would do if they were in the free condition. This, as already pointed out, they cannot do—but for the elements present in the acid blow, the difference is so slight as to be negligible. In the basic blow there is always a large quantity of ferrous phosphide. The heat of formation of this body cannot be entirely neglected. The phosphide is $Fe_3 P$, and therefore for each one part of phosphorus there is present 5·42 parts of iron, so that if the constituents oxidised together the heat evolved for each gramme of phosphorus would be :—

Phosphorus = 1 × 5868 = 5868 heat units.
Iron = 5·42 × 1582 = 8574·44 ,,

14442·44 ,,

The heat of formation of the phosphide for each gramme of phosphorus is about 3247. This amount must be deducted from the total. It is best not to deduct it from any particular constituent, as the iron may be re-reduced.

It must also be remembered that the formation of calcium phosphate by the union of the lime with the phosphoric acid produced also evolves heat. Each molecule of phosphate formed from lime and phosphoric anhydride gives 33,000 units of heat, and as the phosphate ($3CaO, P_2O_5$) contains 20 per cent of phosphorus, each per cent of phosphorus will evolve 6,600 units in the formation of the phosphate.

It is now easy to sum up the thermal changes that take place. The silicon oxidises much more rapidly than in the acid process, and therefore if the amount of silicon be high, the blow at the outset may be very hot; the carbon follows, and maintains the temperature, and during the after blow the heat evolution depends entirely on the oxidation of the phosphorus and the iron. As at this point the metal is carbon free, and very infusible, a high temperature is required, and therefore the amount of phosphorus present should be considerable.

GENERAL THERMAL BALANCE SHEET OF BASIC BESSEMER BLOW.

Composition of metal C = 3·42 per cent.
Si = 0·83 ,,
Mn = 1·06 ,,
P = 1·79 ,,
S = 0·092 ,,

INCOME.

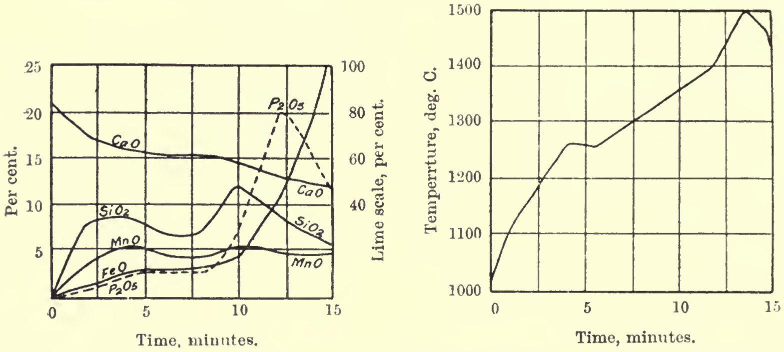
	C.Th.U.	Per cent.
Heat carried in by 10 tons hot metal	2,967,000	38
Heat from oxidation of Silicon	712,000	62
Carbon to CO	812,000	
Carbon to CO_2	376,000	
Manganese	176,000	
Phosphorus	1,146,000	
Iron	1,618,000	
Total	7,807,000	

EXPENDITURE.

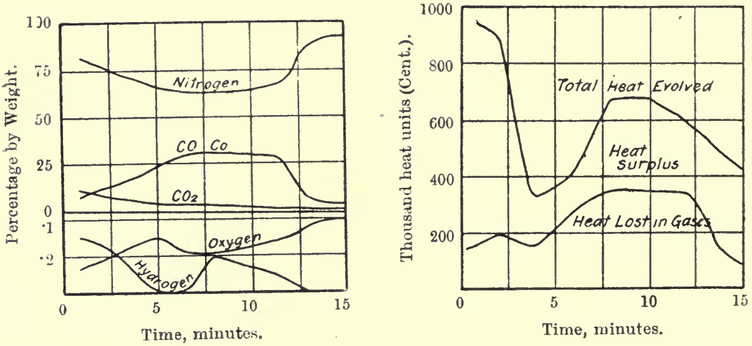
	C.Th.U.	Per cent.
Carried out by gases and lost by decomposing the moisture in the blast	1,946,000	25
Heating lime and lost in slag	1,458,000	21
Carried out in molten steel	3,258,000	42
Lost by radiation and conduction	1,145,000	12
	7,807,000	

PIG IRON.

It is obvious that for such a process the pig iron must be carefully selected. The idea at the outset was that the process would render available, for use in steel making, the various phosphoric foundry pigs, such as those of Middlesbrough, Scotland, &c. Whilst it has been found that these can be used, very much better results are attainable by the use of specially-prepared iron. Such iron is now produced in large quantities under the name of "basic pig," the name being given it because of its suitability for use in this basic steel process.



Changes in Slag Composition. Temperature of Converter Gases.



Changes in Composition of the Gases. Heat balance sheet during blow.

FIG. 142.—Graphs of Changes during Basic Bessemer Blow.

Carbon.—The amount of carbon is unimportant. It will be completely removed whether it be much or little.

Silicon.—The amount of silicon should be kept as low as possible. It is no longer needed as the main source of heat supply. Its presence prolongs the process somewhat, makes the blow very hot, and necessitates the use of a large quantity of lime to combine with it and still keep the slag sufficiently basic. A good basic pig should not contain more than 1 per cent of silicon, and in some English works it is now regularly kept at about ·75. Although low silicon is advantageous, the range of silicon content with which the process can be worked is much greater than in the acid process. The writer has known iron with 3 or 4 per cent of silicon to be blown in basic converters, but such cases are quite exceptional. As the percentage of silicon in basic pig is so low, the iron will usually be white.

Sulphur.—The sulphur is little more removed in the basic than in the acid process, though some may pass into the slag as calcium sulphide. The iron must, therefore, be as free as possible from sulphur. It should never contain more than 0·12 per cent.

Manganese.—This element is much more slowly removed than in the acid process, there being less silica to combine with it and form silicate. The amount of manganese should be about ·3 to ·5 per cent.

Phosphorus.—This is the important constituent for basic pig, as it supplies the heat at the end of the blow. The amount present should never fall below 2 per cent, and 3 per cent, or even 4 per cent, is often present. The normal quantity is about 3 per cent.

LIME.

A considerable quantity of lime is used, the quantity varying from 5 to 16, or 18 per cent, about 10 per cent being a usual quantity. Allowing 15 per cent for a 6-ton charge, this will be ·9 of a ton, or about 2,000 lbs.—and as a cubic yard of burnt lime weighs about 1,201 lbs., this will be about 1·5 cubic yards.

The lime should be well burnt. It should be as free as possible from silica and phosphorus, as these, being already combined with the lime as silicate or phosphate, reduce its efficiency.

Other basic materials have been suggested in place of lime, but lime is now always used.

STEEL.

The steel can be made milder than by the acid process, as the silicon and carbon are more completely removed. Unless great care be taken, a small percentage of phosphorus may be left or may be reduced from the slag.

SLAG.

The slag is a very basic silicate of lime, containing a good deal of phosphate of lime.

The following analyses will show its character. It is evident, however, that the composition of the slag must vary with the amount of lime used and with the composition of the lime and iron. The phosphorus is mainly present as a tetra-basic phosphate $4CaO, P_2O_5$.

	1	2	3
Silica	5·03	12·07	16·60
Phosphoric acid	19·46	11·74	16·03
Total acid	24·49	23·81	32·63
Alumina	2·50	1·96	2·10
Lime	49·27	55·94	47·08
Magnesia	5·92	5·37	4·62
Calcium sulphide	2·13	2·88(S)	·12
Ferrous oxide	10·15	6·08	9·13
Ferric oxide	1·85	1·91	..
Manganese oxide	4·36	2·48	4·32
	100·67	..	..

(1) Lowthian Bell. (2) Wedding. (3) Wedding.

CHAPTER XXIX.

THE BASIC BESSEMER PROCESS, PLANT, &c.

The Converter.—The converters used in the basic process do not differ in any essential particular from those used in the acid process. They are usually, though not invariably, of the concentric type, the mouth being parallel to the bottom for the reason that there is usually a mass of refractory slag formed which is difficult to remove. Frequently the same converters are used for the acid and basic process, the linings only being changed. Owing to the large amount of lime which has to be used, the converter must either be larger than that for the acid blow or a smaller quantity of material must be used. A 10-ton converter will hold about six tons of metal for a basic blow.

The other parts of the plant are also the same as for the acid process.

The Lining.—This is the essential part of the basic plant.

Materials.—As already mentioned, several materials were suggested and tried before the magnesia-lime, which has now become universal, was discovered. A full account of the various materials which have been tried will be found in Wedding's "Basic Bessemer Process." Of these only the most important will be mentioned here.

Magnesian Limestone.—Dolomite is a double carbonate of calcium and magnesium in equivalent proportions, $Ca\,CO_3$, $Mg\,CO_3$ or $(Mg\,Ca)\,CO_3$, containing therefore 54·3 per cent of calcium carbonate and 45·7 per cent of magnesium carbonate. When strongly heated the carbon dioxide is expelled and a mixture of lime and magnesia is left. Whilst this magnesia-lime slakes much less readily than ordinary lime, alone it would not be suitable for basic linings.

Magnesian limestone, often improperly called dolomite, is a mixture of the mineral dolomite, with excess of calcium carbonate some silica, and other impurities. The presence of these impurities, especially silica, is essential in a material to be used for linings, because when the material is strongly heated the silica combines with some of the lime or magnesia to form a more or less fusible silicate, which frits or binds the whole into a solid mass. The quantity of binding material being necessarily small, as the basic material must be kept in large excess, the basic linings or bricks are always comparatively weak and friable. The more silica, within limits, the stronger is the material likely to be; but at the same time the less predominantly basic. About 8 per cent of silica is probably the limit which is allowable, or less in the presence of alumina, which, in contact with a large excess of base, will act as an acid radical. Magnesian limestones mostly belong to the primary period, that of the North of England being of Permian Age.

Limestone may be used in place of magnesian limestone if it contains enough binding material, but is never so satisfactory.

Magnesite is also an excellent material, but it occurs much less abundantly, and is therefore more costly.

The following analyses (Nos. 1-5) from Wedding, will give an idea of the composition of the materials available for the preparation of basic linings :—

	1	2	3	4	5	6
Lime	29·86	31·36	30·12	28·32	47·46	1·72
Magnesia	20·17	19·28	19·21	17·56	2·93	44·06
Ferrous Oxide	..	..	·26	1·78	3·41	3·56
Manganous Oxide	..	..	..	..	·29	..
Carbonic Anhydride (CO)	45·64	45·86	44·97	43·05	42·85	48·02
Silica	4·34	2·00	1·35	6·52	2·48	1·93
Alumina	..	1·50	2·05	2·57	·53	·41
Water	..	..	2·00	..	..	..

No. 1.—From Trier, used at Creusot.
No. 2.—Used at Hörde.
No. 3.—Used at Peine.
No. 4.—Used at Middlesbrough.
No. 5.—Limestone, used at Witkowitz.
No. 6.—Magnesite, Veitsch.

Burnt magnesite is usually of a chocolate colour, from the presence of ferric oxide ; it resists the action of air and moisture better than dolomite-lime, but it crumbles on long exposure.

Preparation of the Material.—The dolomite or other material is calcined to expel moisture and carbon dioxide and leave a " lime." The more magnesium carbonate the material contains the higher must be the temperature of calcination, pure magnesite requiring an intense white heat.

The calcination is carried on in the usual way, the material being in lumps. Ordinary kilns in which the stone is mixed with the fuel may be used ; but as this contaminates it with ash, rectangular chambers, like the kilns used for burning bricks fired by separate coal fires or by gas, are better suited for the purpose.

In some cases where suitable materials are not available, lime or magnesia-lime may be used, with the addition of some binding material such as clay. In this case the stone is usually ground, and the mixture made before calcination, a reverberating furnace being used for that purpose.

The calcined magnesian-limestone is broken up in a stone breaker, and is then crushed under edge runners to a coarse powder. It may either be made into bricks or lined into the converter at once.

Basic Bricks.—As lime or magnesia-lime possesses no binding powder, something must be mixed with it to give the mass cohesion until the temperature is high enough for the mass to bind. The material first used was clay; but this has now been completely displaced by tar. Ordinary tar as it comes from the gasworks contains a considerable quantity of water, the presence of which would be fatal to its use for brickmaking, as it would combine with, and slake, the lime. The tar is therefore heated till all the water is expelled, and it is then known as anhydrous, or boiled, tar.

The ground calcined magnesia-lime, which should be used as soon as possible after calcination, is transferred to the iron pan of a mill with two vertical runners, and hot tar is ladled in from a boiler, or the magnesia-lime and tar are mixed on a hot iron plate and then transferred to the mill, and the mass is mixed up as rapidly as possible. If a plate be used, it should be heated by steam below, and the bottom of the pan should also be heated, so as to ensure sufficient fluidity of the tar for perfect mixture.

The amount of tar required depends on the composition of the material and the temperature at which it was burned, as these determine the extent to which sintering has taken place. The more sintered and the coarser the particles, the smaller will be the amount of tar required. Also, the hotter, and therefore the more fluid, is the tar the less will be required. As a rule, the magnesia-lime is sieved, so that only particles of suitable size pass to the mixer, the finer material being used for mortar.

"The tar is usually measured, and the amount used is, on the average, 20 per cent by volume of the dolomite. Taking the specific gravity of the burned dolomite at 3, and that of dehydrated tar at 1·2, the amount of tar added is 8 per cent by weight. These numbers, however, are different at the different works. At Alexandrowsky they use 17 to 18 per cent; at Hörde, 10 to 12½ per cent; at Creusot, 10 to 11 per cent; at Middlesbrough, 9 to 10 per cent; at Kladno, where the mixing of the lime and tar is performed by hand with a shovel on hot iron plates, 9 per cent; at the Rhein Steel Works, 8 to 9 per cent; at Rotheride, only 7 per cent."*

The hot mixture is transferred to iron moulds, where it is subjected to great pressure. Fig. 143 shows a basic brick press used in one works. The horizontal rotating table carries three moulds.

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* Wedding, page 59.

The one is filled, turned under the hydraulic ram, and pressed. At the same time the brick last pressed is lifted out of its mould, and the mould, from which a brick has just been removed, comes forward, is lubricated with paraffin or similar material, and is ready for filling, so that three bricks are made at each rotation. The bricks in this case are of large size, about 12 in. in each direction. Wedding describes the manufacture of the bricks by hand. He says: "Bricks are made in iron moulds. The moulds are made of wrought or cast iron. If the first, they corrode more quickly; if the second, they must be protected from overheating. The moulds must be covered on the inside with some substance which will prevent the mass from adhering to them; paraffin is mostly used. This is to be done before the mass is tamped in. The tamping into the moulds must be done with heated hammers or mallets. When the mould is full, or a little more than full, the mass (brick) is struck with the broadside of a heavy hammer and driven home."

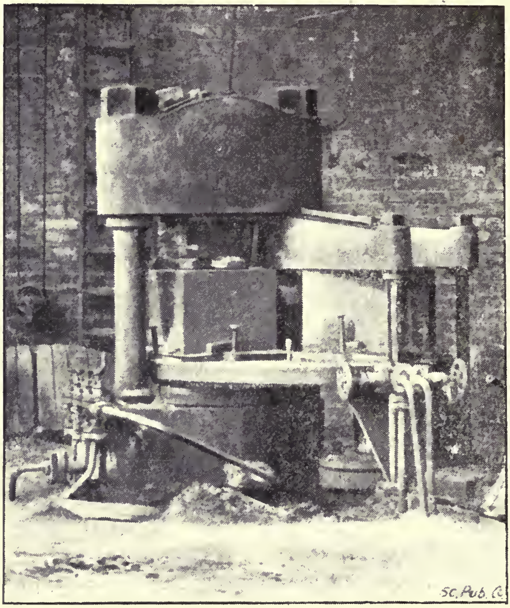

FIG. 143.—Basic Brick Press.

The bricks may either be used as they are, or burnt in kilns; machine-made bricks being the best if to be used direct. The bricks are placed in a kiln—the hand-made bricks still in their moulds—and are fired to a red heat. The tar is decomposed, and the carbonaceous residue binds the mass together. The burning takes from 12 to 48 hours, according to the temperature used.

Lining the Converter.—The body of the converter may be lined with bricks, or direct by tamping, the former being the more usual method.

The brick lining is commenced at the bottom, the first ring being supported on a projecting iron flange. The bricks may be set without any mortar; but usually a mortar made of a mixture of dolomite and tar, like that used for the bricks, is used. If the bricks are used unburned the vessels are very gradually heated. In one case the heating occupied five hours at a low heat, then three hours at a strong heat.

When a rammed lining is to be made, a core of iron, or of wood covered with iron, having the form which the interior of the converter is to have, is placed in position, and a layer of the mixture of magnesia-lime and tar is rammed in with hot rammers; the ramming is continued till the layer is hard, then a new layer is put on the top, and so on.

Another method described by Wedding consists in using a heated iron core, and filling the space between it and the lining with a magnesia-lime tar concrete. The tar is melted by the heat, and thus the mass fills the space perfectly, and the heat is continued till it is hardened.

The bottom is, of course, the most important part of the converter. At one time basic tuyeres were largely used, the basic mixture being rammed hot round dummies, which were afterwards removed, and the tuyeres inserted. Tuyeres are now rarely used, and "pin bottoms" have become almost universal. The bottom casing is brought over a "pin" plate, in which there are as many pins as there are to be tuyere holes in the bottom, and lowered down upon it. The space between the pins is filled up with the basic tar mixture spread in thin layers, and each layer is well rammed with hot rammers, which are heated in an adjacent fire. Solid rammers are used for the bulk of the bottom, and annular rammers—through the centre of which the pin will just pass—for ramming round the pins. About 40 or 50 layers will be required to make a bottom 18 in. thick. The bottom is then placed on a carriage and run into a drying oven, the surface being sprinkled over with iron ore, powdered dolomite, or some similar material, to prevent oxidation.

The junction between the body and the bottom is made by a thin layer of the basic tar concrete.

Repairs.—After every heat the lining must be examined and repaired, if necessary. The repairs are usually made immediately after each blow by introducing balls of the basic tar concrete and pressing them into the places needing repair by means of iron rods. The new material adheres readily to the old.

The bottoms wear out very rapidly, standing only 15 to 30 heats, whilst the body will stand 100 to 110 heats, or in rare cases even more.

Phenomena of the Blow.—The converter, having been emptied, is examined, and any necessary repairs are made. The requisite amount of lime is put in and the iron run in from a ladle in the usual way. The blast is then put on and the converter is turned up. A vigorous ejection of sparks takes place as the converter goes up, this being more vigorous than in the case of the acid blow, probably owing to the ejection of finely-divided lime. The flame is much the same as that of the acid blow, except that it is somewhat more luminous, and it goes through the same changes, and when the carbon is all removed the flame drops. The after blow then commences, and this is accompanied by the evolution of dense brown smoke, characteristic of the combustion of iron. The flame does not give a certain indication of the finish of the after blow, so when the foreman thinks it has been going on sufficiently long the converter is turned down and the air turned off. A sample is then taken in a small ladle at the end of a long iron rod, poured into a mould, the hot ingot is cooled in water, flattened out under a steam hammer and broken, and from the appearance of the fracture the condition of the metal is judged.

If there is much phosphorus the fracture will be largely crystalline, and probably show cracks. As the phosphorus diminishes in quantity the crystals grow smaller, until, when it is all removed, the steel breaks with a dull granular fracture. The appearances are not easy to describe, but the experienced eye can at once determine by the appearance the probable amount of phosphorus present. If the whole of the phosphorus has not been removed the blast is put on, the converter turned up, and the blow continued for the period which is judged to be necessary; another sample is taken, and so on till the metal is in the right condition.

The slag is then carefully poured off into a slag bogie, lime is added to stiffen any slag that remains, and the metal is run into the ladle, the pasty slag being held back by an iron rabble. The casing is brought over a " pin " plate, in which there are as many pins recarburiser—spiegeleisen or ferro-manganese—is added either as the metal flows into the ladle, or after the metal is in the ladle, and the metal is teemed into the moulds. As soon as all the metal is in the ladle the converter is turned mouth downwards, and the remaining slag run out.

The blow takes from 10 to 20 minutes. Wedding gives the following estimate: " It takes from 13 to 25 minutes, or an average of 18 minutes, divided as follows: Two minutes for the refining (desiliconisation), 11 minutes for the decarburisation, and five minutes for the after blow. If five minutes are reckoned for the charging of the lime, five minutes for the addition of the recarburiser, and seven minutes for the pouring, it takes altogether 40 minutes, and it would be possible to make, if no repairs of the bottom were necessary, 38 heats in 24 hours. But the repairs on the bottom take so much time that very seldom more than 30 heats—mostly 20 or 24 heats, but often only 14 or 15— are made in 24 hours. The putting on of a bottom generally takes 45 minutes."

The average times of working are now considerably less than those given.

The loss of iron is larger than in the acid blow, considerable oxidation taking place during the after blow. It may range from 10 to 20 per cent. Wedding gives the average as about 14 per cent of the pig iron.

Comparison of the Acid and Basic Processes.—The great advantage of the basic process is that it allows of the use of phosphoric pig, and therefore does not need the costly pure hæmatite iron. As also basic pig must be low in silicon, it can be made at a lower temperature (*i.e.*, the furnace can have a heavier burden), and therefore at less cost; and phosphoric materials should be cheaper than those free from phosphorus. On the other hand, the process is more costly to work, the amount of lime used is large, the capacity of the converters is therefore reduced, and the blow is prolonged, whilst the increased time needed for repairs diminishes greatly the output of each converter.

The steel is likely also to be less uniform than that made by the acid process. It is much more difficult to hit the end exactly, and if the slag be not very completely removed there is always the possibility of the reduction of phosphorus, which would injure the quality of the steel. There is still in many quarters a considerable prejudice against steel made by this process.

Which of the two forms of the Bessemer process will be used of course depend largely on the iron available. In districts where hæmatite pig is available, as in the United States, the basic process has been but little used; but where phosphoric materials are abundant, as on the Continent, it has become very popular.

CHAPTER XXX.

MODIFICATIONS OF THE BESSEMER PROCESS.

The Bessemer Process is carried out in different ways in various districts, and many modifications have been made in the plant to suit special conditions of working. The practice in localities where it differs considerably from that already described will be given, and also one or two of the principal modifications that have been suggested.

Swedish Method.—It was in Sweden that the Bessemer process first became a practical success, and this even before Bessemer himself had mastered the difficulties in England. This was largely owing to the work of Mr. G. F. Goransson, who, using much larger tuyere openings and less blast pressure than Bessemer recommended, succeeded in 1858 in making steel of good and uniform quality.

The material which he used, and which is still exclusively used in Sweden, was Swedish pig iron. The best qualities are made in charcoal furnaces with a cold blast, and as such furnaces are small, and the output also very small, the iron is necessarily expensive. In the manufacture care is taken to keep the silicon low, the average being about 1 per cent, many samples containing much less. It is also very free from sulphur.

The method used at first, and still nearly universal in Sweden, is to blow the iron in an acid-lined converter until the carbon is reduced to the required amount, and then to tap or teem the metal into the ladle or moulds without the addition of any recarburiser, or at most with a very small quantity—from ·2 to ·6 per cent—of ferro-manganese, the steel being thus made direct. This was also the method used by Bessemer in his works at Sheffield for the first two years of its existence.

The conditions under which this method of working is possible are : (1) That the quantity of silicon in the iron be small ; and (2) that the blow be not too hot. If either of these conditions are not complied with, silicon may be left in the metal, and thus the steel will be of inferior quality.

As there is no external indication as to when the carbon is reduced to any particular quantity, the hitting of the end presents some difficulty. If the supply of iron be of perfectly uniform quality, the end may be judged by the time occupied in the blow, or an experienced man may form some idea by the nature of the flame and the amount of sparks coming from the converter ; but the usual method is to stop the blowing, take a sample in a ladle attached to a long iron handle, and subject this to a rough hammer test, by which the condition of the metal can be judged. When the metal is right the blow is stopped, a very small quantity of ferro-manganese added—or in many cases none—and the metal is removed as usual.

In cases where the pig iron contains 2 per cent or more of silicon, as sometimes happens, the blow is continued to the end in the usual way, and the metal recarburised with ferro-manganese, or with pig iron.

The converters first used in Sweden were small, fixed, side blown (Fig. 144), but these have now been completely replaced by tilting bottom-blown converters of the usual type. They are of small size—having a capacity of about three tons—and the mouths are contracted, so as to avoid loss of heat as far as possible.

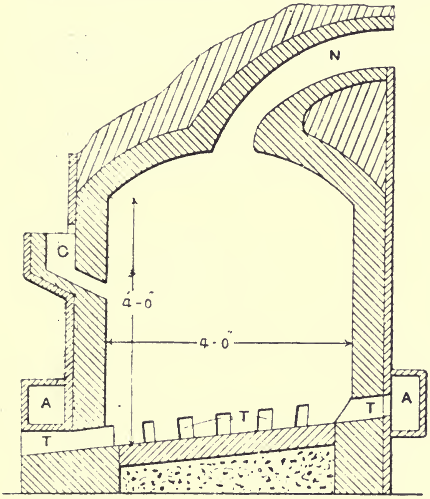

Fig. 144.—Swedish Fixed Converter. A, Air Chest; T, Tuyeres; T, Tap Hole; C, Charging Opening; N, Neck.

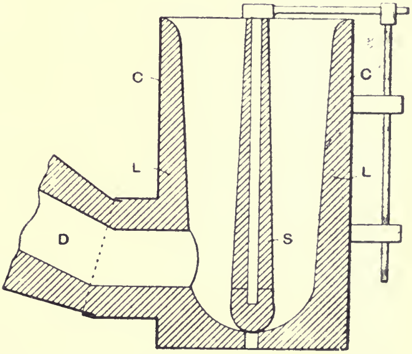

Fig. 145.—Casperson's Converter Ladle. C, Ladle Casing; L, Ladle Lining; D, Mouth of Converter; S, Stopper.

Owing to the small quantity of silicon in the iron, the blow is short, and comparatively cold, the latter condition sometimes leading to difficulties. The slag is said to be more basic than in ordinary converters—perhaps because at the low temperature the lining is not so much attacked—and therefore more fluid. The coldness of the blow is of less moment when the metal is not to be very soft, as the carbon left in increases its fusibility, and at the same time the blow is much shorter, as there is less carbon to be removed.

The waste of iron varies from 9 to 12 per cent, varying, however, very much with the conditions of the blow, and being greater the softer the metal. It is greater than in the process as ordinarily conducted, even though in the latter case the quantity of silicon is much larger.

When the metal is poured in the usual way, owing to its low temperature, there is considerable loss in ladle skulls, *i.e.*, metal chilling and becoming solid in the ladle—a difficulty always met with in working small or cold charges, and much more when these conditions are combined.

This has been overcome by the use of Casperson's converter ladle (Fig. 145), which, instead of being carried on a crane, is attached to the mouth of the converter. As soon as the blow is over the converter is turned down, and the ladle is attached by means of wedges ; the metal is then poured into it, and by lifting the stopper is allowed to flow into the moulds. The ladle is small, and therefore has little cooling effect, and the bulk of the metal remains in the converter. As the ladle is fixed the moulds must be movable, and are brought under it to receive the metal.

Bessemer steel containing from ·1 to 1·5 per cent of carbon is largely made in Sweden, and considerable quantities are exported to this country.

American Practice.—American practice differs very considerably from that in this country. As good hæmatite iron is readily obtainable, the basic process is rarely used, the original form being almost universal.

The pig iron used is usually low in silicon, containing about 1 to 1·75 per cent, the average at the Edgar-Thomson Works being given by Mr. Gayley as 1·1. The amount of heat evolved in the blow is therefore comparatively small, and the blow itself will be short. In order to allow of the satisfactory working of such a pig iron, loss of heat must be guarded against, as far as possible, and as the principal source of this loss, which is under control, is that due to radiation whilst the converter is empty, the blows must be made to follow one another as rapidly as possible, so that there is no delay ; and as the blows are also short, this requires very rapid working. This, as already remarked, in many cases necessitates the provision of increased appliances for dealing with the metal. The actual duration of the blow varies from about eight to (in rare cases) 14 minutes.

As examples of work done, the following may be taken—though, probably, not as an average, but rather as being somewhat exceptional : At one works, with two 6·5-ton converters, 104,441 tons of rails was made in six months, giving an average of 144 heats in 24 hours, or six blows per hour, the average being thus 10 minutes. At another works 318,635 tons was made in one year with two 10-ton vessels, being at the rate of 1,176 tons, 118 blows, in 24 hours.

The quality of the metal does not seem to be deteriorated or the cost of production increased by rapid working.

Direct metal—*i.e.*, direct from the blast furnace—is now very generally used, it being first passed through a metal mixer so as to minimise accidental inequalities in the quality of the metal.

The Windsor Richards Process.—The working of Cleveland iron high both in silicon and phosphorus in the basic converter is attended with considerable difficulty, owing partly to the very large amount of lime required and partly to the very high temperature produced during blowing, and to meet this difficulty this process has been devised, and is in successful use in Middlesbrough and in Scotland.

A charge of iron ore, with a small quantity of lime, is put into the converter, and the molten metal is run in upon it; the converter is then turned up, and the blow is continued until the appearance of the carbon flame, the converter is then turned down, and as much as possible of the liquid slag is poured off. Lime is then added, the converter is turned up, and the blow is finished in the usual way.

During the first portion of the blow the silicon is oxidised, silicate of iron is formed, some iron being reduced from the oxide, and the temperature becomes high. The slag is perfectly liquid, and contains little phosphorus. One sample was found to contain :—

Silica	53·77	per cent.
Alumina	7·02	,,
Protoxide of iron	4·11	,,
,, ,, manganese	4·27	,,
Lime	27·47	,,
Manganese	2·80	,,
Sulphur	·09	,,
Phosphoric acid	·67	,,

During the second part of the blow the phosphorus is oxidised, as there is little silicon now present, the quantity of lime required is small, and although the iron at starting only contains about 1·5 per cent of phosphorus, a slag rich enough in phosphorus for a manure and containing little silicon is obtained. The after blow is shorter than in the ordinary basic blow. The time of the blow, including the pouring of the first slag, is somewhat shorter than the usual basic blow, and the yield is larger.

The Walrand-Robert Process.—This process is of interest on account of the somewhat peculiar form of converter used—a form which seems to have been first suggested by Walrand, and then known as the Walrand converter,* but subsequently reintroduced as the Roberts' converter.†

The converter is carried on trunnions, so that it can be tilted in the usual way. It is, however, not round, but D-shaped in horizontal section (Figs. 146 and 147), the tuyers being placed in a row along the flat side. They are not put in at right angles to the side, but are inclined, so that as the air enters it will impart a rotary motion to the metal in the converter. The converter is turned down, and the metal is run in in the usual way from a ladle. The converter is then turned up, and as soon as the surface of the metal is about an inch

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* J. I. and S. I., 1887, page 314. † J. I. and S. I., 1889, page 266.

below the tuyere level the blast is turned on. The air strikes on the metal opposite the tuyeres, and the evolution of sparks commences. "The apparatus is gradually raised, and the sparks diminish as the greater portion of the air slips over the surface of the metal. When the molten iron arrives at the level of the tuyeres the noise made by the blast becomes duller, and the sparks increase, because the air penetrates a thin layer of the molten metal. At this moment the tilting must be stopped, that the 'lighting' may be done properly. When the sparks diminish and change their colour the apparatus must be gently raised until the flame begins to issue from the mouth. In this position the converter is stopped, and the flame allowed to issue. It is only when it is well alight that the apparatus must be further raised until it arrives at a position where if the blast were shut off the tuyeres would be covered by about 1½ in to 2 in. of metal."*

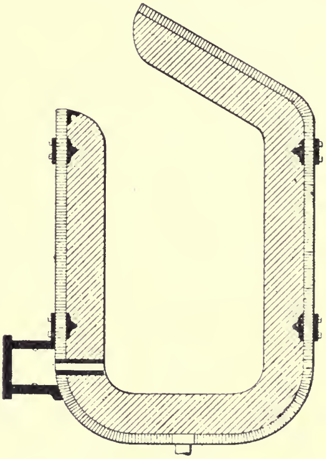

FIG. 146.—Roberts' (Walrand) Converter. Vertical Section.

"The first period of the blow lasts from seven to eight minutes, the second from three to four. At the end of the second period the flame disappears, and it might be supposed that the carbon has been eliminated. The blow, however, is continued during a third period, lasting from one and a half to two minutes, in which the flame reappears, and is of considerable size. As a rule the blows are quiet. As soon as the flame drops after the third period

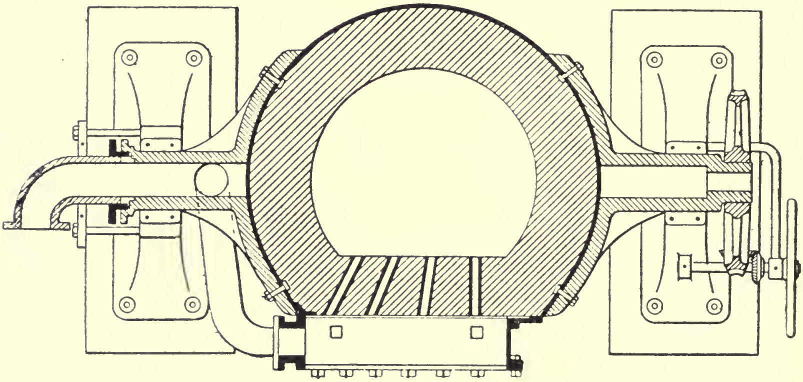

FIG. 147.—Roberts' (Walrand) Converter. Horizontal Section.

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* Garrison. J. I. and S. I., 1889. Vol. ii., page 268.

the converter is turned down and about 1 per cent of 70 per cent ferro-manganese added. The converter is then allowed to stand about 10 minutes to allow the ferro-manganese to melt and disseminate."*

The average pressure of the blast used is about 4 lbs. It is contended that the tilting of the converter gives a valuable power of controlling the rate at which the oxidation goes on, and that much less blast pressure is necessary than in the ordinary type of converter; also that the excess of air causes the carbon monoxide formed to burn inside the converter, and thus keep up a high temperature; whilst the circulation of the metal, due to the direction in which the blast is sent in, ensures all the metal being brought under oxidising influences.

The converters usually have a capacity of about one ton, but five-ton converters have been used. The converter may be either acid or basic lined, and the tuyeres may either be separate or made in the lining on pins. The axes of the tuyeres are all in the same horizontal plane, and in one converter five were used inclined 0 deg., 5 deg., 10 deg., 15 deg., and 20 deg. to a perpendicular to the surface.

The Tropenas Process.—In this process a circular, tilting, side-blown converter is used. There are two rows of tuyeres placed on one side of the converter. The lower series, or fining tuyeres, are circular, and are set radially so as to avoid imparting a gyrating motion to the metal, and are so placed that the air impinges on the surface of its metal, but does not penetrate it. The upper set of tuyeres, or combustion tuyeres, are flat in section, and are supplied from a separate blast box. Their function is to supply air to burn the carbon monoxide, and thus increase the temperature of the flame. The capacity of the converters is about 30 to 32 cwt., and the blow takes about 20 to 25 minutes. The air is used at a pressure of about 4½ lbs., and the loss of iron is from 16 to 19 per cent.

Small Converters.—The ordinary Bessemer plant is only suited for a continuous very large output, and many attempts have been made to introduce plant by which steel can be made on a much smaller scale. The converters for this purpose may be of the ordinary type, or fixed converters similar to those once used in Sweden.

Of the small converters of the ordinary type the best known is the Davy portable converter. This does not differ in any essential from the ordinary Bessemer converter, except that it is much smaller, and that it is so arranged that it can be lifted by an overhead crane and carried to the moulds where the casting is to be made. The recarburiser is added to the converter, stirred with a rabble, and the whole is then taken to the moulds. With a 10-cwt. charge the blow is said to take from 8 to 13 minutes, and the loss of metal 11 to 12 per cent. In casting, the slag is a difficulty, unless it be

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* Garrison, loc. cit.

removed, which is not easy, and it has been suggested to use Casperson's converter ladle.

Fixed Converters.—Many attempts have been made to use small fixed converters. These are always side blown, and many forms have been suggested, the best known being that of Messrs. Clapp and Griffiths.

The converter consists of a cylindrical vessel cased with iron, with a mouth turned to one side much as in the ordinary Bessemer converter. The tuyeres pass through the sides of the vessel, about six being used. They are placed horizontally equidistant round the circumference. Each tuyere has one hole $1\frac{1}{3}$ in. diameter, and the openings are 8 in. above the bottom of the converter, and about the same below the surface of the metal. The blowing is therefore higher than in the old Swedish converters.

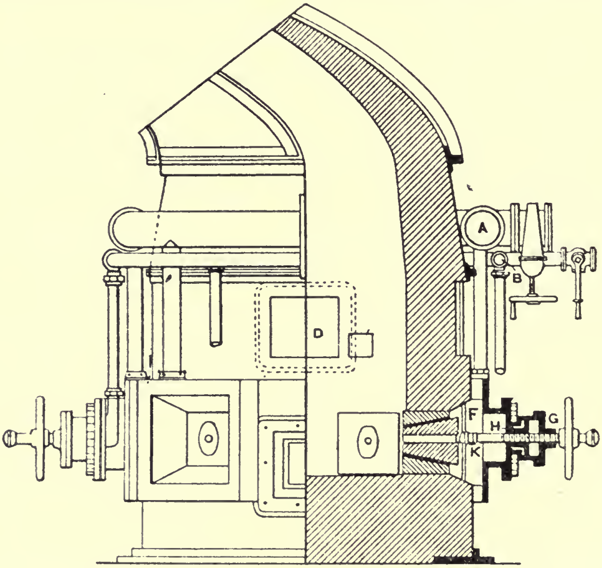

Fig. 148.—Clapp-Griffiths' Converter.

One difficulty in all fixed converters is that the blast must be continued till the metal is clear of the tuyeres, otherwise the metal would run back and solidify in them, thus effectually choking them. There is, therefore, always a danger of over-blowing, and the lower the tuyeres the more likely is this to take place. In the Clapp-Griffiths converter this is to a certain extent overcome by an ingenious arrangement.

"A (Fig. 148) is the main pipe carrying the blast, which is controlled by a large valve. B is an auxiliary pipe carrying the same pressure of blast to the cylinder G, in which works the differential piston H." When the converter is at work the air enters the main blast box F from the main A, and through the tuyeres into the converter. When the blast is turned off A the pressure of the air in B drives forward the differential piston H ; this carries the stopper K, which closes the tuyere, and through which there is a small opening by which just enough air enters to keep the tuyeres clear whilst tapping.

The charge is introduced from a ladle through the door D, and the blast is put on. As the metal rises over the tuyere openings, enormous quantities of red smoke are given off, " showing that iron is burned at the very commencement of the blow." This decreases considerably towards the end of the blow, but never entirely ceases. When the blow is over the tap hole is opened, and the metal is quickly run into a ladle, ferro-manganese added, and the metal taken at once to the moulds. At the moment the tap hole is opened, air is cut off from A, and the piston with its stopper is carried forward. As soon as the metal is clear of the tuyeres, the air is admitted to A, and cut off from the main B, and the valve with its stopper goes back into its former place, so as to admit the full blast of air.

The waste of iron is very considerable, being from 13 to 15 per cent, but often rises to over 20 per cent. The tuyeres stand about 20 blows.

" The lining at the mouth of the converter is rapidly wasted away by the action of the oxide of iron projected against it during the blow, and repairs are generally necessary after about 40 or 50 blows ; sometimes it is worn down to the shell by 25 blows, and occasionally lasts as many as 75 blows. The ganister lining lasts from 400 to 600 blows. A modified form of the converter has been suggested, in which the body is carried on short columns and the bottom is made movable. In one case 173 blows have been made without cooling down the vessel for repairs or changing the bottom."*

The Hatton converter is similar, but the differential pistons are done away with, the air valves being partially closed when the tap hole is opened, so that the blast is reduced to just sufficient to keep the tuyeres clear.

Small v. Large Converters.—The small converters can never become general, as they are necessarily more costly to work than large ones, and the tendency of modern practice is all in the direction of increasing rather than diminishing the size of plant. At the same time there may be cases in which the use of small converters might be advantageous. It is, as a rule, more difficult to ensure uniformity of product in a small converter, and there is always danger of the smaller quantity of metal chilling.

Side v. Bottom Blowing.—The action of the air must be much less uniform with side than with bottom blowing, and the metal becomes much less uniformly mixed with the oxide formed. More

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* Hardisty, J. I. and S. I., 1886. Vol. ii., page 651.

oxide of iron is also formed, and the loss of metal is considerably greater; Howe gives the increased loss as being about 4 per cent. With side blowing the oxidation must, to some extent, continue while the metal is being tapped, and thus the last portion is likely to be more oxidised than the first. As the bottom of the converter wears away the air is supplied nearer and nearer to the top of the metal, and therefore the less perfect is likely to be the mixture.

Fixed *v.* Rotating Vessels.—That Bessemer commenced his experiments with fixed vessels, and that these have now been almost completely replaced by tilting vessels, is of itself proof that the latter are the most generally useful. Howe states fixed converters have four chief defects :—

(1) They do not permit bottom blowing, and therefore the loss of metal will be higher than in tilting converters.

(2) If a tuyere fails, the whole charge must be at once removed from the vessel, and thus made scrap.

(3) The charge must be tapped out. This takes time, and therefore the composition of the metal varies during tapping, and there is always danger of the tap hole becoming stopped in case of a cold charge.

(4) It is impossible to recarburise in the vessel.

He adds : "It must be admitted that the work done in the little fixed Clapp-Griffiths vessels as improved by Witherow is extremely creditable. The difficulties that hung about the old Swedish fixed vessels . . . have certainly been overcome to a most surprising degree. That 46 heats should be made in a pair of fixed vessels in eight hours speaks volumes for the energy cf the superintendent, and something for the possibilities of a vessel long despised and rejected."

"The fixed vessel is certainly very much cheaper than the rotating one ; and where it is absolutely imperative that the cost of installation should be as low as possible (even at the cost of additional loss of iron in conversion and of some slight irregularity in the proportion of carbon in the product) it may be used with advantage, but under all common conditions the rotating vessel is to be preferred." *

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* Howe, "Steel," page 42.

CHAPTER XXXI.

HISTORICAL NOTES ON THE BESSEMER PROCESS.

In most cases the history of a great invention is involved in more or less obscurity. Inventors have usually been too busily engaged in working out their inventions, and often too anxious to keep what they were doing a secret from others, to publish details of their work, so that a complete history can hardly ever be written. The Bessemer process is, however, an exception. At almost every stage the inventor patented his improvements and made them public ; indeed, he thought that the difficulty was not that manufacturers would take the inventions of others, but rather that they were too slow to adopt any change.

In most cases the development of an industry comes by slow additions of many individuals, each doing some little to help it on and adding some small detail, and it is extremely rarely that the inception and working out of a process are due to the same mind. It was so, however, in this case ; and not only so, but when a great development was made by another, the original inventor welcomed it gladly. The history of the Bessemer process is so closely connected with the life of Bessemer that to write one would almost be to write the other. A biography is, of course, beyond the scope of this book ; but the student will find a study of the life of Bessemer helpful and invigorating. Henry Bessemer was born in 1813, at Charlton, in Hertfordshire, and died in London, on March 15th, 1898, his life and work, therefore, extending over the best part of the century. From his earliest days he showed great inventive genius, and invented and patented many things, some of which have not yet been superseded.

In 1853 Bessemer was experimenting with the manufacture of projectiles, and, after many experiments, it became evident that, if his method was to be made a success, it would be necessary to make the guns of some stronger material than the cast iron that was then in use, and to the preparation of such a material he turned his attention. He was not a practical ironmaker, so he studied all the literature of the subject, not then very extensive, and, by visiting works and often making considerable stays, learned exactly what was being done, and he secured a place in London where he could put experimental plant and put his many ideas to the test of actual experiment. Method after method was tried and abandoned, furnace after furnace was erected and pulled down, improvements were made in old processes, but nothing of very great importance was achieved.

At the end of 18 months, he says, “ the idea struck me of rendering cast iron malleable by the introduction of atmospheric air into the fluid metal.” A very simple apparatus, Fig. 149, was designed for the experiments. “ It consists simply of an ordinary air furnace, in which is placed a 40 lb. clay crucible having a perforated cover, through the centre of which a fire-clay tube descends nearly to the bottom. In this crucible 10 lbs. or 12 lbs. of pig iron is first melted. The clay tube is then introduced through the cover in order to convey a blast of air down into the molten metal. In this simple apparatus my first experiments were made, and the important part was ascertained that molten pig iron could be rendered malleable by simply passing a blast of air through it.”*

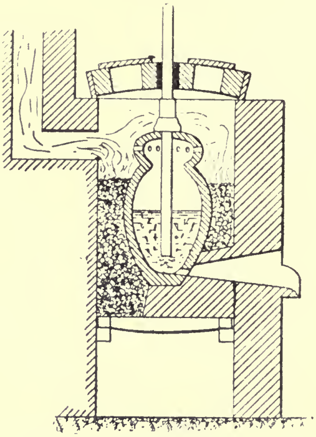

Fig. 149.—Bessemer's First Crucible Converter.

It was soon seen that when the air was passed in the temperature rose very considerably, and then attempts were made to blow without applying external heat. This was found to be possible, and the first tilting converter (Fig. 150) was designed and patented in 1855 ; but most of the experiments were made in a vertical fixed converter (Fig. 150A). Gradually the plant was modified, different types were tried, and ultimately the present form of tilting converter was designed, one of the earliest erected being shown in Fig. 118, which is similar to that erected when the works of Bessemer and Company were started in Sheffield.

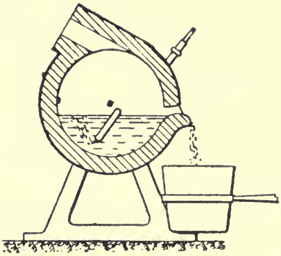

Fig. 150.
Bessemer's First Tilting Converter.

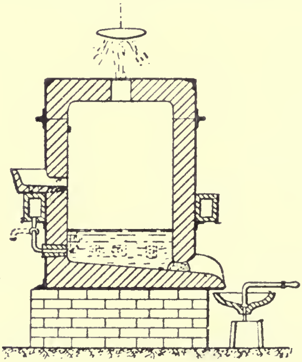

Fig. 150A.
Bessemer's Fixed Converter.

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* Bessemer, J. I. and S. I., 1886. Vol. ii., page 639.

By 1856 the process had been proved to be practicable on a small scale, and good malleable metal had been made from pig iron by simply blowing air through it. Bessemer asked Mr. G. Rennie to see an experiment, and subsequently, acting on his advice, he read a paper before Section G of the British Association at Cheltenham, on August 11th, 1856, and this was the first public announcement of the new process.

The paper attracted universal attention, and many engineers visited Baxter House, St. Pancras, where Bessemer had his experimental plant, and many successful experiments were made, as a rule the blow not being continued to the end, but being stopped whilst a little carbon remained in the metal. Several ironmasters at once entered into negotiations for working the process, and experiments were made in several places, notably at Dowlais and at Glasgow, but in both cases the experiments resulted in failure, the metal obtained being useless. The process was first made a success in Sweden in 1858, fixed converters being used.

Investigation soon showed that the cause of the failure in the British works was the presence of phosphorus in the iron, which was not removed during the blow. Bessemer had used Swedish pig iron, which is free from phosphorus, and this seemed to be the only iron available for the process. The only iron district in the United Kingdom where phosphorus-free ores occur is that of Cumberland and North Lancashire; but it was found that even the pig iron from these districts contained phosphorus, because phosphoric cinder was added in the smelting. Indeed, up to this time there had been no demand for phosphorus-free iron. Such, however, soon began to be made, and was known as Bessemer or hæmatite pig, and, as the process developed, large quantities of suitable ore were imported from Bilbao and elsewhere. On the 24th May, 1859, Bessemer read a paper before the Institution of Civil Engineers, in which he described the work which he had done since his British Association paper in 1856, and showed samples of the metal he had made. But, alas! no one would now believe in it; and, as a last resource, he, his partner, Mr. Robert Longden, and Messrs. Galloway, of Manchester, joined to form the firm of Bessemer and Company. Land was secured in Sheffield, and works were erected. When the works were started, the steel began to sell and to attract attention, as it was £20 a ton cheaper than steel made by the older processes; and in 1861, when the process was in actual operation, Bessemer read a paper, giving a description of his plant, before the Institution of Mechanical Engineers, which met in Sheffield in that year. Mr. J. Brown, whose works were next to those of Bessemer at Sheffield, was the first manufacturer to take out a licence and erect plant for working the new process.

Up to this time, and for the first two years of its existence, the firm of Messrs. Bessemer and Co. made only tool and similar steels. The complete removal of the carbon, and the production of malleable iron, which was Bessemer's first idea, had not been carried out owing to great practical difficulties. When the carbon was all removed oxygen was taken up, and the quality of the metal was thus injured. It became hot short and in extreme cases both hot and cold short.

Mr. R. Mushet heard Bessemer's paper read at Cheltenham, and he states that he saw the process could not succeed exactly in the form described, and he suggested the use of manganese to remove the difficulty. He says: "I charged 16 melting pots with 44 lbs. of Bessemer metal, and when this was melted I poured into into each pot 3 lbs. of melted speigeleisen. I then poured the contents of the 16 melting pots into a large ingot mould, and the ingot thus made was sent to the Ebbw Vale Ironworks, and there rolled at one heat into a double-headed rail." This rail, which may be said to be the first Bessemer steel rail, was put down and used at Derby.

It is needless to enter into the controversy which arose between Bessemer and Mushet over the use of manganese, as it is now entirely a matter of history. Suffice it to say that Mushet let his patents lapse, and that later Bessemer made him an allowance. It is certain, however, that the use of manganese as speigeleisen, and later as ferro-manganese, rendered possible the production of mild steel.

William Kelly made his first experiment in 1847, at his ironworks near Eddyville, Kentucky, for converting molten cast iron into malleable steel, by what he called a "pneumatic process," and it is asserted that years before Bessemer started his experiments there were steamboats on the Ohio River with boilers made of iron refined by Kelly's "air-boiling" process. Financial difficulties prevented his developing the plant he had constructed, and in fact his patent was only restored to him about 1863. In 1870 both Kelly and Bessemer applied to the U.S.A. Patent Office for renewal of their rights. Bessemer was refused, and his claim disallowed, but Kelly's was renewed for seven years. This led to objections from the steel makers, who dreaded increased royalties, and they therefore lauded Bessemer, whose claim to royalties was now at an end, as the original inventor, and Kelly was belittled as an interloper. Both the Bessemer and Kelly process was dependent on the use of recarboniser, due to Mushet, for their complete success.

The subsequent development of the Bessemer process had been in the direction of improvements of the plant and the further use of the metal. In 1862 Mr. Ramsbottom, of Crewe, made for the L. & N. W. Railway the first steel rails, which were put down at Crewe "on the day the Prince of Wales was married." In 1881 these rails were still in use. In 1863 Mr. Ramsbottom had the first locomotive boiler made of Bessemer steel plate, other boilers having been previously made by Mr. Daniel Adamson at Hyde, Manchester, in 1860, and in 1863 the first ship, a stern-wheel barge, was built of the new metal, and the first passenger steamer, the

"Cuxhaven," was built in 1864. Many other engineers took up the work, many improvements were made in the details of plant, and by about 1880 the process was in use on a very large scale all over the world.

Bessemer had failed entirely to make good steel from iron containing phosphorus. It is true the need for this seemed less urgent, for Bessemer pig was made abundantly from imported ores ; but there were districts where the iron, owing to its phosphorus, did not lend itself to the Bessemer process, and the ironmasters never lost sight of the desirability of the discovery of a method by which steel could be made from phosphoric pig ; and as the demand for mild steel increased, it looked as if the production must be limited by the lack of suitable ores.

Mr. G. J. Snelus, when working with the Danks puddling furnace, was struck with the fact that phosphorus was removed when the slag was highly basic, and tried to apply the same principle to the converter. He found that the lime made by burning limestone, or magnesium limestone, could be made into bricks, and that these bricks were better if some fusible base was present, and he lined a small converter for experiment ; and, making a blow of one or two hundredweight of Cleveland iron, found that the phosphorus could be eliminated. In 1872, at a meeting of the Iron and Steel Institute, he stated that he was working on the problem, and in 1873 he alluded to the method he had devised. He took out patents, but for various reasons he did not carry his process to a practical and commercial success.

In the seventies, Mr. Sidney Gilchrist Thomas turned his attention to the same problem. In conjunction with his cousin, Mr. P. C. Gilchrist, he made a large number of experiments, which were mainly carried out in crucibles, and about 1877 they began to obtain satisfactory results. Mr. Martin, of the Blaenavon Works, where Mr. Gilchrist had gone as chemist, placed facilities at their disposal for work on a larger scale, with the results that they were able to read an account of their process before the Iron and Steel Institute in September, 1878. In 1883 the Iron and Steel Institute awarded the Bessemer medal to Mr. Thomas and Mr. Snelus for their work in connection with the basic Bessemer process.

CHAPTER XXXII.

THE SIEMENS OR OPEN-HEARTH PROCESS.

Whilst Bessemer was developing his process, two young German engineers, C. W. and F. Siemens, were experimenting on quite a different line, one which seemed to have no connection with iron and steel production, and yet which was destined to lead to a new method of making mild steel, a method, too, which was to be not only an important, but the successful rival of that of Bessemer.

The experiments of Siemens were in connection with the economy of fuel, and a furnace was devised in which the products of combustion were used to heat to a high temperature a chamber filled with firebrick, the air to supply the furnace being then heated by passing through this hot chamber, and as the waste heat of the products of combustion were thus saved or regenerated, the furnace was called a regenerative furnace.

The first practical application of the principle was to stoves for heating the blast for blast furnaces, as already described.

It was soon seen that better results could be obtained by using gaseous fuel and two pairs of regenerators, both the gas and the air being heated to a high temperature before combustion, and it was found that a very high temperature could thus be obtained—high enough, in fact, to melt steel or carbon-free iron. The furnace was first applied in glass making; then for melting steel in crucibles; then for melting steel scrap with the addition of pig iron—the Siemens-Martin process; and, lastly, for the production of mild steel by melting pig iron with iron ore, the Siemens process.

Outline of the Process.

The furnace used is fed with gas, and is provided with four regenerators. It has gas ports at both ends, so that the air and gas can be sent in either direction, and the direction is usually reversed every hour. The gas and air for combustion are passed through two of the regenerators, and thus become strongly heated, and the products of combustion pass away through the other regenerators to the chimney. Each regenerator must be so arranged that it can be put in connection with (1) either the air or gas supply, (2) the furnace, and (3) the chimney. Suitable valves must be provided for this purpose, the arrangement being shown diagrammatically in Fig. 151 from one of Siemens' papers.

A charge of pig iron is put on to the hearth of the furnace and melted. If it were simply kept melted, exposed to the oxidising action of the flame, oxide of iron would be slowly formed, and this would remove the silicon and carbon exactly as in puddling; but the process would be far too slow—except in cases where the charge was mainly scrap, so that there was only a small quantity of material to oxidise out—so it is hastened by the addition of oxide of iron, in the form of hæmatite. When the iron is melted, ore is added from time to time, till the carbon is removed. As the temperature is very high the metal still remains liquid, and can be tapped out, ferro-manganese being added to recarburise the metal and remove dissolved oxides exactly as in the Bessemer process.

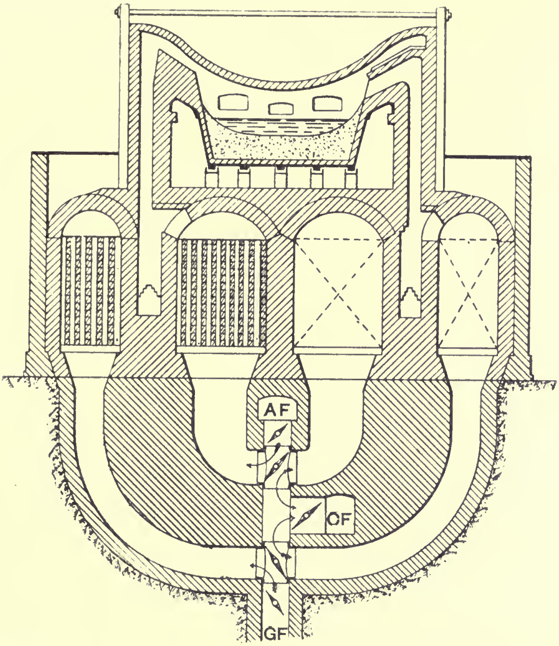

FIG. 151.—Section of Siemens Steel Melting Furnace, showing arrangement of Regenerators, Flues and Valves.

A F—Air flue. C F—Chimney flue. G F—Gas flue.

The process at once gives a means for using up steel scrap, and this is the form in which it was first used by M. Martin. He melted scrap steel with pig iron, and thus not only recovered the steel scrap but made a somewhat larger quantity of steel. This is the Siemens-Martin, or scrap and pig process. Whenever ore is used, whether scrap be used or not, the process should be called the Siemens process, and the furnace always the Siemens, not the Siemens-Martin furnace, though the names are often used very carelessly.

The metal is tapped into a ladle and distributed to the moulds in the usual way.

Chemistry of the Process.

The charge, which usually consists of pig iron with some scrap, is introduced on to the hearth of the furnace, the furnace being at a bright red heat.

As an example of a charge may be taken*—

	Pig Iron.	Scrap.	The Charge.
Carbon	3·750	·170	2·850
Silicon	2·200	·025	1·666
Sulphur	·043	·045	·042
Phosphorus	·043	·045	·042
Manganese	·500	·500	·500
Iron	93·464	99·215	94·900
	100·000	100·000	100·000

As soon as the charge is put in it begins to get hot and then to melt, and when it is melted, iron ore is added till the oxidisable constituents are removed, the carbon being either completely removed or reduced to a suitable amount according to the method of working in use ; then the necessary recarburiser is added to bring the steel up to the required carbon content.

The process thus consists of three stages :—

(1) Melting.
(2) Oreing { Slag formation. / Boiling.
(3) Recarburising.

(1) **Melting.**—During melting oxidation goes on very vigorously, so that the time occupied is by no means lost. The pig iron melts first, and runs down to the bottom of the hearth, often leaving a shell of more refractory materials (the outer skin of the iron and sand from the pig moulds) which melts down with the scrap. The time occupied in melting will be about five hours for a 30-ton charge, the flame being kept short, sharp, and oxidising.

The amount of oxidation which takes place will depend on the conditions of working—the length of exposure, the character of the flame, and the nature of the charge. The pig, melting first, will be least oxidised, and the more refractory scrap will be much more

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* J. W. of S. I. and S. I., vol. iii., page 174.

oxidised, and therefore will carry oxygen to the molten pig. The more finely divided the scrap, the larger the surface it will expose to the air, and therefore the more oxidised will it become.

Scrap cannot be melted without pig iron, because the amount of oxygen taken up during melting would be more than that required to completely remove the oxidisable constituents, and the slag would be pasty and the metal too highly charged with oxides.

The amount of decarburisation which takes place during melting will, of course, vary very much. Campbell* says that during this stage about half the carbon and nearly all the silicon and manganese should be oxidised.

He gives as an example the following figures as an average of 19 charges :—

	Pig.	Steel Scrap. Rail.	Steel Scrap. Boiler.
Pounds used	11,700	39,580	5,970
C, per cent	3·50	·40	·13
Si, per cent	1·72	·07	·02

So that the average charge would contain—

Carbon	1·004
Silicon	·401

After melting, before addition of any ore, the metal contained—

Carbon	·54
Silicon	·02
Manganese	·09

In this charge, however, the amount of scrap was very large, so that oxidation could take place very freely, and the amount of metalloids to be oxidised away was small.

For a charge of pig with 10 per cent of scrap, Messrs. Dick & Padley give the composition of the melted charge as being—

Carbon	3·19
Silicon	2·25
Manganese	·30

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* Proc. I.M.E., vol. xix.

It is therefore obvious that the amount of removal that takes place depends very much on the conditions of working, and all that can be said is that the carbon and silicon will be, to some extent, removed during melting. Campbell says: "If the proportion of pig iron be reduced to the lowest possible point so that no ore is required, the oxidation during fusion will approach 100 per cent of the total, while if the charge contains no scrap, the greater part of the oxidation must be done after fusion." By the time the metal is melted it will be covered with a layer of slag, which protects it from too rapid oxidation.

(2) **Oreing.**—The addition of ore is now commenced, it being shovelled in from time to time as required. If the oxidation has gone far enough to remove most of the silicon during melting, the boil will begin at once; but if the silicon has not been sufficiently reduced there will be a preliminary period of slag formation, during which the metal is coming to the boil.

The ore (Fe_2O_3) may be regarded as a mixture of 2FeO and O. The former will combine with the silica formed by the oxidation of the silicon by the oxygen and will pass into the slag; but when the silicon has all been removed there will be no further need for the oxide, as the slag will probably be quite sufficiently basic, and it will be reduced by the carbon, carbon monoxide being evolved and iron liberated, though it cannot be assumed that some oxide is not reduced to metal by silicon or carbon in the early stages, or that some ferrous oxide is not added to the slag in the later stages.

No calculation can be made as to the actual amount of ore that will be required, because atmospheric oxidation is always going on, more or less. "If the charge is hot it dissolves the ore rapidly, leaving to the flame little chance to do its share of the oxidation; if the charge is cold, only a small amount of ore will be added, and the oxygen will be derived from the gases. Thus any attempt to make an arbitrary equation of the action must fail. It may be broadly said that if the bath contains 1 per cent of carbon in a 25-ton charge, 1,500 lbs. of ore may be used for bringing it down to ·08 per cent. The first 500 lbs. will reduce it to about ·80 carbon, the second to ·40, and the third will finish the work."* Obviously, the presence of silicon or manganese will retard the process and increase the quantity of ore required, and in the case of highly siliceous or manganous ores the amount of ore required will be very largely increased.

In the case of the charge already mentioned from Campbell, the metal before tapping contained—

Carbon	·13
Silicon	·02
Manganese	·04

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* Campbell.

and Dick & Padley give the following analyses of the charge referred to at different stages :—

	Going on Boil.		Boiling.			Steel.	
Carbon	3·17	3·18	2·83	1·51	·53	·20	·14
Silicon	2·0	1·5	1·09	·046	·035	·03	·03
Manganese	·25	·21	·14	·09	Trace	Trace	Trace

It will be seen that during the early stage the silicon is more rapidly reduced than the carbon, and that the latter element goes rapidly when the boil actually begins.

The end of the process will be determined largely by the quality of steel being made. At the end of the boil the metal would be ready for tapping if a hard steel for rails or similar purposes were required ; but if required to be very mild the operation is continued for an hour or two longer.

When the process is over the metal is tapped, and a small quantity of ferro-manganese is added, the amount being such that about ·4 per cent of manganese is left in the metal. The effect of the ferro-manganese is much the same as in the Bessemer process ; *i.e.*, the removal of dissolved oxides, and the imparting of the necessary amount of carbon to the metal. The amount required will be less than in the Bessemer process, because more carbon can be left in the metal, and therefore it will not be necessary to add so much. It might seem that with ·2 per cent or more of carbon in the metal there should be no oxide left ; but it is impossible to ensure such complete mixture that all the oxides shall be brought in contact with the carbon. Manganese, however, diffuses itself so rapidly through the metal that it quickly removes all the oxygen.

The history of the separate elements can now be traced.

Carbon.—The removal of the carbon is slow at first, but is rapid when the boil begins.

Silicon.—This element is rapidly removed from the first. The iron oxide carried into the molten pig iron by the oxidised scrap, and subsequently by the ore, ensures its removal. A very high temperature tends to retard the oxidation of the silicon in relation to the carbon ; but the temperature is always much lower than that of the Bessemer converter, and as the metal is protected by the slag, and cold ore is added from time to time, there is little danger of too high a temperature being attained. For this reason the removal of the silicon in proportion to the carbon is more rapid in the Siemens than in the Bessemer process ; and, as already remarked, if required the process may be stopped when there is as much as ·5 per cent of carbon present.

Manganese.—The manganese is oxidised readily in the early stages of the working, but if there be much it may unduly prolong the process and lead to a large consumption of ore.

Sulphur.—Little sulphur is removed. There seems to be some elimination, as sulphur dioxide, during the process; but at the same time, as the gases always contain sulphur, this element may be taken up. Stead, for instance, says that pig with ·01 per cent of sulphur may yield steel with ·025 to ·040 per cent. This, however, does not seem to happen often. Part of any sulphur in the ore may also find its way into the metal, but Campbell says that the quantity so absorbed depends largely upon accident.

Phosphorus.—None of the phosphorus is eliminated, the whole remaining in the steel.

Iron.—Iron is oxidised from the first and passes into the slag. The loss is, however, balanced to some extent by that which is reduced from the ore added.

History of the Slag.—The history of the slag follows from that of the metal, as the iron oxidises during the melting stage, and the oxide comes in contact with the silicon and manganese. The slag formed at first will be a silicate of manganese and iron. It will have a yellowish colour; but becomes darker and darker as more iron passes into it. When the ore is added, part of the oxide of iron is reduced, and the other part passes into the slag.

Campbell gives the following figures as representing one charge:—

	1	2	3	4
Silica	50·27	49·27	52·77	50·97
Manganese oxide	14·91	15·20	14·70	14·22
Ferrous oxide	31·23	30·68	26·96	31·70
Manganous ferrous oxides	46·14	45·88	41·66	45·92

(1) Before addition of ore.

(2) After 500 lbs. of ore.

(3) After 1,000 lbs. of ore.

(4) After 1,500 lbs. of ore, just before tapping.

During the earlier stages, as the ore is added, a considerable portion is reduced, the remainder passing into the slag.

The following figures, given by Campbell, refer, of course, only to the particular charges from which the average is taken :—

Before addition of ore	709 lbs. of iron in slag.
After 500 lbs. of ore	803 lbs. ,, ,,
After 1,000 lbs. of ore	856 lbs. ,, ,,
After 1,500 lbs. of ore	991 lbs. ,, ,,

"From these figures the amount of oxide of iron added to the slag during each of the intervals may be deduced by subtracting each figure from the one below it."

	1	2	3
(1) Increment of Fe O in lbs.	94	53	135
(2) Amount of Fe O added in ore	405	405	405
(3) Amount of Fe O reduced............	311	352	270

The increase in the amount of oxide passing into the slag in the last stage was not attended with any increased basicity, so that silica must have been taken up from the furnace lining.

The composition of the slag from a charge nearly all pig is given by Dick & Padley as being—

Ferrous oxide	23·59 per cent.
Manganous oxide	3·82 ,, ,,
Lime	4·16 ,, ,,
Magnesia	·21 ,, ,,
Silica	68·02 ,, ,,
	99·80

The amount of slag will, of course, vary with the composition of the iron and the amount of ore added.

THERMAL CONDITIONS.

The amount of heat evolved by the oxidation of the oxidisable constituents of the iron must be the same whether the oxidation takes place in a Bessemer converter or an open-hearth furnace. In the former case, however, the heat evolution is rapid ; whilst in the latter it is so slow that it ceases to be important. The whole of the heat required is, therefore, except under special conditions, supplied by the combustion of the gas. The carbon monoxide from the metal during the boil burns in the furnace, and, no doubt, helps to keep up the temperature.

THE MATERIALS.

Pig Iron.—The pig iron used must be haematite or Bessemer, and must be nearly free from sulphur and phosphorus. The silicon need not be as high as in the Bessemer process, as its oxidation is not required as a source of heat. It should not be over 3 per cent, or it will prolong the process, and lead to an undue expenditure of ore. The amount of carbon is not very important, and there is always enough present in pig iron.

It is obvious that the Siemens process allows a somewhat wider range in the selection of the pig iron than does the Bessemer process.

The Ore.—The selection of a suitable ore is of very great importance. Quite obviously it must be free from phosphorus, and should contain no sulphur, though in any case probably only part of the latter would enter the metal. It should be low in silica, as this will increase the quantity of slag and use up iron oxide which otherwise might be available for oxidising. The presence of lime in small quantity is not objectionable, as it tends to make the slag more basic; but in large quantity might cause damage to the hearth.

The favourite ore is Campanil, from Bilbao, of which an analysis has already been given; but as this is now nearly exhausted, Rubio, Almeria and other Spanish ores are used. Messrs. Dick & Padley give the following analysis of Somorostro ore, which they say is very satisfactory:—

	Per cent.	
Ferric oxide	77·500	= 54·25 per cent iron.
Manganese dioxide	1·500	
Alumina	1·200	
Lime	4·800	
Magnesia	·320	
Silica	5·250	
Sulphur	Trace	
Phosphorus anhydride	·032	
Carbon dioxide	4·280	
Water (combined)	5·020	
	99·922	

Scrap.—Any scrap may be used, provided it be free from phosphorus and sulphur.

CHAPTER XXXIII.

THE SIEMENS PROCESS : PLANT.

The plant required for the Siemens, or open-hearth process, consists of—

(1) The gas producers.
(2) Valves for regulating the gas and air supply.
(3) The regenerators for heating the gas and air.
(4) The furnace itself.

THE GAS.*

(1) The gas used is invariably producer gas, made by passing air and steam over red-hot coke. In practice the producer is charged with coal, so that the producer gas becomes mixed with the coal gas from the destructive distillation of the coal.

When air is passed over coke heated to redness, and in sufficient excess, carbon monoxide is formed, thus $C + O = C O$. As the carbon monoxide occupies twice the volume of the oxygen from which it is formed, and as air contains 21 per cent by volume of oxygen, the resulting gas will contain carbon monoxide 34·7 per cent and nitrogen 63·4 per cent. Such a gas is combustible, but its calorific power is very low, only $\cdot 347 \times 2,430 = 843$ C.U., or 1,489 B.T.U.† 100 cubic feet (N.T.P.) weighs about 78·9 lbs., and 1 cubic foot, therefore, evolves on combustion, 65·55 C. units of heat.

It will be seen that the gas is produced by the partial combustion of the fuel, and this, of course, evolves heat.

A pound of carbon burning to form $2\frac{1}{3}$ lbs. of carbon monoxide will evolve 2,400 C. units (4,320 B.T.U.), and the combustion of the $2\frac{1}{3}$ lbs. of carbon monoxide to form $3\frac{2}{3}$ lbs. of carbon dioxide will evolve 5,680 C. units (10,220 B.T.U.). The former quantity will be evolved in the producer, and will therefore be lost, except in so far as it can be recovered by using the gas hot, whilst the latter portion only will be available for the production of heat in the furnace. Thus, of the total heat which could be produced by the combustion of the fuel, $\frac{2,400}{8,080}$, or about 30 per cent, will be evolved

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* For further particulars of the manufacture of Producer Gas, see the Author's "Producer Gas," Scientific Publishing Co.

† A centigrade (C.) unit of heat is the amount of heat required to raise 1 lb. of water 1 deg. Cen. A British thermal unit (B.T.U.) is the amount of heat required to raise 1 lb. of water 1 deg. Fah. When units of heat are mentioned, centigrade units are understood, unless otherwise stated.

in the producer, and therefore will be useless, whilst 70 per cent at the most will be available for use in the furnace. In practice the gas will always contain some carbon dioxide, so that the heat evolved in the producer will be considerably more than the theoretical minimum, and the value of the gas will be correspondingly reduced.

The value or heating power of the gas may be increased and the loss of heat in the producer at the same time reduced by the use of steam. When steam is blown over hot coke it is decomposed, thus $C + H_2 O = C O + 2H$. Thus a pound of carbon burnt by steam will give the same volume of carbon monoxide as if it were burnt with air ; but this, instead of being mixed with twice its volume of inert and useless nitrogen, will be mixed with its own volume of combustible hydrogen. The reaction is, however, strongly endothermic, *i.e.*, it absorbs a very large quantity of heat, and therefore would soon stop unless heat could be otherwise supplied. As will be seen from the equation, 12 lbs. of carbon will liberate 2 lbs. of hydrogen from 18 lbs. of steam. The burning of 12 lbs. of carbon to carbon monoxide will evolve 29,000 units of heat, whilst the separation of the 2 grammes of hydrogen will absorb 68,000 units ; so that the net result will be the absorption of 39,000 units of heat for each 12 lbs. of carbon consumed, or, as it may be stated—

$$\begin{array}{rcl}
[C\,O] & = & 29{,}000\ + \\
[H_2\,O] & = & 68{,}000\ - \\
\hline
[C + H_2\,O = C\,O + 2H] & & 39{,}000\ -
\end{array}$$

It will be seen therefore that in order to prevent the temperature being reduced, for each 12 lbs. of carbon burnt by steam it would be necessary to burn 1·38 lbs. by air if there were no loss of heat. This is, however, an impossible condition. The escaping gas will always carry away a considerable quantity of heat, and there will be loss by heating up the air and the fuel and by radiation ; so that in practice about 5 lbs. of carbon are consumed by air for each 1 lb. consumed by steam.

Such a gas will have the composition—

	By volume.	By weight.
Carbon monoxide ..	37·00 per cent.	39·74 per cent.
Hydrogen	7·4 ,,	·50 ,,
Nitrogen	55·6 ,,	59·70 ,,

Owing to its extreme lightness, the percentage of hydrogen by weight is small.

The calorific power of the gas will be—

$$\begin{array}{rcrl}
\cdot3974 \times 2{,}430 & = & 965\cdot69 & \text{C. units.} \\
\cdot0056 \times 34{,}180 & & 191\cdot42 & ,, \\
\hline
 & & 1157\cdot11 & ,,
\end{array}$$

an increase of 314 units, or over 30 per cent, over the simple producer gas.

The amount of heat evolved in the producer will also be very much less.

A pound of the gas will contain ·1703 lb. of carbon, which would evolve on complete combustion—

·1703 × 8080 =	·1376 C. units.
1 lb. of gas will give	·1157 ,,
Loss	·0219 ,,

or about 15·9 per cent.

In practice, however, a richer gas is obtained. The producer gas is mixed with coal gas from the destructive distillation of the coal. This greatly enriches the gas, and increases its calorific power. Such a gas might have the composition—

	By volume.	By weight.
Hydrogen	11·9 per cent.	·98 per cent.
Hydrocarbons	4·2 ,,	2·75 ,,
Carbon monoxide ..	34·1 ,,	39·12 ,,
Nitrogen	49·8 ,,	57·15 ,,

and would have a calorific power of about 1,660 C. units.

Carbon Dioxide in Producer Gas.—If the temperature of the gas producer falls too low a considerable quantity of carbon dioxide is produced, and this involves very serious loss. In the first place, the carbon burnt to carbon dioxide cannot oxidise further, and therefore, instead of being converted into a combustible gas, is converted into one which is inert, thus causing a loss of combustible gas. At the same time, the formation of the carbon dioxide evolves a much larger amount of heat in the producer, and this is lost.

As an example of the influence of carbon dioxide on the character of the gas and the economy of production, take the manufacture of simple producer gas, and assume that one-fourth of the carbon is burnt to carbon dioxide. Carbon dioxide occupies the same volume as the oxygen which it contains. The composition of the gas would therefore be—

	By volume.	By weight.
Carbon monoxide ..	27·2 per cent.	26·5 per cent.
Carbon dioxide	4·5 ,,	6·9 ,,
Nitrogen	68·3 ,,	66·6 ,,

This amount of carbon dioxide is frequently contained in producer gas.

The calorific power will be—

·265 × 2,430 = 643·9, C. units,

or about 25 per cent less than that of the simple producer gas when no carbon dioxide is produced.

The loss of heat in the producer will be much increased. Four parts of carbon burning to carbon dioxide would give 32,320 units of heat.

In the producer one part to carbon dioxide gives	8,080
Three parts to carbon monoxide, 2,400 × 3	7,200
Total heat of combustion of gas from four parts of C. ...	15,280
Four parts of C. could give	32,320

So that the loss of heat by evolution in the producer is 15,280 or about 47 per cent.

So important is the quantity of carbon dioxide in the gas, that the value of the gas is often decided by a determination of it alone, and this is quite satisfactory where the object is only to ascertain whether the producers are working satisfactorily, since all the carbon, except from 3 to 5 per cent which may be retained in the ash, will leave the producer either as carbon monoxide or carbon dioxide. Producer gas should not contain more than 4 per cent of carbon dioxide.

Use of Steam.—The advantage of the use of steam has been already discussed. The more steam it is possible to use, within limits, the better ; but a limit is soon reached beyond which excess of steam is very objectionable. As the percentage of steam is increased, its decomposition reduces the temperature of the producer, and thus : (1) Favours the production of carbon dioxide, because at moderate temperatures the reaction $C + 2 H_2 O = 4 H + C O_2$ tends to take place, and also a low temperature prevents the decomposition of any carbon dioxide formed by the combustion of the carbon ; (2) a large amount of steam may pass through undecomposed. Both these results tend to deteriorate the quality of the gas and increase the loss of heat. In general, therefore, too little steam is better than too much ; but for a special reason, to be mentioned directly, excess of steam is sometimes preferred by furnace managers.

Tar in Producer Gas.—When the gas is—as is now always the case—made from coal, it carries over with it a considerable quantity of tarry matter, the presence of which is objectionable for many reasons. Several methods have been suggested for removing it :—

(1) Cooling the gas by passing it through overhead cooling tubes. This was the method used by Siemens.

(2) Destroying the tar by passing the tar-laden gas down through the hot fuel.

(3) Washing the gas.

(4) Using a large excess of steam.

The first method is now little used, as it involves the loss of the sensible heat of the gas, and the cooling tubes are very troublesome. The second, first used by Mr. Wilson, answers admirably provided the gas can be used hot, otherwise it involves loss, as the gas leaves the producer at a high temperature. The third is as yet little used, but will probably become much more general in the future. The products of the distillation of the coal which can be secured are of considerable value, but the washing somewhat reduces the heating power of the gas. The fourth method is largely used, but is very unsatisfactory and wasteful. The tarry matters, passing into the checkers at a very high temperature, are decomposed into carbon and permanent gases, and, if there is a large excess of steam, this acting on the carbon converts it into carbon monoxide. In absence of steam the carbon remains till the gas is reversed, when it is burnt by the excess of air in the products of combustion, and thus tends to raise the temperature of the escaping gases and to injure the brickwork of the checkers. For this reason producers are sometimes worked with a large excess of steam.

A steel furnace was worked in Scotland for a time with gas direct from the blast furnaces, and the results are said to have been satisfactory.

Analyses of Producer Gas.

	1	2	3	4	5	6	7	8	9
Combustible per cent	30·0	35·40	39·06	40·53	44·42	92·75	40·4	44·80	96·40
Hydrogen	4·40	8·60	14·81	12·13	18·73	52·76	27·2	3·68	22·00
Methane, &c.	..	2·40	1·14	2·00	·62	4·11	2·2*	3·62	73·00
Carbon monoxide	25·60	24·40	23·11	26·40	25·07	35·88	11·0	27·50	1·40
Carbon dioxide	4·30	5·20	4·84	9·16	6·57	2·05	17·1	6·15	·60
Nitrogen	65·70	59·40	56·10	50·31	49·01	4·45	42·5	59·27	3·00

* Including ·4 per cent olefines.

(1) Siemens, open-hearth (Snelus).
(2) Siemens, closed, steam blow (Snelus).
(3) Wilson (Ritchie).
(4) Siemens, steam blown (Ritchie).
(5) Dowson (Thorpe).
(6) Water gas (Moore).
(7) Mond gas.
(8) Blast-furnace gas, coal fed (Archibald).
(9) Natural gas (Thorpe).

Gas Producers.

So many forms of gas producer have been suggested, and are in use, that it would be impossible to describe them all, and the differences between them are often so small that there is little need. It will be sufficient, therefore, to describe the more prominent types.

The producer as originally designed by Siemens (Fig. 152) was little more than a large closed fireplace with bars below, and an exit for the gas and a hopper for supplying coal above. The draught was produced by means of a chimney or tube passing to the furnace, and the fuel rested on firebars, which were either horizontal or inclined. The ashpit was open, and contained water, and water was sprayed on to the bars.

These producers have many defects, and have now been almost completely abandoned. The draught which can be obtained is always very feeble, so that only a thin layer of fuel can be used, and therefore the amount of carbon dioxide in the gas is apt to be very large, and as a draught has to be produced by the ascending gas, this must leave the producer at a high temperature. The combustion, and therefore gas production, is slow, the gasifying power being from 10 lbs. to 15 lbs. per square foot of grate area per hour.

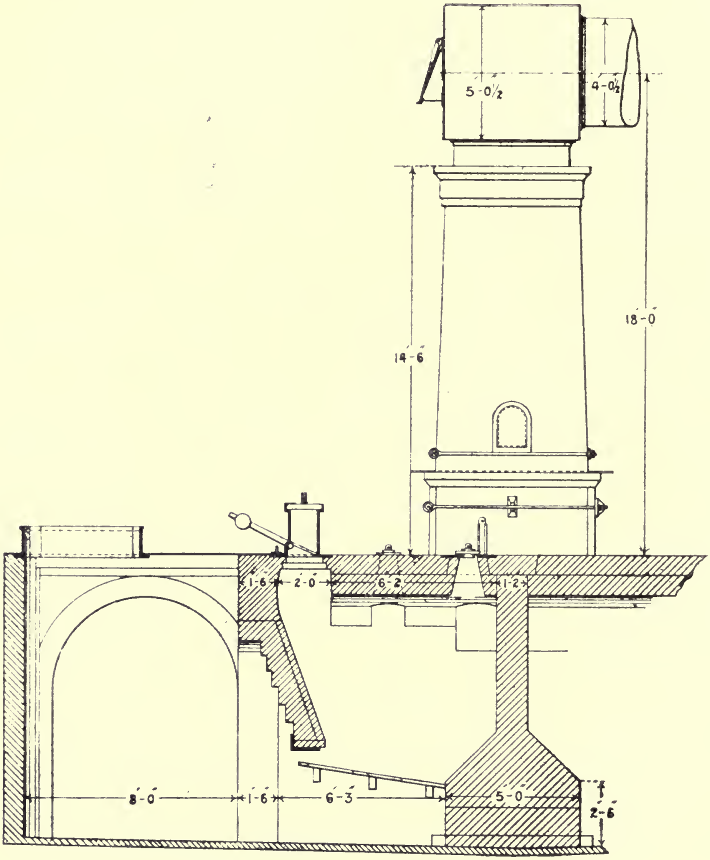

FIG. 152.—Siemens Gas Producer.

The grates can only be made of small size, as they must be of such size and form as to allow of every part being reached with the poker, and as the grate is open very little steam can be used. A considerable loss of fuel is also likely to take place by the fall of unconsumed coke through the bars.

As the draught has to be produced naturally, the producer should be at a lower level than the furnace, so that the gas may rise to the regenerators. As this is very rarely possible, Siemens designed the overhead cooling tube for the purpose of cooling the gas and at the same time producing a draught. A vertical tube, 12 ft. to 16 ft. high, led the gas from the producer to a horizontal iron cooling tube, which carried the gas to the furnaces, these being placed so far from the producers as to allow of efficient cooling. At the other end of the cooling tube another vertical tube led the gas to the furnace. As the gas in the "up" tube would be hot and that in the "down" tube cool, the latter would be much the heavier, and thus a syphon action would be set up by which the current of gas would be maintained.

Closed-hearth Producers.—Almost all producers are now worked with a closed hearth, air and steam being supplied under pressure, so that syphon tubes are no longer needed to carry the gas to the furnace.

Blowers.—As air and steam have to be supplied together, the steam-jet blower has become universal. In this a steam tube opens by a jet at the top of a wider tube, and steam at 60 lbs. or 70 lbs. is blown through it. The suction of the steam carries with it a large quantity of air. The ordinary solid steam jet offers very little surface of contact between the steam and air, and as it is on this the amount of air carried through depends, the proportion of steam to air is often far too large for satisfactory working; indeed, it is hardly too much to say that the solid jet is quite unsuited for the purpose, and is largely responsible for the "over-steaming" so frequent in gas producing. By using an annular jet a much larger proportion of air can be given, as both the inside and outside surfaces of the steam jet are available, and if the width of this ring is made adjustable the amount of steam can be reduced or diminished without, to any serious extent, altering the quantity of air. Many

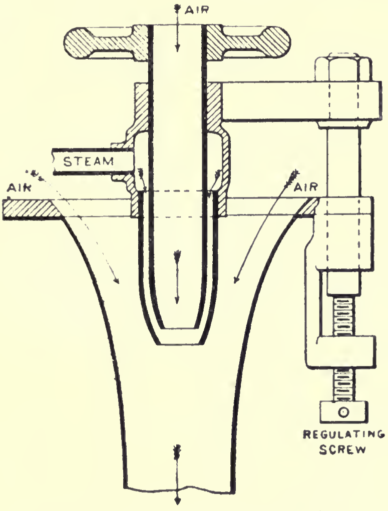

FIG. 153.—Thwaite Annular Steam Jet Blower.

forms of jet have been invented, of which Thwaite's (adjustable annular), Körting's (a series of cones below the jet), and Grainger's (a series of small solid jets) may be mentioned as being satisfactory in use.

The proportions of steam and air used will vary somewhat, but about 6 per cent of steam by weight is a very good proportion. This will give about 4 lbs. of carbon burnt by air to one part burnt by steam, and as this is about the maximum practicable, a larger proportion of steam will rarely be required. About ·3 lb. of steam will be required for each pound of carbon consumed, and as this carbon will be the fixed carbon of the coal only, the amount of steam per pound of coal can be calculated. Suppose the coal being used to yield 70 per cent of fixed carbon, then the amount of steam required will be $·7 \times ·3 = ·21$ lb. per pound of coal. Each pound of carbon will require also 4·7 lbs. of air, or 58·2 cubic feet (N.T.P.), which must of course be sent in with the steam. A Thwaite's blower with a 1 in. nozzle, and steam at 60 lbs., will give about 1,200 cubic feet of air per minute measured at the atmospheric pressure.

As a rule, the best amount of air and steam is determined by experiment.

Classification of Producers.

Closed-hearth producers may be divided into three groups, viz. :—

(1) Bar-bottom.
(2) Solid-bottom.
(3) Water-bottom.

(1) **Bar-bottom Producers.**—These are now but little used for steel furnaces. The rate of combustion is slow, the keeping the bars clear is troublesome, and the loss by fuel falling into the ashes is large.

(2) **Solid-bottom Producers.**—Of these the Wilson producer is the best known. The bottom is solid, and across it runs a raised ridge of brickwork, into which the air and steam is sent, and from which it passes by a series of openings some little distance above the bottom. The ordinary Wilson producer is circular and cased with iron, and is provided with a conical arrangement near the top, by which the gas is forced downwards through the hot fuel so as to destroy the tar. In steel works the producers are sometimes circular, sometimes square, and in the latter case are built in blocks. The tar-destruction arrangement is very often not used. In all solid-bottom producers the ashes are withdrawn periodically, the producer being stopped for the purpose. This is usually done every 12 or 24 hours. A usual size for a producer of this type is about 8 ft. diameter or 8 ft. square, but they have been made up to 12 ft. The limit is that at which the cleaning can be easily done, and the air and steam be uniformly distributed through the fuel. The consumption of fuel is ordinarily about 20 lbs. per square foot of

bottom, but it can be increased to 40 lbs. by giving plenty of air and steam. The gas is also richer than that made in bar-bottom producers as a larger proportion of steam can be used.

The only objection to the solid-bottom producer is the necessity for stopping for cleaning.

Water-bottom Producers.—In these the ashes fall into water. They differ from solid-bottom producers only in the bottom being so arranged that it can contain water, and, as a rule, in the air and steam being sent into the fuel at a much higher level. As an example, Mr. Duff's producer may be taken. It is a shell of iron, lined with firebrick, the casing dipping into a trough of water to a sufficient depth to give a water seal. Across the body are placed a series of inclined firebars, beneath which the air is supplied by a central pipe. The ashes slip from the bars into the water, and are very easily raked out from beneath the shell. There is thus no heat carried out in the ashes, it being used in heating the water, thus increasing the quantity of steam. Water-bottom producers are now coming largely into use.

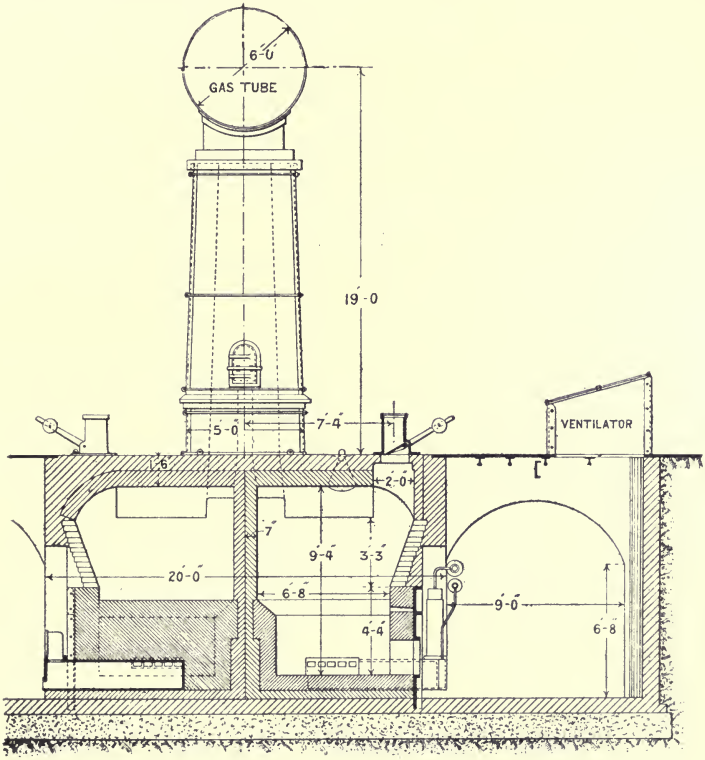

FIG. 154.—Solid-bottom Producer.

It has been said that when water-bottom producers are used there is a tendency for the steel to take up excess of sulphur, and the author has seen figures from one works which seem to prove that this was the case there. On the other hand, in many works where water-bottom producers are used nothing of the kind can be detected. If, therefore, it does occur it must be due to some peculiarity in the fuel used. It is possible, if the fuel contained a large proportion of calcium sulphate, this would be reduced to calcium sulphide, which might escape decomposition by the steam, but which would be decomposed on coming into the water, and thus sulphur which in a dry-bottom producer would remain in the clinker might find its way into the gas. This is, however, not at all likely to occur except in very rare cases.

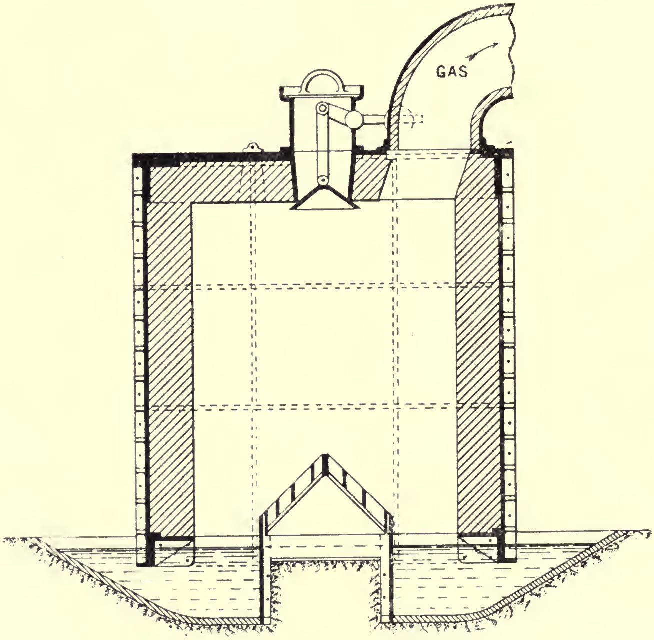

Fig. 155.—Duff Water-bottom Producer.

Other varieties of gas, such as water gas and Mond gas, are made ; but, as they have not come into use for steel making, there is no need to describe the plant here.

Arrangement of Gas Plant.—As already mentioned, in the early forms of plant the producers were placed some distance from the furnaces, so as to allow of the cooling by the overhead tube. The cooling tube is not now used. Owing to the use of the blast, the syphon action is not necessary, and the gas is used hot. Where the overhead tube is retained it is no longer a cooling tube, but is lined with firebrick, so as to retain the heat as far as possible. In modern works the gas is carried to the furnaces where possible by underground flues. The producers are also placed as near as they conveniently can be to the furnaces, so that there may be little cooling of the gas.

Plant Required.—The amount of fuel used varies considerably. For our present purpose it may be assumed to be about 700 lbs. for each ton of steel made, and the making of the steel may be taken as occupying 12 hours ; so that for a 25-ton charge 17,500 lbs. of fuel will be required, or at the rate of about 1,000 lbs. to 1,300 lbs. per hour. Assuming circular producers 8 ft. diameter to be in use, the area of the bottoms will be $\pi r^2 = 3{\cdot}1416 \times 16 =$ about 50 square feet, and if the gasification is at the rate of 20 lbs. per square foot per hour this will give 1,000 lbs. per hour. It will be seen, therefore, that with furnaces varying from 25 to 50 tons from one to three producers will be required according to circumstances.

It need hardly be said that these figures are intended as little more than an illustration, for every factor may vary so much that only the very roughest approximation can be given.

THE VALVES.

The gas from the producers passes by the mains to the valves, by which it can be distributed to the furnace. The gas valve must be so arranged that the gas can be sent to one of the gas regenerators whilst the other regenerator is in connection with the chimney flue, and so that this arrangement can be quickly reversed when it is desired to reverse the direction of the current.

The passage of the gas to the valve box, which contains the reversing valve, is controlled by a valve so arranged that the gas can be completely cut off when required. This controlling valve is usually a crown valve, often water cooled, though the arrangements vary much in different works.

The actual reversing valve is usually of the "butterfly" type, the tongue being of cast iron, cast with thick ribs on either side, and carried on a pivot so that it can be turned from outside. Such an arrangement is very simple. When the valve is as shown in Fig. 156 the gas enters at the top, and passes to the regenerator by the left-hand passage, whilst the gases from the other regenerator come from below and by the right-hand passage to the chimney main. When the valve is reversed so that the tongue is at rest on the opposite side of the casing, the direction of the currents is reversed. A simple turn of the valve only is therefore necessary to reverse the gas.

An exactly similar valve is provided for the air, the only difference being that the air main is open to the air and is provided with a cover which can be lowered when necessary.

It will be seen that the efficiency of the valve depends on the accuracy with which it fits upon its seat. The vertical portions are turned and the valves fitted by hand, and although the fitting may be good enough with a new valve when all the faces have been carefully machined, it is likely soon to become imperfect under the action of heat and oxidation. The heating of the tongues is also very irregular, and as one side will always be hotter than the other, warping is very likely to take place, this being more marked in the case of the air than of the gas valve.

A badly-fitting gas valve may lead to serious loss. It will be seen that on one side of the valve is the gas passing to the regenerators, on the other the products of combustion passing to the chimney. The chimney draught will be more powerful than the furnace draught, so that gas may be drawn through and thus wasted. Not only so, but coming in contact with the excess of air on the other side it will burn, and the high temperature thus produced will lead to the rapid destruction of the valve.

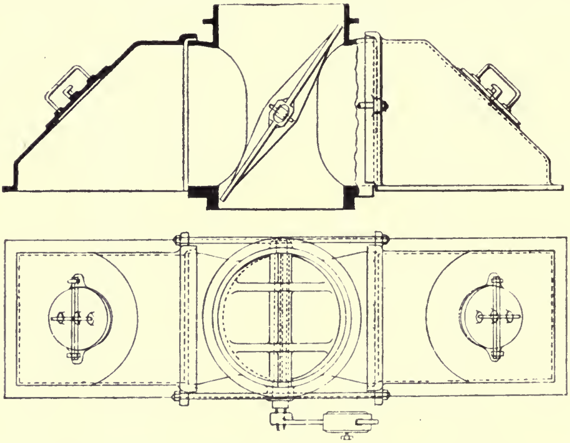

FIG. 156.—Simple Butterfly Reversing Valve.

The objections to the simple butterfly valve are well understood, and though many attempts have been made to overcome them, or to replace it by a better form, it still remains in almost universal use.

The conditions necessary for a good valve are :—

(1) Practical gas tightness ;
(2) Simplicity of working parts ;
(3) Non-liability to get out of order by great heat ;
(4) Durability ;
(5) Low first cost.*

In a new type of valve designed by J. Barr "ledges are cast on the body and on the end doors on which the edges of the tongue bear. These edges, as well as the edges of the tongue, are machined. Ample play is left between the outer edge of the tongue and the body to allow for expansion and contraction."

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* Barr, "J.W. of S.I. and S.I." vol. i., page 254.

In a modified form of the arrangement of the ordinary valves suggested by Mr. Paul† the ordinary reversing valve does not reverse

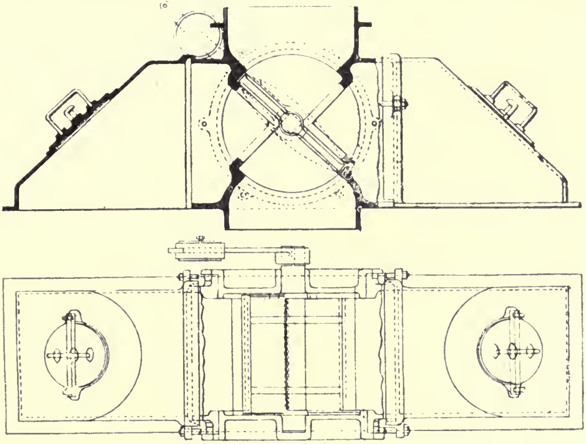

Fig. 157.—Barr's Reversing Valve.

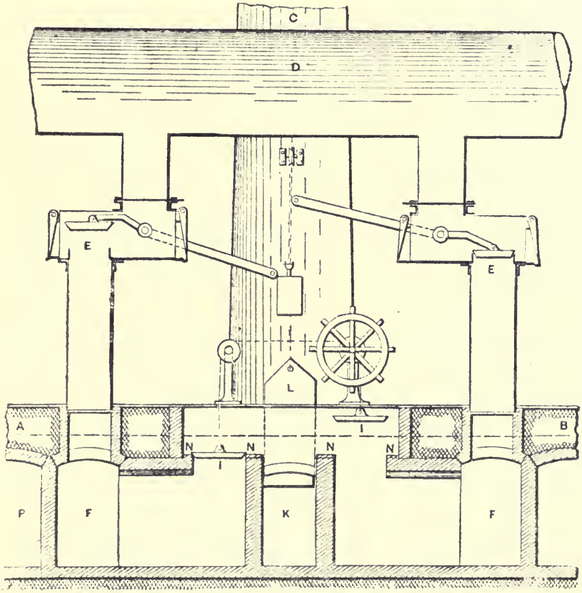

Fig. 158.—Campbell's Valve.

D—Gas Main. F—Regenerator Mains. E E.—Regenerator Valves. K—Chimney Flue. I—Chimney Valves. N—Water-cooled Valve Seats.

the gas supply, but merely serves to put the regenerators alternately in connection with the chimney, whilst the gas is supplied by two separate mushroom valves, one for each regenerator.

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† Paul, "J.W. of S.I. and S.I.," vol. i., page 211.

In a modern American valve invented by Mr. J. W. Higgs the tongue is hollow, and by means of pipes passing through the spindle a constant current of water is kept passing through it, so as to keep it cool, and thus avoid warping.

In an arrangement suggested by Mr. Campbell (Fig. 158) separate valves are used, so that in reversing the gas is never in connection with the chimney.

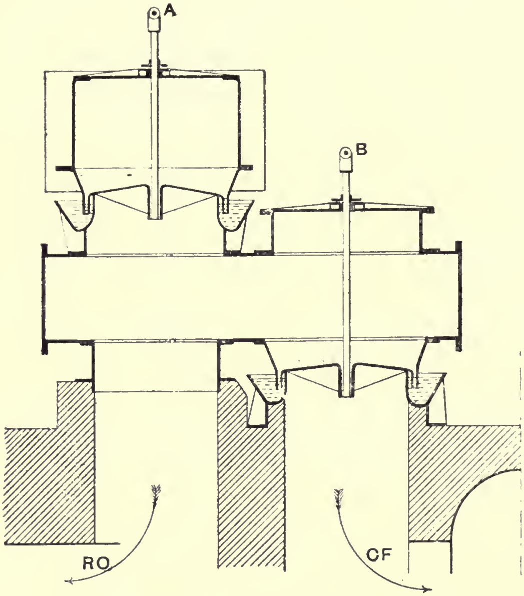

FIG. 159.—Wailes' Valve. Section.

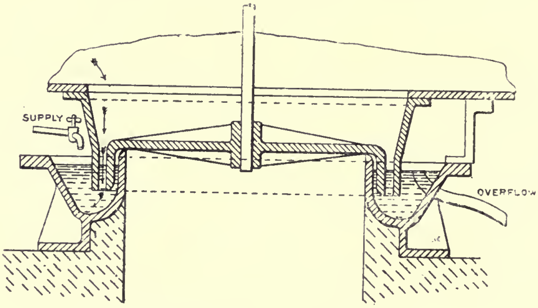

FIG. 160.—Wailes' Valve. Details of Water Seal.

The gas from the main D passes to the regenerators F by the valves E E, the right-hand one being open and the left shut, whilst the products of combustion pass to the chimney flue K by the valves I, the right-hand side one being open and the left-hand one shut. The stack is provided with a damper L, and the valves I rest on water-cooled seats N.

During the last few years several water-cooled valves have been introduced, and of these two may be mentioned.

The Wailes valve is perhaps the best known of these. Four valves are used, two for gas and two for the flue. (In the sketch both valves are down.) The casing of the valve box fits into a water trough so as to give a water seal sufficient to prevent the passage of air or gas, and the valve, which is a simple disc valve, works in the same water trough. The trough, being open to the outside, can be kept constantly clean. Any dust or dirt also falls downward into the water trough, and can be removed.

Another form that deserves mention is that of Mr. Mills, which is shown in Fig. 161. It is a double valve, and all the parts are water sealed, the valves being water sealed both in their top and bottom position. Water is introduced from a service pipe into the valve spindles, and travels down till it reaches the upper surface of the valve; it then escapes through holes in the spindle, and thus flows over the upper surface of the valve into a channel at the edge thereof, which thus forms a water seal when the valve is at the top position. Thence the excess water flows over a slot into the trough below, which forms the seal when the valve is in its lower position, and thence excess of water flows away.

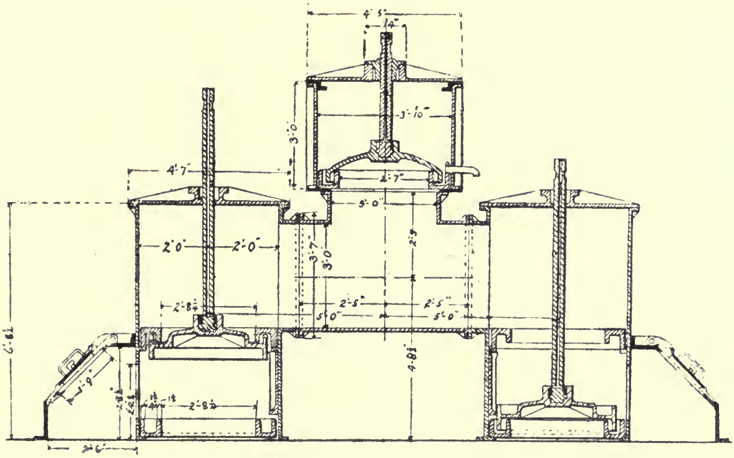

Fig. 161.—Mills' Water-cooled Valve.

Constant improvements are being made in valves, and it cannot be said that as yet there is any best form. The simple Siemens valve continues in very general use on account of its low first cost, simplicity, and the fact that it needs little or no attention.

REGENERATORS.

The regenerative chambers in which the gas and air are heated are of very great importance. They are chambers filled with a checker-work of firebrick, and are usually, though not by any means invariably placed beneath the furnace. The object of the checker work is that the bricks may absorb heat from the products of combustion on their way to the chimney, and give it up again to the air and gas as these pass to the furnace.

Size of Regenerators.—The size of the chambers varies with the capacity of the furnace and the ideas of the designer, and the tendency of late years has been to make them much larger than in the earlier furnaces. Two dimensions, the width and the length, are to a large extent determined by the size of the furnace, the length being the same as the width of the furnace, and the width being such that the chambers can be conveniently placed under the furnace body, so that the dimension which can be most readily altered is the depth. In the earlier small furnaces the chambers were not more than 7 ft. or 8 ft. deep, but in modern large furnaces they are made as much as 20 ft., or even more. It is impossible to say what is the best size, as this, no doubt, will vary with the conditions of working ; but the more perfectly the waste gas can be cooled the better. It must, however, be remembered that the current through the furnace is determined by the chimney draught, and therefore the temperature of the escaping gases in the chimney must be high enough to give an efficient draught. The chimney and the regenerator chamber are attached, and will therefore tend to produce currents in opposite directions, the chimney tending to draw the gas through the furnace, whilst the hot products of combustion in the chamber tend to rise back into the furnace. It is obvious that the temperature of the gases in the chimney must be high enough to overcome this back pressure, or there could be no draught.

At the same time, though the products of combustion are drawn away by the chimney, the chimney draught does not draw the hot gas and air into the furnace. These enter under a positive pressure due to the hot regenerators through which they pass.

Siemens states that "the products of the complete combustion of 1 lb. of coal have a capacity for heat equal to nearly 17 lbs. of firebrick, and (in reversing every hour) 17 lbs. of regenerator firebrick at each end of the furnace per pound of coal burned in the gas producer per hour would be theoretically sufficient to absorb the waste heat, if the whole mass of the regenerator were uniformly heated at each reversal to the full temperature of the flame, and then completely cooled by the gases coming in. But in practice by far the larger part of the depth of the regenerator checker-work is required to effect the gradual cooling of the products of combustion, and only a small portion at the top, perhaps a fourth of the whole mass, is heated uniformly to the full temperature of the flame, the heat of the lower portion decreasing gradually downwards nearly to the bottom. Three or four times as much brickwork is thus required in the regenerators as is equal in capacity for heat to the products of combustion. The best size and arrangement of the bricks is determined by the consideration of the extent of opening between them required to give a free passage to the air and gas, and a surface of six square feet is necessary for the regenerator to take up the heat of the products of combustion of 1 lb. of coal in an hour.

" By placing the regenerators vertically, and heating them from the top, the heating and cooling actions are made much more uniform throughout than when the draught is in any other direction, as the hot, descending current, on the one hand, passes down most freely through the coolest part of the mass, whilst the ascending current of air or gas to be heated rises chiefly through the part which happens to be hottest, and cools it to an equality with the rest.

" The regenerators should always be at a lower level than the heating chamber, as the gas and air are then forced into the furnace by the draught of the heated regenerator ; and it may be worked to its full power, either with an outward pressure in the heating chamber, so that the flame blows out on opening the doors, or with a pressure in the chamber just balanced, the flame sometimes blowing out a little and sometimes drawing in."*

It will be seen that the conditions vary so much that it is impossible to decide the best size of regenerator except by actual experience.

Material for Regenerators.—The checker-work must be made of very refractory bricks. They may be made of special form, but as a rule the ordinary bricks are used. Silica bricks are often used, but they are not the most suitable, as they are readily attacked by oxide of iron dust, which is carried over by the gases in considerable quantity.

Relative Size of the Regenerators.—One regenerator has to heat the air, the other the gas ; and as the gas and air should reach the furance at nearly the same temperature, the size of the regenerators must be properly adjusted.

Assuming the producer gas to contain, by volume—

Carbon monoxide	24	per cent.
Hydrogen	8	,,
Marsh gas	2	,,
Carbon dioxide.........................	4	,,
Nitrogen	62	,,

The volume of oxygen required for combustion will be $\frac{24}{2} + \frac{8}{2} + (2 \times 2) = 20$, and as air contains 21 per cent by volume of oxygen, the required oxygen will be contained in 95 parts of air. An excess of air must always be used. Allowing 25 per cent excess,

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* Collected Works, vol. i., pages 227, 228.

which is a fair amount, the amount of air required for each 100 volumes of gas will be about 119 volumes, assuming both to be at the same temperature. As the volume specific-heat of the gases is very nearly the same, if both were supplied and delivered at the same temperature the air regenerator should be 25 per cent larger than the gas regenerator ; as, however, the air will usually be supplied at a lower temperature, and therefore will require more heating, its regenerator may be proportionately larger. There is no recognised proportion for the two regenerators, but the air regenerator is usually made the larger, often by as much as 50 per cent. As the length and depth of all the chambers will, for convenience of construction, be the same, the breadth is varied as required.

Arrangement of the Chambers.—The two air chambers are usually placed inside, and the gas chambers outside, but sometimes the order is reversed. The chambers may be placed close together, or a space may be left across the centre of the furnace, separating the two pairs. The latter arrangement is now largely used, and it has two advantages :—

(1) The gas passages can be carried up nearly vertically to the ports, whilst if the chamber is under the middle of the furnace the passage must run under the furnace bottom. It thus reduces the danger of overheating the bottom.

(2) It brings the division wall between the chambers under the end of the furnace, which it thus helps to support. Weight must not be thrown on to the crown of the arch of the regenerator, so that if the end wall of the furnace comes in such a position it must be carried on a strong girder to keep the weight off the chambers. In the Wellman furnace the regenerators are placed, not under the furnace, but under the working platform in front of the furnace. This has the advantage of relieving the regenerators of all the weight of the furnace, but it must tend to make the working floor very hot.

THE FURNACE.

In the earlier small furnaces the furnace body was built on the regenerators. This is now rarely done, but the end supporting walls, which may be the terminal walls of the regenerators or may be independent thereof, are carried up to some little distance above the top of the regenerators. Three or four longitudinal iron girders are put across from wall to wall, and across these are placed transverse girders, on which is laid a floor of thick (about 2 in.) iron plates, which carries the furnace bottom. There is thus a considerable air space—generally from 1 ft. to 2 ft.—between the top of the regenerators and the bottom of the furnace, this tending to keep the bottom cool. The side walls are built up from the iron plate ; they are vertical, and are from 12 in. to 15 in. thick, and are carried up about 5 ft. to 5 ft. 6 in., to the springing of the arch of the roof. At about 3 ft. from the bottom plate are the sills of the doors. There are usually three working doors on each side of the furnace.

These vary in size according to the purpose for which the furnace is to be used. If only for pig iron and ordinary scrap they will be of uniform size, about 2 ft. 6 in. long and 1 ft. 6 in. to 2 ft. high, but if large scrap is to be used one or more of them may be made very much larger.

The end walls are set some little distance back, and sloping iron plates are put at the end of the floor plate connecting with them, and above this is often put an iron girder to carry the weight of the masonry. The end walls will be 4 ft. to 6 ft. thick, as they have to contain the flues from the regenerators and the ports which open into the furnace.

The roof of the furnace is thrown across from side to side with comparatively little rise, 9 in. to 12 in. in the 11 ft. or 12 ft. width of furnace.

The furnace is obviously a reverberatory furnace, but as the fuel is supplied alternately at each end, the roof cannot slope from the fire end to the flue end ; but the general form was retained as far as possible, the roof being made to dip from the two ends towards the middle. In the older furnaces this dip was very conspicuous, but in most modern furnaces it has been reduced, whilst many are now built so that the crown of the arch runs horizontally from end to end, or it may even be arched upwards.

The object of the dip was to deflect the flame downwards on to the hearth, but how far this is necessary or advantageous is somewhat uncertain. The temperature attainable in the furnace seems to be limited by the temperature of dissociation of carbon-dioxide, and this seems to be lowered by contact with solid matter ; so that it has been urged that the impinging of the flame on the roof not only causes rapid destruction of the furnace, but also reduces the temperature attainable by the combustion of the gas. In most of the large furnaces recently constructed the dip in the middle of the roof is either absent or is insignificant ; but even if the roof is horizontal over the body of the furnace, it is made to rise considerably at the ports.

The end wall contains the passages leading from the regenerators. These should be as nearly vertical as possible, but their position will depend on that of the regenerators.

The gas is delivered to the furnaces by means of ports. The passages are turned horizontally, and then splayed out very considerably, so that the actual opening into the furnace is much larger than the passage itself. The ports are placed in two rows, arranged so as to break joint. The gas ports are below, just about at the door level, whilst the air ports are above, usually quite close to the roof. The gas ports are rectangular, nearly square passages, whilst the air ports are usually much flatter in section, and extend almost across the whole width of the furnace.

The heavier air, being delivered above, tends to fall ; and the lighter gas, delivered below, tends to rise ; and thus there is perfect admixture.

In small furnaces the ports are often set back and made to open into a combustion chamber at the end of the furnace, so that combustion may begin before the gases enter the body of the furnace. In larger furnaces this is quite unnecessary.

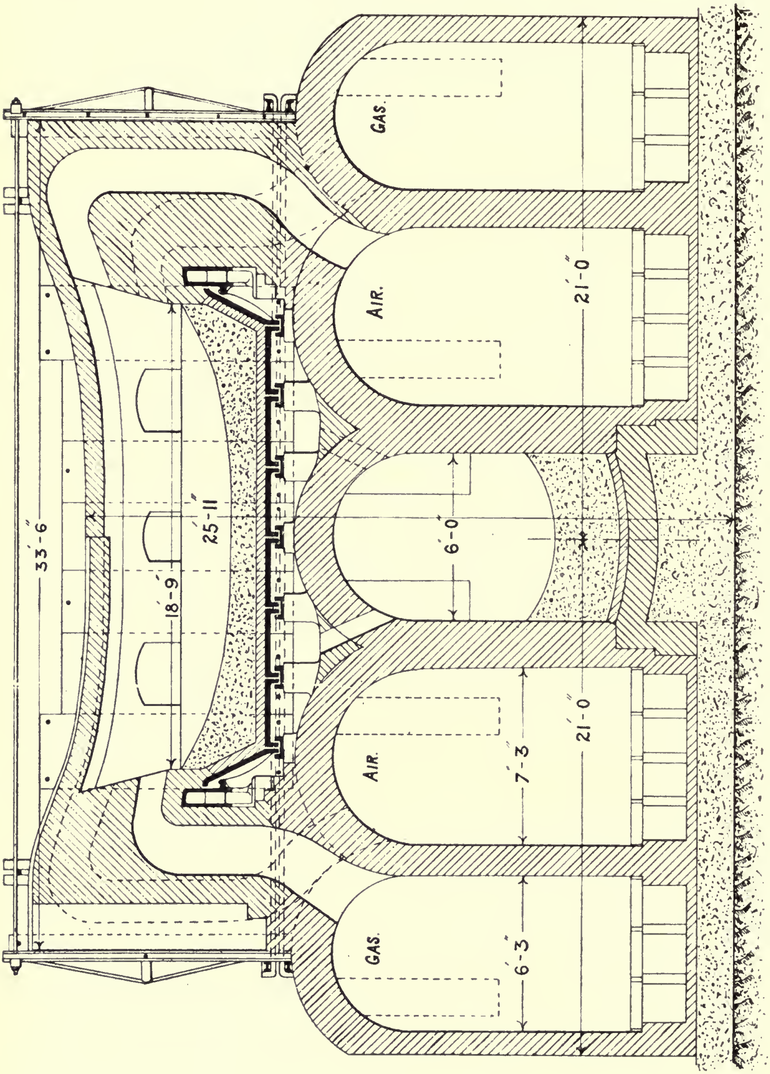

Fig. 162.—Twenty-five-ton Steel Furnace. Section Left Hand through Gas Port, Right Hand through Air Port.

Usually each passage from the regenerator opens into the furnace by its own port; but a better arrangement is for the passages to lead to a horizontal chamber, running across the width of the furnace, and opening into it by the ports. By this arrangement there is less

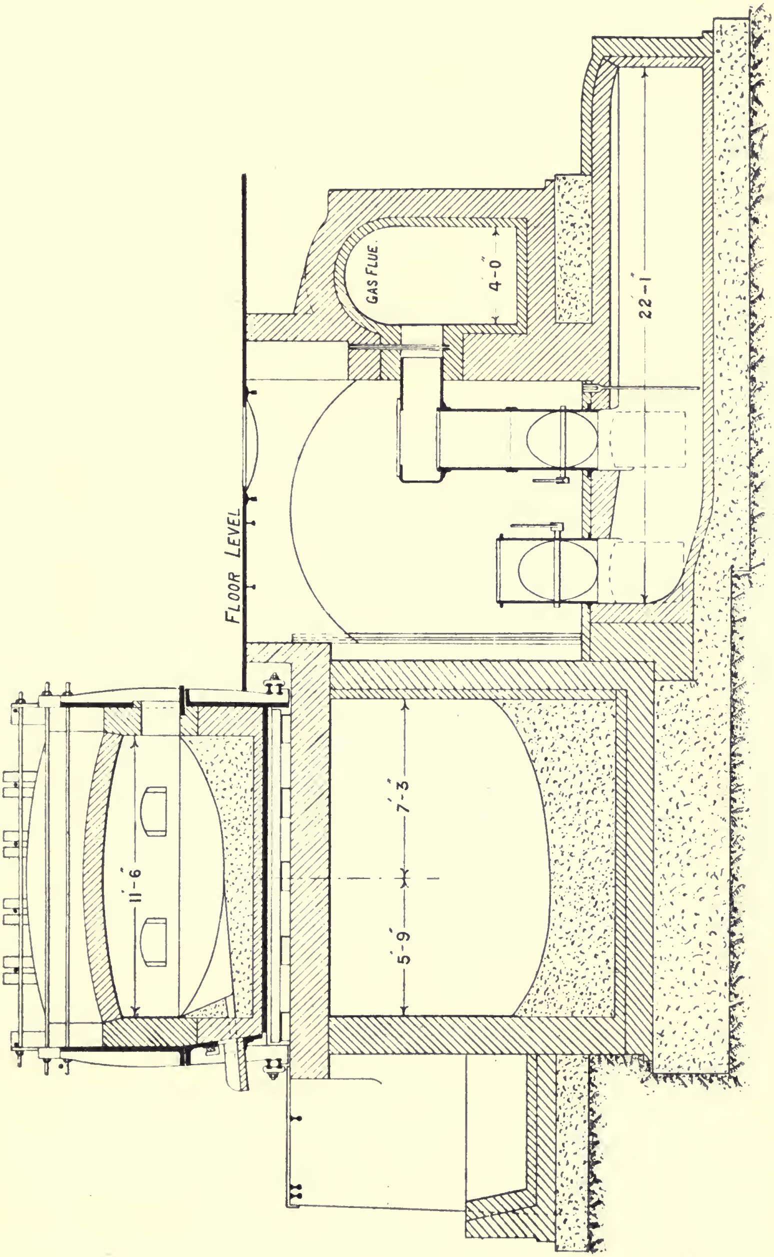

Fig. 163.—Twenty-five-ton Steel Furnace, Cross Section.

interference with the uniform distribution of the air and gas should one of the passages become wholly or partially stopped by dust, an accident not unlikely to happen, especially in furnaces where the flues run for any considerable distance either horizontally or at a slight inclination.

The masonry of the furnace not being very massive, it must be very securely stayed, and is almost invariably completely cased with iron ; indeed, the furnace may be regarded as an iron shell lined with brick. The casing plates are put in position, and the brickwork is built up inside them. The details of the staying varies, but the principle is always the same. The plates are kept in position by heavy stays of cast iron, or of steel, which are united above and below by strong steel tie rods. The ends of the furnace are usually protected in the same way ; but as the thrust of the roof is taken by the sides, the staying of these is far more important. Figs. 162 and 163 will give an idea of the arrangement of the stays. The door openings are protected by iron castings, and have a projecting sill to carry the doors, and at the back of the furnace an opening is left through the plates for the tap hole.

Materials of the Furnace.—The whole of the furnace must be built of very refractory materials, as it will have to stand a very high temperature. Silica bricks, set in a very siliceous mortar, are almost always used.

Position of the Furnace.—As the metal has to be tapped from the furnace, the tap hole must be sufficiently high at the back, or tap hole side, to allow of a ladle being run under (as shown in Fig. 164), whilst at the front the working platform must be sufficiently high to allow of charging and working. There is always a gallery along the back of the furnace, at about the floor level, sufficiently wide to allow of the charge being worked from that side if necessary, a gap being left through it opposite the tap hole for the passage of the metal shoot. The valve chamber is usually under the working floor (as shown in Fig. 163).

Making the Bottom.—The building of the furnace having been completed, the next step is to put in the bottom, on which the charge is to be worked.

The iron plates are first covered with a layer of brickwork, one brick thick, set on edge. The whole of the masonry will be damp, and before anything can be done it must be thoroughly dried.

For this purpose coal fires are lighted in the furnace, being usually supported on temporary firebars, the smoke being allowed to escape from the door openings. This drying may take several days. When it is complete the ashes are raked out and gas is put on. The heating by gas is continued till the interior of the furnace is red hot.

The lining is then commenced by throwing on to the brick bottom a mixture of loam and sand. The mixture must be such that it vitrifies, or fuses, at a low temperature, and thus fills up the crevices of the brickwork.

When enough of this has been added, a mixture of a refractory white sand with one less refractory is thrown on in small portions at a time and spread evenly. As each layer becomes vitrified another is put on, and as the temperature rises the mixture is made more refractory by using more of the refractory sand, the object being to use a mixture that will just vitrify at the temperature of the furnace and by the end to get this up to the working temperature.

In one case, for a 25-ton furnace, the amount of sand used was 13 tons, and the time occupied was—

Drying with coal....................	4 days.
Making bottom	8 ,,

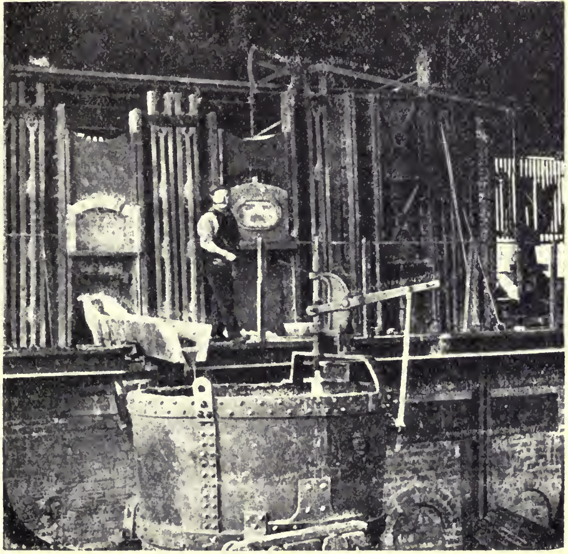

Fig. 164.—Back of Steel Furnace, showing Stays, Door, Tap Hole, and Metal Shoot.

The bottom being made thus far, the last layers being of very refractory sand, a quantity of slag, usually several tons, is introduced at intervals, often with some hammer scale or similar material, and is melted. As the slag melts it is absorbed by the bottom, and more is added, melted, and rabbled about till no more seems to be absorbed which may take several hours. Any residual slag is then tapped off, the hearth dried by the addition of sand, and any holes that may have formed are repaired.

The tap hole is made by filling the aperture in the brickwork with ganister from inside the furnace, the ganister being rammed against a plate wedged against the tap hole casting on the outside. This is done before the gas is put on, and when the bottom is nearly finished, a hole is cut through the ganister and sand from the outside.

The hearth is so shaped as to slope in all directions towards the tap hole.

The First Charge.—The working of the first charge differs considerably from the working of subsequent charges, and may be considered as part of the making of the hearth.

The first charge is always small, and consists mainly of pig iron, but little scrap being used, and, if possible, not a very soft steel being made. Part of the pig is spread on this hearth, the scrap above it, and the remainder of the pig on the top, and the charge is melted. As the hearth is still very porous, slag-forming materials must be added, those usually used being slag from a previous charge and broken red bricks, which are added in such quantity as to keep the metal well covered with slag. The charge is worked in the usual way. The first charge usually takes a longer time to work than subsequent charges, and the bottom may need considerable repair after it.

Furnace Doors.—When the furnace is at work the working openings are closed by doors. These are almost always iron frames filled with firebrick slabs. They rest on the sill, and are attached by chains to the one end of a lever, by which they can be lifted.

Size of Furnace.—The size of furnace has increased very much since the process was introduced by Siemens. The early furnaces had a capacity of about five or six tons. One of the earliest erected in Scotland had a capacity of six tons. The hearth was 10 ft. long and 7 ft. wide, and the gas regenerators were 4 ft. 3 in. wide and 7 ft. 6 in. deep, the air regenerators being 6 ft. 1 in. wide. The furnace shown in Figs. 162 and 163 is a 25-ton furnace. Forty-ton furnaces are frequently used, and many 50-ton and a few 100-ton furnaces are at work, and probably the limit is not reached. There is no agreement as to what is the best size for a furnace. A furnace under 15 ft. long is not likely to be economical, as there is hardly space for complete combustion of the gas. It seems that a limit would be reached beyond which the heating would be irregular, but furnaces up to 40 ft. long have been found to be satisfactory. Many managers contend that, in general, a 25-ton furnace is the most easily managed, and the most economical, whilst others prefer those much larger. In Scotland 50-ton furnaces seem to be the most popular.

Furnace Proportions.—The proportions of furnaces have, as a rule, been obtained by the method of trial and error, and therefore the proportions used in different districts and by different designers are far from uniform. The length of the furnace will be limited by the length over which uniform heating can be obtained. With ordinary regenerative furnaces, this may be up to 40 feet, or perhaps even more; the longer the furnace, the more completely will the heat be utilised.

The width must be such that any working of the charge that is necessary can be easily done, and any repairs of the hearth can be easily effected, and by the strength of the bricks used for the arch. The width rarely exceeds 16 feet. Great width may have the same effect as length in allowing complete combustion and utilisation of the heat, as the flame will be more spread out in a wide furnace than a narrow one.

The ratio of length to width is usually roughly about 3 to 1, though it may vary very considerably. The area of the furnace for a given charge will depend on the depth of the metal on the hearth; for ordinary furnaces a shallow hearth is best, as it allows greater surface for heating and oxidation, but with the Talbot process, where only a portion of the charge is poured at a time, a much deeper charge is used. The depth of charge in an ordinary 50-ton furnace averages about 12 inches; but in the larger furnace it may reach 20 inches, as the hearth slopes gradually, the maximum depth may be from one and a half to twice this.

A cubic foot of molten steel weighs about 430 lbs., so that a ton of the metal will occupy 5·25 cubic feet, with 5·25 cubic feet per ton the average depth of the metal would be 1 foot. The average hearth area is about 8·25 square feet per ton, thus giving a considerably less average depth. The nominal and actual capacity of a furnace are not by any means the same. The former is that for which it is designed, the latter that at which it is actually worked.

The following table gives the dimensions of some furnaces in actual work*:—

Capacity.	Length. Feet.	Width. Feet.	Hearth. Square feet.	Area. Per ton. Sq. feet.	Length. ÷ Width.
25	25	10½	262	10·50	2·38
35	24	12	288	8·23	2·00
40	24	12	288	7·20	2·00
50	28	10¼	287	5·74	2·73
50	32	10	320	6·40	3·20
70	30	9	270	3·86	3·33
100	32	12	400	4·00	2·67
200	40	16	640	3·20	2·51

The furnace bottom requires repair after every charge.

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* A. D. Williams. "The Iron Age." Sept. 21st, 1905.

ARRANGEMENT OF PLANT.

It is obvious that the arrangement of a works for the open-hearth process will differ very much from that required for the Bessemer process.

The furnaces are, as a rule, arranged in a line. On the front, or charging side, the floor is at such a height as to allow of the ready charging of the furnace. There must be ample space to allow for the stacking of the pig and scrap, so as to have them ready for charging; also for the ore, the sand for repairs, and other necessary materials. There also are the valve levers for regulating the air and gas supply to the furnace. Close at hand must be the sand furnace for calcining the sand, and the ferromanganese furnace for heating the ferromanganese. These are small coal-fired reverberatory furnaces. Close in front of the furnace is the "water bosh," an iron trough, containing water, in which the tools can be cooled and the breaking away of adherent slag thus facilitated. Where possible, a railway track is brought to the furnace, for convenience of bringing up the materials.

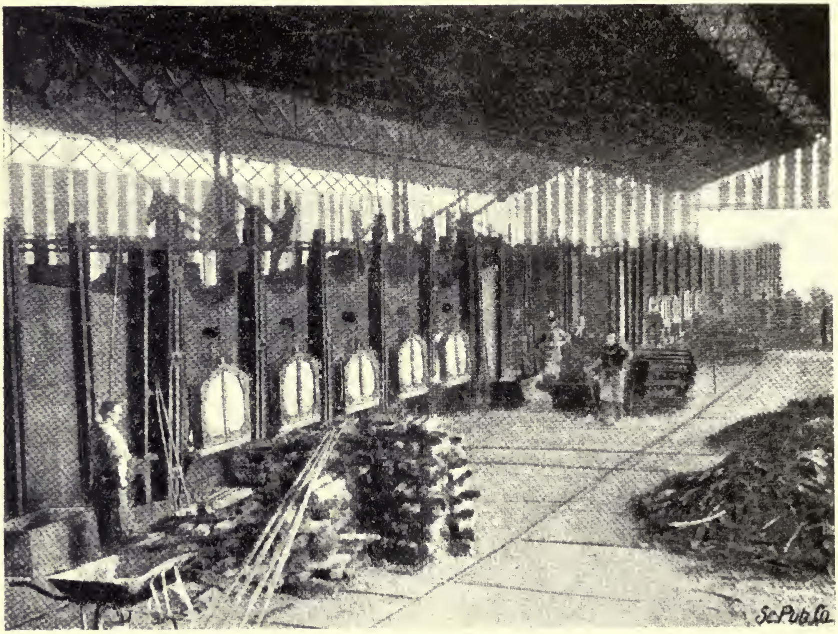


FIG. 165.—Charging Side of Row of Siemens Furnaces. (Dalzell Steel Works.

Back of the Furnace.—At the back, or casting side of the furnace, the floor level must be low enough to allow of the ladle being drawn under the tap hole to receive the metal. At the same level as the front working floor a gallery, about 2 ft. wide, is carried along the furnace, so that access may be obtained to the doors on that side of the furnace for charging or other purpose. This gallery is interrupted opposite the tap hole, a shoot being put across to carry the metal to the ladle. This shoot is often hinged, so that it can be tilted up as soon as all the metal has flowed over, allowing the slag to run to the ground.

The ladle is carried on a truck, and rails are laid along the whole length of the furnaces, so that the ladle can be drawn along by an engine. The casting pit is between the rails, so that the ladle is drawn over the ingot moulds. It may be opposite the furnaces, but it is often placed at a little distance away—clear of the furnaces—the ladle being drawn along to it when full of metal. Very large ingots are now frequently required, and for these a deep pit must be provided. This is often placed at the end of the pit containing the ordinary ingot moulds.

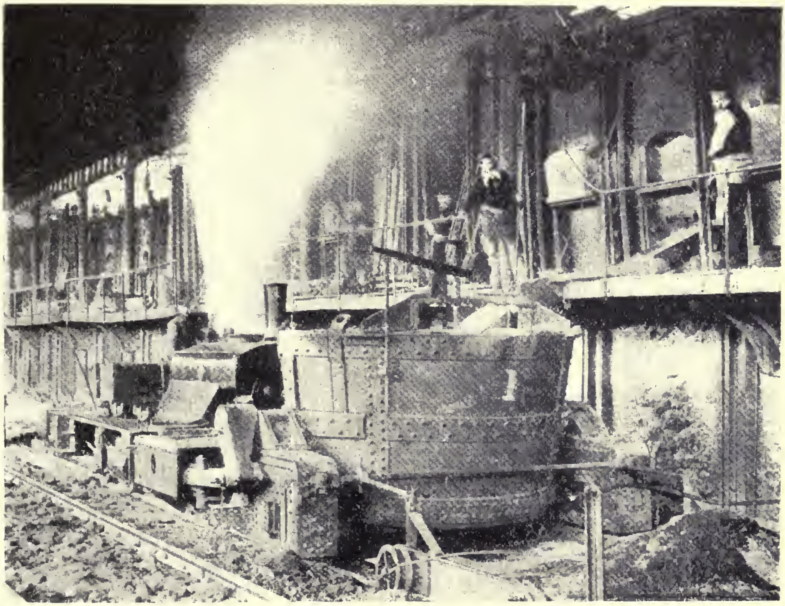


Fig. 166.—Casting Side of Furnaces. (Dalzell Works.)
(Showing ladle and ladle locomotive.)

The arrangement may be modified to almost any extent, as the ladle can be easily drawn to any part of the works as required.

When the metal is to be used direct in the foundry, and not merely cast into ingots for rolling, the ladle is often lifted by an overhead crane and carried to the foundry.

CHARGING.

The furnaces are usually charged by hand. The pigs of iron are lifted on to a flat iron paddle with a long handle. This is pushed into the furnace, and the pig dropped as gently as possible on to the bottom of the furnace. When the pig is in, the scrap is either thrown in or put in on the paddle.

The process of hand charging is laborious and slow. Only a few men can work together without impeding one another, as the space for working is limited. Six to nine men are the most that can be employed, even when, as in some cases, charging is carried on from both sides of the furnace. With the best and most rapid working, the time occupied is considerable. It takes about two hours to charge a 25-ton furnace ; more if small scrap is being used ; and for large furnaces the time occupied is very much longer. Two methods have been suggested for shortening the time of charging : (1) The use of liquid metal, (2) charging machines.

Liquid Metal.—Fluid metal has long been used for the Bessemer converter, and though the conditions of the open-hearth furnace are very different, there seems to be no reason why, where liquid metal is available, it should not be used.

At the Wishaw Works of the Glasgow Iron and Steel Company two 50-ton furnaces are supplied with metal direct from the blast furnaces. The metal is tapped from the blast furnaces into ladles. These are hauled by an endless chain to the front of the furnace, and the metal is tapped from the ladle into the furnace through a shoot. Circumstances do not allow of the tipping of the ladle, or that might be better.

This arrangement saves labour at the blast furnace, as it does away with the casting of the metal into pigs, and also saves time and labour in charging the steel furnace. It does not, however, seem to materially shorten the actual time taken in working a charge. It must be remembered that the time of charging and melting is not altogether lost. Oxidation takes place ; the surface of metal exposed to the air is much larger than after the metal is melted, and therefore it oxidises more rapidly, and the oxide is ready to act on the silicon of the metal. Probably more ore would be required to compensate for this diminution of the rate of oxidation when liquid metal is used.

Charging Machines—Many machines have been suggested for charging open-hearth furnaces, but only one has come sufficiently largely into use to need description.

A charging machine, to be a success, must not only save time at the furnace, but must not involve much additional labour elsewhere. It must be capable of dealing with materials of all kinds, and must be movable, so that it can be drawn away, and hand charging used should it be necessary.

The Wellman charging machine is the best known. This consists of a heavy carriage, running on rails in front of the furnace. The pig, scrap, or other material is charged into boxes in the yard. These boxes are run up to the furnace on small trucks, from which they are lifted by the machine, their contents emptied into the furnace, and the boxes returned to the truck. There will thus be two lines of rails laid before the furnace : A narrow gauge line, leading to the yard, for the trucks ; and a wide (12 ft.) gauge line, running from end to end of the furnaces to be served, for the charger itself.

The charging boxes are 6 ft. long, 2 ft. wide, and 1 ft. 9 in. deep, each of which will hold about one ton of scrap or ore, or rather more of pig iron. These are loaded, three or four of them placed on a charging bogie, and taken to the furnace.

The charging machine itself consists of a strong framework of steel girders, about 14 ft. wide at the bottom, a little less at the top, and 10 ft. or 12 ft. high. It is mounted on wheels, and is driven by a motor. The framework is made high enough to allow of current being obtained from conductors near the roof of the building. At the top are two cross beams, which project forward nearly to the level of the furnace front. These carry rails, on which runs a 4-wheel charger truck, which carries the motors for driving. From the charger truck descends a strong bracket, which carries the charger bar, which hangs freely in a bearing, so that it can be rotated by a small motor on the operator's platform. To this charging bar is attached the operator's platform, and by means of motors motion can be given to the bar either up or down or right or left ; and as the charging platform follows the motion of the bar, the operator is always exactly opposite the working end of the bar, and thus can see into the furnace when the charge is being put in.

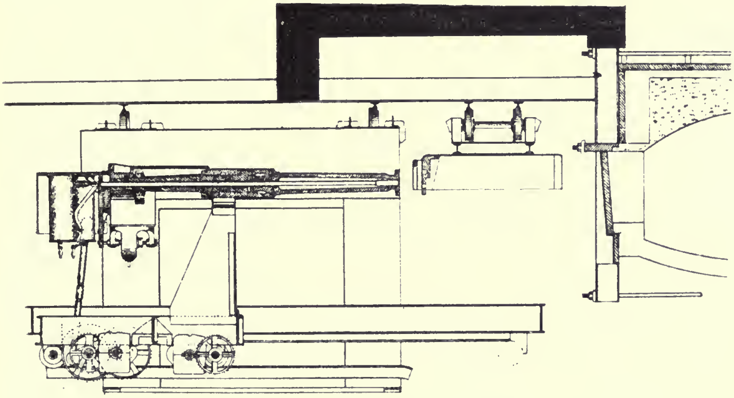


Fig. 167.—Wellman Charging Machine.
(Charging bar is shown in section.)

The charging boxes have at the end a socket, into which the end of the charging bar is lowered.

The charging bar is hollow, and through it runs another bar (the locking bar) for holding the boxes in position. The end of the charging bar is dropped into the socket of the box, and by means of a lever the operator pushes forward the locking bar, thus fixing it securely. Drawing back the locking bar releases the box.

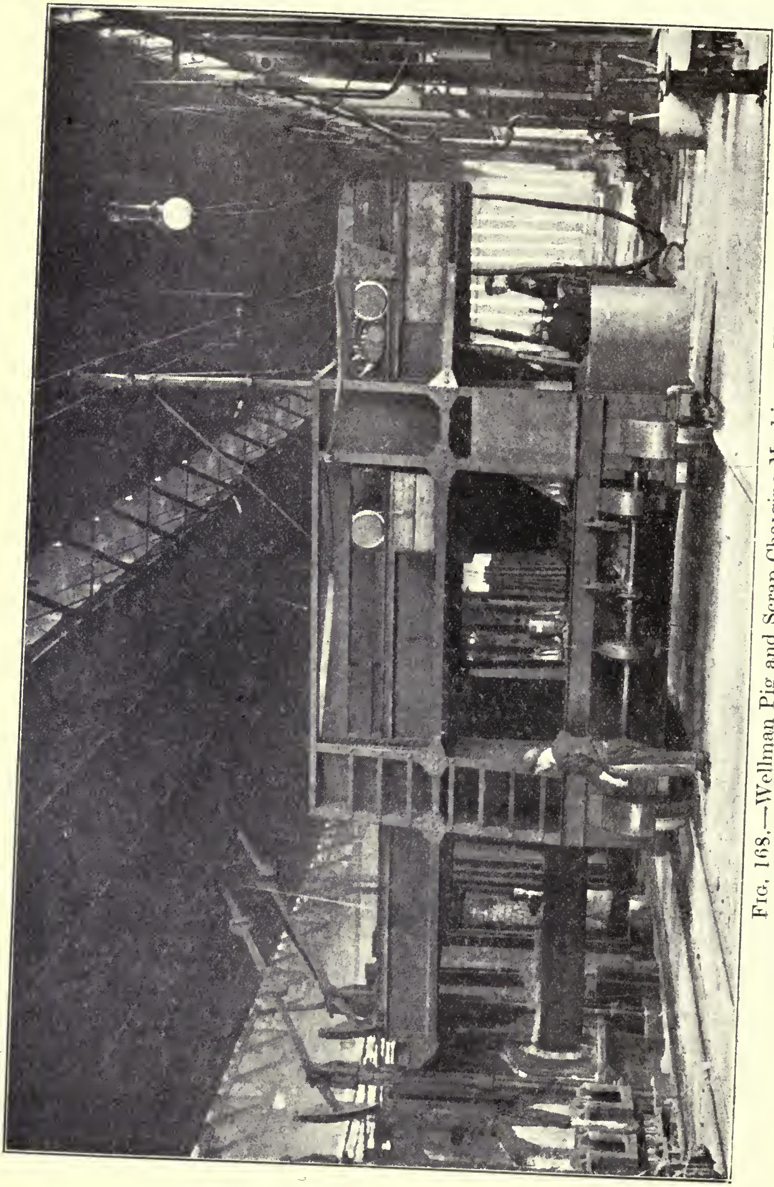


Fig. 168.—Wellman Pig and Scrap Charging Machine at Work.

The charged box, being in front of the machine, it is locked to the charging bar. This is raised, carried forward by the charger truck till the box is in the required position inside the furnace; it is then turned over, the contents emptied into the furnace, the box brought back, placed on its truck, released, and another box lifted on. The motors are each 25 H.P., except a small one on the operator's platform for twisting the bar so as to empty the box, which is $3\frac{1}{2}$ H.P.

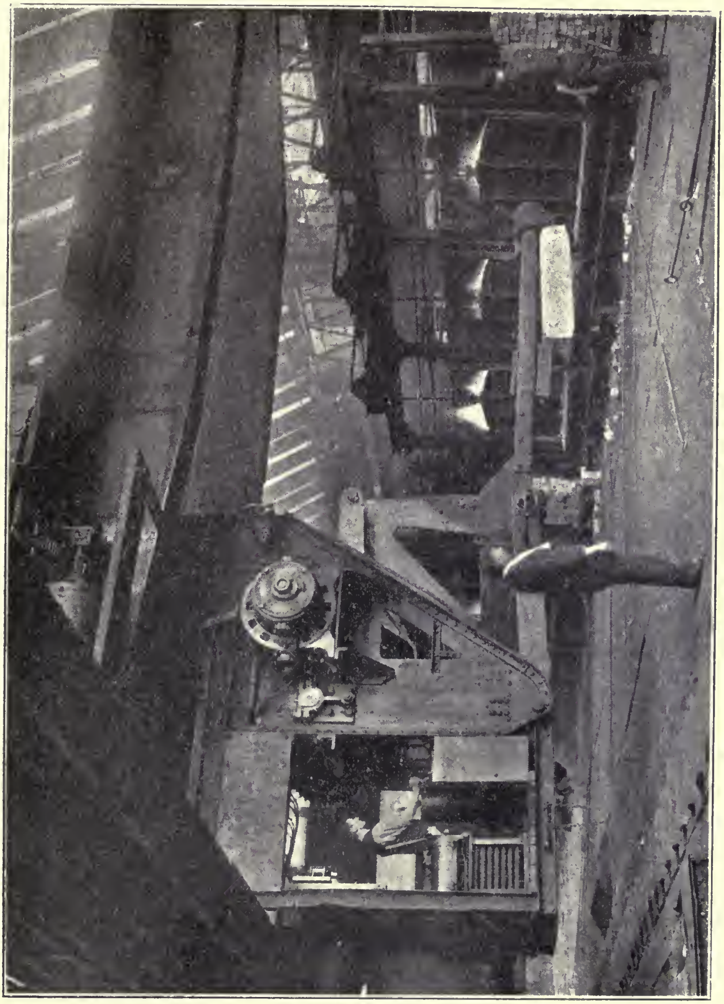


Fig. 169.—Wellman Slab Charging Machine supported on Overhead Girder.

By means of this machine 48 tons have been charged in an hour, and as a rule the machine can lift, discharge, and return the boxes at a rate of one a minute.

The saving in time in charging is thus very great. The output of the furnace is increased, and the saving in labour is very considerable—in one case the labour being reduced by one half.

One machine can keep six furnaces charged when all is going well; but two should be supplied for each six furnaces, so as to avoid any danger of delay or loss of time from breakdowns.

Working a Charge.

The furnace having been tapped, the bottom is examined, and repaired wherever necessary by spreading sand over the bad spots in successive layers, hardening each layer before the next is applied. The time thus occupied will usually be an hour or more. The pig iron is then charged evenly on to the hearth by hand or machine, as the case may be, and on the top of the pig iron is put the scrap to be used.

The pig iron melts first, and frequently leaves a shell of refractory material—sand and oxide of iron—which melts later, and helps to form the slag. During this stage a large surface is exposed to the air, and a considerable amount of oxidation takes place. When the metal is melted it is covered with a layer of slag. During the melting-down stage the flame is kept "short sharp," or oxidising, and the temperature rising, it will occupy about five hours (30-ton charge). When the charge is completely melted the addition of ore is commenced. The boil begins, small bubbles of gas making their appearance on the surface. Then the bubbles become larger and ignite, burning with the characteristic blue flame of carbon monoxide, and small globules of metal are seen coming to the surface, eddying round, and then disappearing. In about five hours (30-ton charge) the boiling subsides, or the metal is "through the boil." Samples are now taken with a long spoon, and the carbon is rapidly determined. If the carbon be not low enough more ore is added, and the process is repeated; but if it be, the metal is ready for tapping; the temperature is increased as much as possible, so as to keep it perfectly fluid.

The tap hole is now forced open with a long pointed steel bar and a sledge hammer, and the metal is run into the ladle with enough slag to cover the surface and protect it from the action of the air. The requisite amount of ferromanganese, heated nearly to redness in a furnace, is thrown into the metal as it flows to the ladle. As soon as all the metal is in the ladle the runner is turned up, and the excess of slag allowed to run to the ground. The tap hole is closed, and the furnace made ready for the next charge.

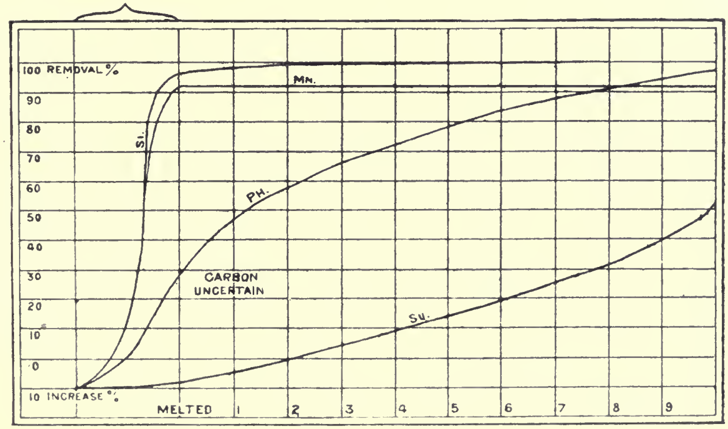
The ladle is hauled away by the engine to the casting pit, and the steel is run into the moulds. As soon as the metal is all out the ladle is turned over, and the slag poured into an iron or sand mould, whence it can afterwards be removed to the slag tip.

CHAPTER XXXIV.

THE BASIC OPEN-HEARTH PROCESS.

When the basic Bessemer process was proved a success, it was, of course, natural to think that similar results might be obtained by working in an open-hearth furnace with a basic lining. Attempts to carry the idea into execution were met with serious and unexpected difficulties in furnace construction ; but when these were overcome the process was found to be not only practicable, but to offer some advantage over other processes. It is rapidly coming into use, and promises in the near future to be the most largely used steel process in this country.

Chemistry of the Process.—The chemistry of the process is in the main the same as that of the ordinary open-hearth process, differing from it much as the chemistry of the basic Bessemer process differs from that of the acid Bessemer. The foreign constituents of the pig iron are removed by oxidation, mainly indirectly by means of oxide of iron, formed or added as hematite ; but the order and rate of oxidation are very much modified by the basic materials present. Not only is the furnace lined with basic material—magnesite or dolomite—but a large quantity of lime is added, so as to keep the whole slag strongly basic.



Units of Time.

FIG. 170.—Basic Open-hearth Process Removal Curves.

History of the Metal.—As the iron becomes hot, surface oxidation takes place, exactly as in the acid process, and as the oxidised metal melts the oxide comes in contact with the oxidisable non-metals in the iron, and these are oxidised out—the silicon first, then the carbon. The rate of oxidation of the non-metallic constituents is limited in the acid process by the necessity for the presence of enough oxides of iron and manganese to combine with silica formed to form silicates of iron or manganese. In the basic process this is not necessary, as there is ample lime present to combine with any silica formed ; thus the whole of the iron oxide is available for oxidising the impurities.

The changes that take place are well shown in the following figures of a charge and the diagram (Fig. 170) given by Mr. Harbord.*

	Charge.	Melted (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Steel.
Carbon	2·30	·42	·23	·178	·094	·075	·07	·06	·05	·045	·05	·13
Silicon	·87	·06	·07	·07	·05	·04	·045	·05	·045	·025	·010	nil.
Phosphorus .	2·30	1·22	1·18	1·00	·84	·70	·48	·33	·192	·116	·085	·065
Manganese ..	·96	·08	·06	·088	·062	·064	·060	·085	·065	·080	·051	·51
Sulphur	·23	·230	·213	·206	·183	·170	·165	·157	·160	·137	·130	·125

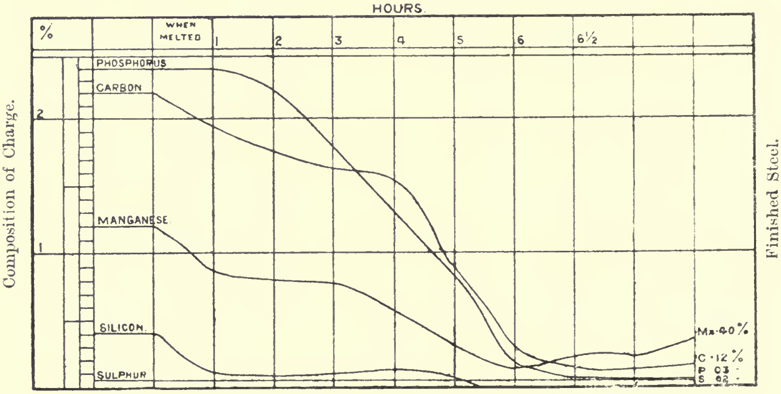


FIG. 171.—Basic Open-hearth Process Removal Curves.

The charge was melted, and samples were taken every half-hour.

The diagram (Fig. 171) gives the results of another charge by Mr. Darby.†

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* J. I. and S. I., 1886, vol. ii., page 701.
† J. I. and S. I., 1889, vol. i., page 82.

The following figures are given by Campbell,* the mode of statement only being slightly altered.

	(1) Charge.	(2) After Complete Fusion.	(3) Beginning Boil.	(4) Ready for Receiver.	(5) Steel in Ladle.
Carbon	2·23	·71	·34	·12	·16
Silicon	·43	·06	·01	·01	·01
Manganese	·84	·33	·25	·22	·49
Phosphorus	·203	·046	·022	·013	·018

The charge in this case consisted of Bessemer pig, basic pig, and scrap.

Carbon.—The carbon is removed almost exactly as in the acid process. The removal is, perhaps, more rapid in its early stages, owing to the excess of available oxide of iron, and can be made practically complete.

Silicon.—The silicon is rapidly removed, and there is ample base for the silica to combine with as soon as it is formed. A large proportion is removed during the melting-down stage, so that the molten metal never contains more than a very small quantity, and the boil begins at once on addition of ore. The removal would be complete whatever is the quantity of silicon present in the iron. At very high temperatures carbon may reduce silica, so that in the acid process silicon may remain in the metal, but calcium silicate is much more stable, so that this is not likely to occur in the basic proces.

Manganese.—The removal of the manganese takes place more slowly than in the acid process, there being no available silica with which it can form silicate; ultimately, however, it is all removed as silicate.

Phosphorus.—The phosphorus removal is the most important reaction in the basic open-hearth process. It will be evident from the figures that the removal takes place very differently in the open-hearth and the Bessemer processes. In the latter the phosphorus remains in the metal till the overblow; in the former the removal goes on from the very first. Phosphoric anhydride is an acid oxide, and competes with the silica for the bases present. In the acid process, where the amount of base is small, the silica combines with it all, and the phosphorus is not removed; in the basic process, where the amount of base is large, the phosphorus is removed. In order that removal may be complete, the slag must be kept strongly basic; the more basic the more complete is the removal.

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* "The Open-hearth Process," page 87.

The reason for the removal of the phosphorus from the very first, and not only at the end of the process, is due to two causes: (1) The silicon is so largely removed during the melting stage that by the time the metal is melted it is almost in the condition of the Bessemer charge at the end of the blow; and (2) the temperature in the converter is far higher than that in the open-hearth furnace, and this very high temperature retards the oxidation of the phosphorus, probably by increasing the reducing power of the carbon.

Sulphur.—The sulphur removal is only partial; the percentage removed varies very much, and it is best not to count on any removal in the selection of a pig.

Recarburisation.—The recarburisation is done with spiegeleisen or ferromanganese, exactly as in the acid process. As in the acid open-hearth process, the operation can be stopped when there is any required amount of carbon present; the amount of recarburiser required is less than in the Bessemer process, and its function is only the addition of carbon. It often happens that the whole of the manganese can be accounted for in the metal, none passing into the slag.

As in the basic Bessemer process, there is always the possibility of the re-reduction of phosphorus if the recarburiser is added in presence of phosphoric slag. The slag is, therefore, usually separated before the addition.

History of the Slag.—The history of the slag necessarily follows that of the metal. There is one difference between the slag from the acid and basic processes: In the former case the whole of the slag is derived from the metal and the ore; in the latter it is largely made up of the added lime.

The following analyses of the slag from the charge, the figures of which are given on page 371 (Mr. Campbell's), will show the character of the changes that take place:—

	2	3	4	5
Silica	19·21	16·37	15·08	15·75
Ferrous oxide	13·68	16·29	20·34	16·63
Manganese oxide	11·12	10·36	9·01	14·11
Lime	42·16	42·78	42·16	39·05
Magnesia	6·64	7·87	8·45	10·40
Phosphoric anhydride	5·149	4·848	3·850	2·961
Silica and phosphoric anhydride	24·359	21·218	18·930	18·711

The slags from Mr. Harbord's charge contained :—

	1	2	3	4	5	6	7	8	9
Silica	22·90	..	..	..	..	..	..	..	17·20
Peroxide of iron	1·17	1·03	1·85	1·90	1·23	1·75	2·20	1·40	2·31
Protoxide of iron	14·90	10·40	7·20	5·94	5·91	6·61	9·09	9·91	13·30
Oxide of manganese	3·69	..	..	..	..	..	..	..	2·09
Alumina	14·20	..	..	..	..	..	..	..	12·20
Lime	28·00	..	..	..	..	..	..	..	33·60
Magnesia	1·70	..	..	..	..	..	..	..	2·27
Phosphoric anhydride	12·5	..	..	..	..	..	..	..	16·19
Iron	11·60	8·96	6·90	5·97	5·45	6·38	7·10	8·75	9·88
Silica and phosphoric anhydride	35·40	..	..	..	..	..	..	..	33·39

It must be remembered that it is impossible to get a sample of the slag which at any moment will represent exactly the whole bulk, as the composition in different parts varies very much.

It will be seen that the slag gradually becomes more basic ; this is, to a small extent, due to the increased oxide of iron, and perhaps, to some extent, to basic gangue in the ore, but probably mainly to the action of the slag on the bottom. It is not easy to see why there should be so much oxide of iron in a slag which is already so strongly basic ; it may, however, assist in the fusibility of the slag. Campbell says that high oxide of iron accompanies low silica, and this is the best condition for phosphorus removal. He says, "It remains to be discovered whether an increase in FeO has any connection with the amount of phosphorus removed," and he comes to the conclusion that the FeO is an important agent. "Whether the iron oxide is valuable for its oxidising power, or for its enhancement of the fluidity, remains undecided."

Other things being equal, the more basic the slag the more efficient will be the dephosphorisation. It is rarely that silica and phosphorus anhydride in the slag rises above 30 per cent. Perhaps in such a basic slag alumina should be considered as an acid, and silica and phosphoric anhydride and alumina be taken as the measure of acidity. Silica should not exceed 20 per cent, or the hearth may be attacked.

The following figures give the history of the metal and slag of an ordinary Staffordshire charge :—

ANALYSES OF METAL.

	1	2	3	4	5	6
Carbon	2·05	·17	·05	nil	trace	trace
Silicon	·213	·01	trace	nil	nil	nil
Phosphorus	1·943	1·007	·143	·037	·023	·015
Manganese	·757	·41	·34	·175	·150	·155
Sulphur	·045	·036	·024	·031	·034	·023

ANALYSES OF SLAG.

Ferric oxide	24·572	6·56	1·28	4·08	3·080	6·514
Ferrous oxide	..	·792	6·624	7·575	8·216	7·765
Manganese oxide ..	1·025	6·450	7·710	8·390	8·100	7·530
Alumina	Not estimated.					
Lime	48·342	47·630	44·00	42·910	43·030	43·450
Magnesia..........	..	5·766	5·470	5·010	5·010	5·920
Silica	1·979	11·960	9·780	8·950	9·972	9·810
Phosphoric anhydride	·303	15·427	21·910	17·269	17·506	15·300
Sulphur	·248	·22	·266	·288	·280	·296
Carbon dioxide	16·945	..	..	..	..	..
Iron	17·199	5·654	5·631	8·475	8·142	10·501
Phosphorus	·132	6·735	9·566	7·540	7·643	6·680

No. 1—Materials as charged .... 3-25 p.m.
,, 2— ,, when thoroughly melted.......... 7-45 ,,
,, 3— ,, ,, ,, ... 8-45 ,,
,, 4— ,, ,, ,, ... 9-15 ,,
,, 5— ,, ,, ,, ... 9-45 ,,
,, 6— ,, when tapping .... 10-5 ,,

Thermal History.—This will, of course, depend on the materials oxidised. It is of little moment, as the heat required is supplied by the combustion of the gas.

MATERIALS USED.

Pig Iron.—Of all the steel-making processes, the basic open-hearth allows the greatest range in the composition of the pig. Indeed, it is hardly too much to say that any ordinary pig iron low in sulphur can be quite satisfactorily worked on the basic hearth. The pig iron is, of course, not the only factor, because scrap is always added to the charge, and serves as a diluent. The iron used may be grey or white ; often it is the latter.

Carbon.—The amount of carbon is immaterial.

Silicon.—The amount of silicon should not be too high, since the higher the silicon the more lime must be added to keep the slag basic, and thus to ensure phosphorus removal and prevent the cutting of the hearth.

Manganese.—This should not be more than 2 or 3 per cent, or it may not be completely removed.

Phosphorus.—The amount is immaterial, since it is not required as a source of heat. It need not be high. If the slag be sufficiently basic it will be completely removed.

Sulphur.—Should be low, as the removal is at best incomplete.

Lime.—The lime used should be as free as possible from silica, since the silica will combine with some of the lime, which will thus be rendered useless, at the same time increasing the bulk of the slag. Magnesite is sometimes used, but has no advantage over lime. Limestone ($CaCO_3$) is used sometimes. The carbon dioxide evolved may act as an oxidising agent, but at the same time the decomposition absorbs heat and delays the melting.

Ore.—The ore should be as free as possible from silica and sulphur, but otherwise any hæmatite will do. If phosphorus be present, it may necessitate the addition of more lime, to keep the slag properly basic.

The Furnace.—The furnace differs only in one respect from that used in the acid process. Basic bricks are too brittle to be used for the walls and roof of the furnace ; acid bricks must, therefore, be used, and as acid and basic materials flux if they are strongly heated in contact, some means must be taken of separating them. An efficient separation of the acid and basic materials was the great difficulty which had to be overcome in the construction of the early furnaces.

Mr. Dawson speaks of magnesite bricks having been used for the walls and roofs of basic furnaces in America, and ascribes the unsatisfactory results to "the shrinkage of the bricks themselves, causing gaping joints and the shrunken bricks to become loose and drop out."*

In this country acid bricks are always used for the walls and roof, and usually a parting of neutral material is put between them where they would come in contact, though this is sometimes left out. The parting is either of graphite or chromite.

The Bottom.—The bottom must be of basic material, and either calcined dolomite or magnesite is used. The former is general in this country, but the latter is largely used in Sweden and in the United States. Magnesite is very durable, and has so little affinity for silica that it can be used without a parting layer; but the cost is prohibitive in this country.

A good bottom will last several years, but it gradually becomes charged with impurities, and so has less and less purifying action on the metal. In Staffordshire the bottoms are usually renewed once a year.

Making the Bottom.—The furnace is built, as usual, up to the level of the cast-iron plate, and the side walls are continued up, so as to carry the roof in the usual way. On the iron plate is put a layer of good, firm firebricks, as neutral as possible, and on this the bottom is put. The bottom must be carried up several inches higher than the slag is ever likely to reach; and where it would rest not on the iron plate but on the brickwork of the furnace, the parting layer is put in. Frequently at the level where the basic lining ceases a course of chrome bricks is built into the wall of the furnace, and between this and the basic lining a joint of chrome ore is made.

There are several methods of making a bottom. The most usual is to use a mixture of calcined dolomite and anhydrous tar. The mixture should be put in in layers, and stamped down with hot iron stamps exactly in the same way as in making the bottom of basic Bessemer converter. Such bottoms are very durable.

Another method is to make the basic material into bricks, which are burned and then set in tar mortar.

Hearths made by either of these methods are made before the furnace is heated.

The hearth may be lined after being heated to its full heat by throwing in the dolomite in thin layers, and fritting them exactly as with the sand in making the acid hearth.

Mr. Millward, speaking of these methods, says: "This is the one I prefer, for the reason that it is necessary to have a perfectly homogeneous lining to work upon. My experience with the stamped and bricked linings is that they are not uniform; especially in the case of the stamped lining, the surface exposed to the action of the heat and boiling metal fuses together for the thickness of a few

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* "Basic Open-hearth Steel Furnaces." P. C. I. of E., 1894-95, page 28.

inches only, whilst the tar in the lower portion simply burns out, and after a time the fused part comes away, leaving great cavities from which the metal has to be removed by some means before the damage can be repaired—the result being heavy repairs and long delay."

"To fuse in a lining is a work of great care ; each layer must be fastened before the next is applied, and generally some description of flux is needed ; it is well, after putting on a certain thickness, to wash out with slag."*

When the hearth is complete it will be porous, and must be saturated by a wash of slag or iron, the former being usually used. Mr. Millward says : "It is certainly better to fill up the interstices of the lining with slag than with metal.

"The time required to put in such a lining is about four days ; but if this is properly done it will wear a very long time. We have a lining working now which appears as good as new, although it has been in continuous working for 32 months."

"The calcined dolomite used has the following composition approximately :—

	Per cent.
Lime	58
Magnesia	31
Alumina	3·5
Peroxide of iron	3·5
Silica	4·0

"Before putting the charge into the furnace, we have to stop the tap hole—a very simple operation, but one upon which great care must be exercised, or the metal will either burst through, or, when the time for tapping arrives, the stopping will have been found to be so effective that it will require considerable expenditure of time and labour to remove it. In the first instance, the hole should be carefully freed from all slag or metal which may have drained into it from a previous charge, then any damage to the surrounding lining may be made good ; the stopping can generally then be put in, and generally consists of a plug of dolomite and tar mixture, backed by some loose crushed dolomite with another backing of dolomite and tar, and finally an outer stopping of loam sand. Inside the furnace a small quantity of dry dolomite should be fused over the hole and its adjacent lining."†

Working the Charge.—When the furnace is ready, the lime to be used, with some of the hæmatite ore, is put on the bed and around the banks, then the pig iron is put in, and on the top of all the scrap, or the pig and scrap may be mixed. The charge is then melted, and ore added in the usual way.

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* N.S.I.I. and S.W.M., 1891.

† Millward, loc. cit.

Mr. Millward gives the following table of materials consumed in and produced in an 11-ton charge :—

Materials.	Charged at Commencement.				Added During Working.				Total.			
	t.	c.	q.	lbs.	t.	c.	q.	lbs.	t.	c.	q.	lbs.
Pig iron	7	10	0	0	0	1	0	0	7	11	0	0
Scrap	3	10	0	0	..				3	10	0	0
Ferromanganese	..				0	1	1	25	0	1	1	25
Total metal	..				..				11	2	1	25
Lime	0	8	0	24	0	4	3	0	0	12	3	24
Limestone	0	14	2	8	0	7	0	16	1	1	2	24
Ore (pottery mine)	0	9	1	12	0	14	2	14	1	3	3	26
Steel ingots produced	..				..				10	11	0	22
Ladle and pit scrap	..				..				0	4	3	3
Total metal produced	..				..				10	15	3	25

= 97·08 per cent of metal charged.

CHAPTER XXXV.

MODIFICATIONS OF THE SIEMENS PROCESS.

The Siemens or open-hearth process has been modified in various ways for various purposes, the variations being of two kinds—those of the plant and those of the methods of working.

Modifications of the Plant.—The furnace lends itself very readily to modification, and the varieties of detail that have been suggested are, therefore, almost endless.

The furnaces now used are much larger than those built in the early days of the process; but mere increase in size, whilst of very great importance economically, can hardly be considered as a modification unless it leads to other important changes. It cannot be said to have been yet settled what is the best size of furnace for economy and output, but there is no doubt that the tendency is towards much increased size. Fifty-ton furnaces are common, and some of at least 100 tons capacity are in use. On the other hand, many managers contend that nothing is to be gained by an increase beyond 40 tons.

If the furnace be too short, combustion will not be completed in the furnace, but will be continued in the flues and chambers, thus causing waste of heat. On the other hand, if the furnace be too long, heating will be irregular. It is generally agreed that the distance from port to port should not be less than 15 ft., but the maximum length has not been determined.

The furnace body is nearly always rectangular, and the length—*i.e.*, from port to port—is considerably greater than the breadth. Elliptical or even circular furnaces have been suggested, but have never come largely into use.

The Roof.—As already mentioned, in the early furnaces the roof was made to dip considerably in the centre, so as to deflect the flame downwards. In modern furnaces the dip is much reduced, or even abolished.

This change is partly due to the change in the form of the ports, which are now so made as to help to direct the flame downwards, and thus remove the need for the "dipped" roof. In the arrangement known as the Hackney port the air port is vertically over the gas ports, and overlaps them at both ends, thus tending to deflect the gas downwards.

In 1884 it was pointed out by Mr. F. Siemens that the "dipped" roof, and the therefore necessarily limited combustion space, was disadvantageous. The limit of temperature which can be obtained in a furnace fired with producer gas—which consists mainly of carbon monoxide—is that at which carbon dioxide dissociates, for at higher temperatures no combustion could take place. If this dissociation point could be raised, it might be possible to attain a higher temperature. Mr. Siemens contends that dissociation is very much facilitated by contact of the gas with hot solids, such as the furnace walls and roof, and therefore that the best way to obtain a high temperature is to allow ample space for combustion, so that the burning gases may not touch solid matter, but heat the furnace and the charge by radiation. To carry out this idea, Mr. Siemens builds his furnaces with an arched roof, and they are said to have been very successful.

Position of the Regenerators.—The position of the regenerators has been much varied. Siemens placed them under the body of the furnace; and this position, though it has manifest disadvantages, has been generally retained, and has been found to be, on the whole, the most convenient. In a few furnaces they have been placed under the working platform, but this position tends to make the working platform uncomfortably hot.

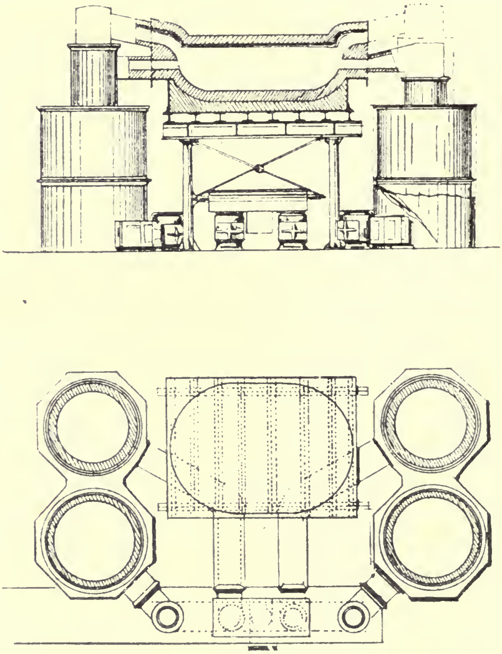

FIG. 172.—Batho Furnace.

Batho Furnace.—In the Batho furnace the regenerators are placed outside the furnace, and quite separate from it. They are usually placed above the floor level, and are circular structures, quite independent of one another, each being contained in a separate casing.

The advantages claimed for this type of furnace are : That it is less costly to erect, as little or no excavation is needed ; that, being above ground, there is little danger of flooding in low-lying districts ; the weight of the furnace is carried quite independently of the regenerators ; and there is no fear of loss of metal into the flues or regenerators ; easy access can also be obtained to the different parts for repairs, and there is no danger of air and gas mixing by leakage either in the chambers or passages, and the checker-work can be changed more quickly. Against these advantages must be set the greatly increased space occupied by the furnace, the loss of "draught" on the entering gas due to the regenerators being at a higher level, and the heating of the working platforms by radiation.

Hilton's Furnace.—The Hilton furnace is in some respects similar to the Batho. The regenerators are quite separate, each with its own iron casing ; but they are placed below the floor level, and are so arranged that there is free air circulation round them and beneath the furnace, and they are put near the corners of the hearth, so that the passages ascend vertically. The gas regenerator is made higher than the furnace bottom, and is connected directly with a horizontal passage at the end of the furnace, from which the ports open. To allow plenty of room, the air regenerator is kept entirely below the working platform, and is connected with the furnace by a vertical passage.

In some few furnaces the regenerators have been placed above the furnace, a position which has little or nothing to recommend it. A furnace with the regenerators above was worked for some time at a small Scotch steel works.

New Type Siemens Furnace.—This furnace does not seem to have been used for steel making, but it is largely used for reheating furnaces. There is only one pair of regenerators—that for air—the gas passing hot from the producer, which is closely attached to the furnace. The products of combustion leave the furnace at the same end as the gas and air enter. (Fig. 173.)

Gas from the producer B passes through the flue C^1 to the gas port, and thence into the combustion chamber h^1 g^1. Air for combustion passes through the regenerator A^1 by an air flue and the air port H^1 into the combustion chamber, where it meets the gas, and combustion takes place. The flame sweeps round the hearth E. and the products of combustion pass away by h g, and go partly through the regenerator A and partly through the gas producer B, to be converted into combustible gas. From time to time the air regenerators are reversed as usual.

The products of combustion contain about—

Carbon dioxide	17 per cent,	Oxygen	2 per cent,
Nitrogen	81 per cent,		

with a considerable quantity of water vapour. As they pass to the gas producer they are at a very high temperature. The carbon dioxide is at once reduced to carbon monoxide, and the water vapour is decomposed yielding hydrogen and carbon monoxide. Steam and air are also supplied, and the gas leaves the producer at a very high temperature. This type of furnace is said to regenerate both the heat and the products of combustion, and to lead to considerable saving of fuel and labour.

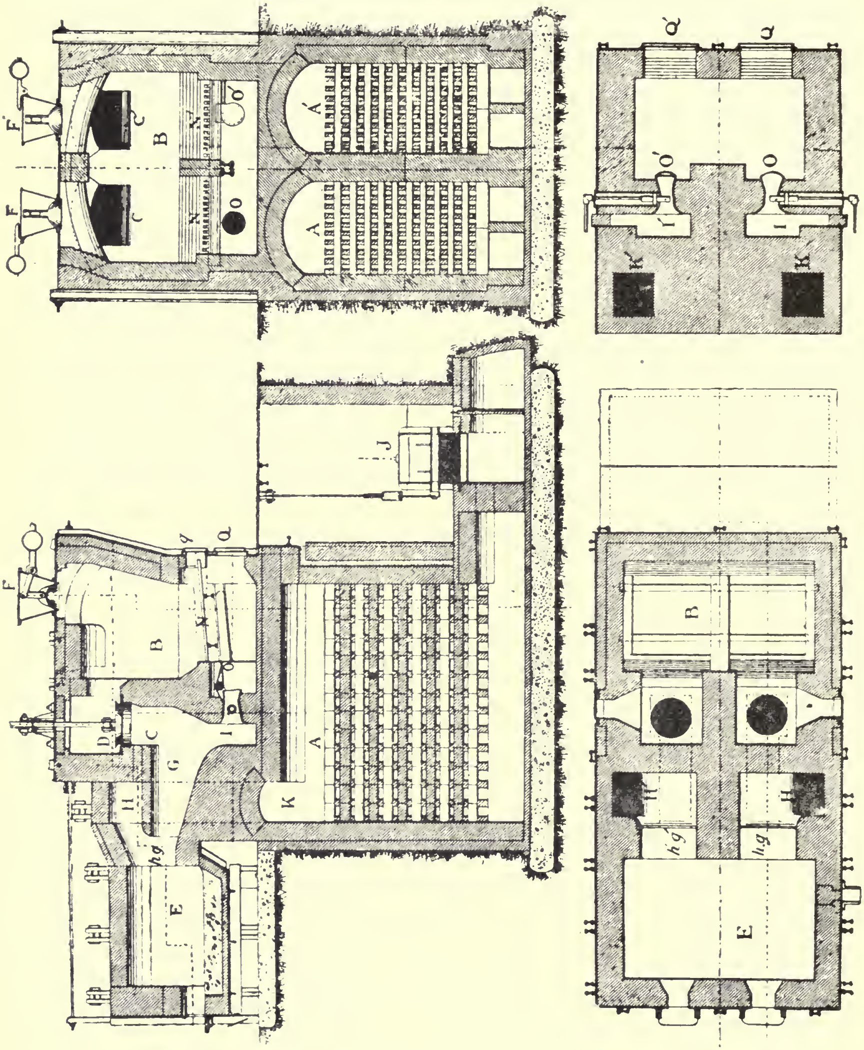

FIG. 173.—Siemens New Type Furnace.

Recuperators.—In the Siemens regenerator the action is intermittent, the direction of the air and gas being reversed from time to time. Attempts have been made to use a continuous system in which the air and gas shall pass continuously in the same direction. In the Gorman recuperator the air and gas to be heated are passed through fireclay tubes outside, which the products of combustion are made to circulate.

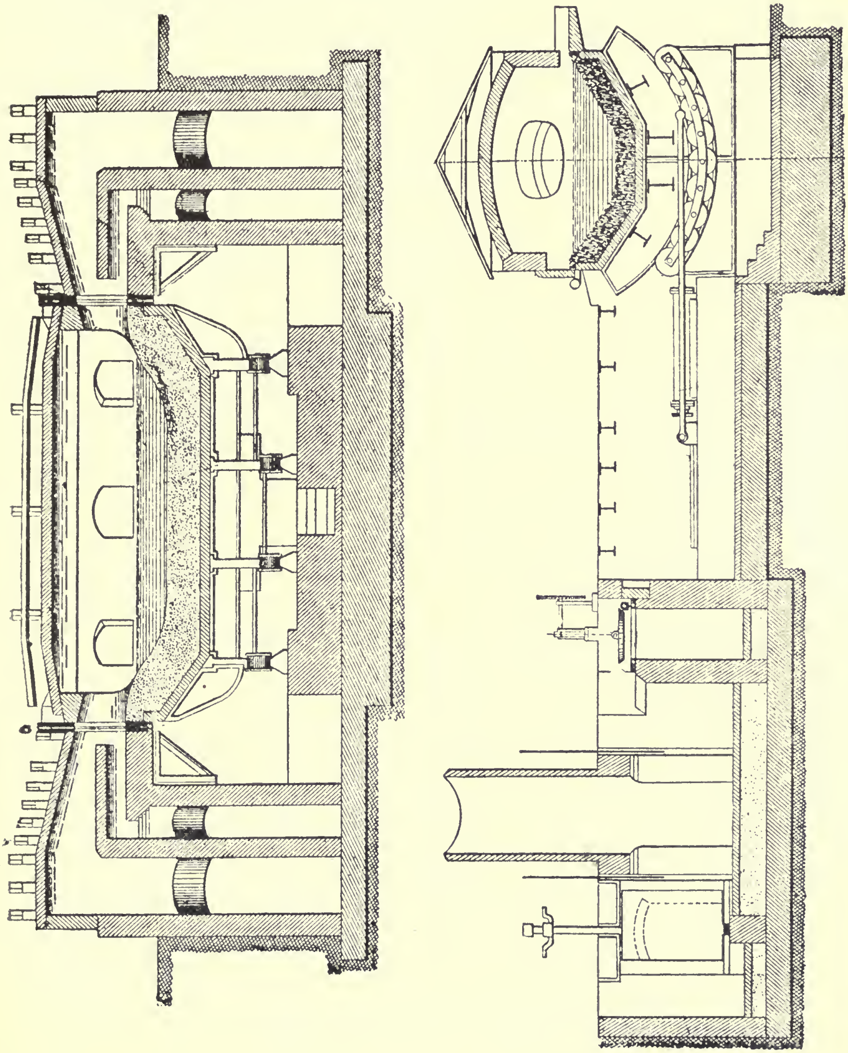

FIG. 174.—The Campbell Tilting Furnace.

Tilting Furnaces.—The working of very large charges is attended with considerable difficulties, and delays are very likely to occur. The difficulties of charging have been to a large extent met by the introduction of the charging machines, which have been already described, and the difficulties of the tapping by the introduction of the tilting furnace. The body of the furnace is securely cased, and is so arranged that it can be tilted over, the charge, therefore, being poured out of a spout, instead of being tapped through a tap hole. This not only reduces the time occupied in tapping, but gives much more perfect control, as the pouring can be stopped at any moment, and the whole or part of a charge can be poured as required; and it also prolongs the life of the furnace.

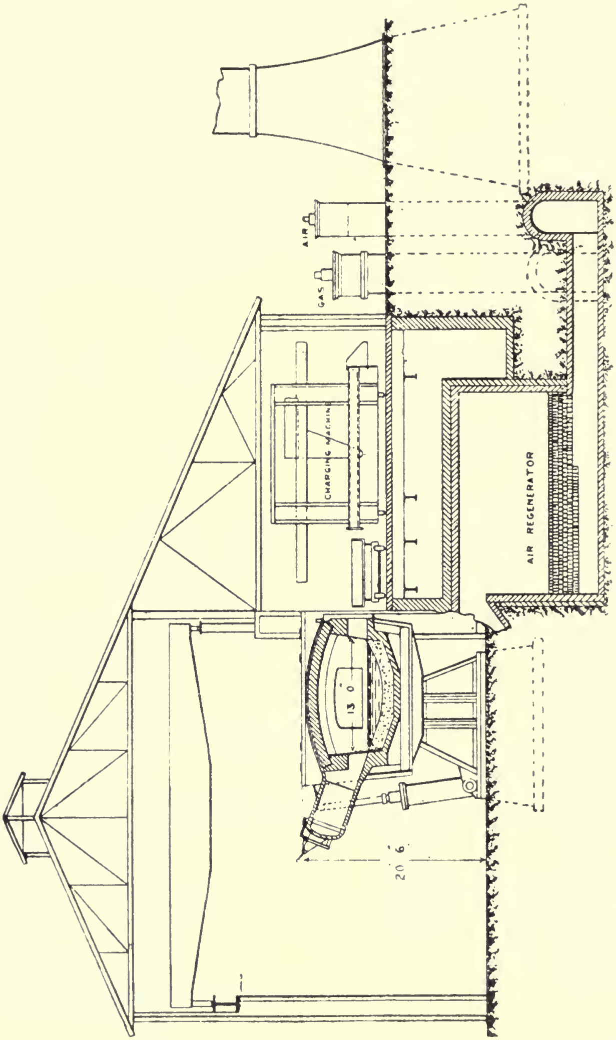

FIG. 175.—Wellman Rolling Furnace. Cross Section, Showing Position of Regenerators. Charging Machine in Front.

The Campbell Furnace.—The first tilting furnace was that designed by Mr. Campbell, which has been in use at Steelton since

1889. The furnace body is strongly cased, and is mounted on strong curved girders. These rest on a series of rollers running on a curved bed, the curvature of which is concentric with that of the furnace girders. The furnace is tilted by means of a hydraulic ram, and as the centre of rotation is the centre of the furnace body, the ports can remain partially open during tilting. The tap hole is above the metal when the furnace is horizontal, and therefore only needs loosely stopping. In order to tap, the furnace is tilted so that the slag is above the tap hole; this is then opened, and the metal is poured from beneath the slag. The wall above the tap hole becomes somewhat attacked, but can be readily repaired once a week.

The Wellman Rolling Furnace.—In the Wellman furnace the tipping arrangement is different. Various modifications have been made since the furnace was first introduced; and as an example of the latest type, the 50-ton furnace at the Alabama Steel and Shipbuilding Company, Ensley, Alabama, U.S.A., may be taken.

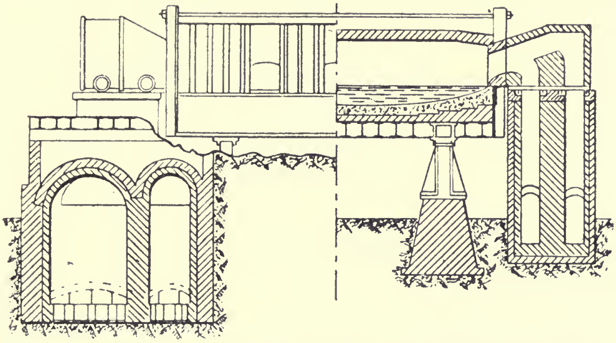

FIG. 176.—Wellman Rolling Furnace. Longitudinal Section.

The furnace is "a very strongly-framed steel shell or casing, of an approximately rectangular section, inside which the lining of silica bricks is built up. On the underside of the structure are fixed two strong curved rockers, which roll on and are supported by strong steel standards with horizontal upper surfaces. When tilting to pour off the steel, the furnace rolls forward on these rockers. The rolling movement is accomplished by two hydraulic cylinders mounted on trunnions at their lower ends, and having the upper ends of their piston rods attached to the pouring side. To tilt the furnace, water is admitted to the top end of the cylinder; while, to return the furnace to the melting position, the water is allowed to escape. In case of accidental failure of this hydraulic system during pouring, the furnace returns by its own weight to the normal melting position."

Furnace Body.—The sides of the furnace consist of two strong plate girders, together with a framework of upright channels tied together and stiffened by longitudinal tie plates and angles. They are also braced across the top of the furnace by diagonal tie rods, arranged in such a manner as to offer the greatest possible resistance to distortion by heat. "Each end of the furnace is provided with openings for the passage of the air and gas, round which is fitted a cast-iron water-cooled ring, which registers with a corresponding ring on the port when the furnace is upright. The furnace bottom is formed of heavy steel plates butt-jointed and well stiffened with cross channels."

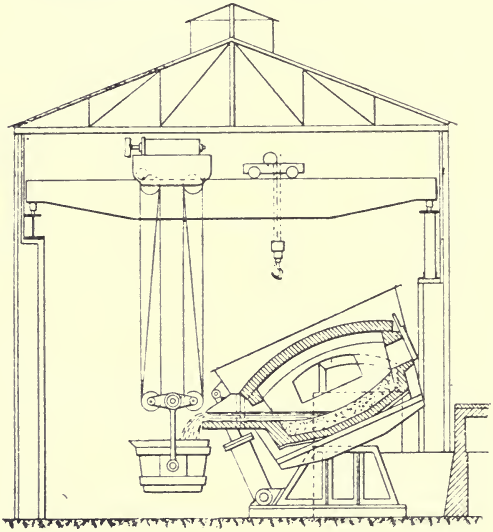

Fig. 177.—Wellman Rolling Furnace. Pouring Through Spout into Ladle Carried on Overhead Crane.

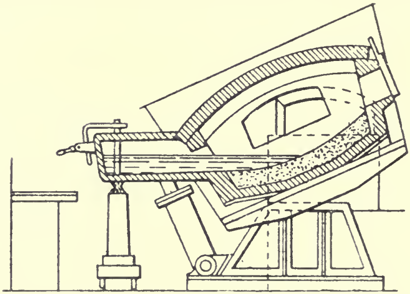

Fig. 178.—Wellman Rolling Furnace Tapping through Forehearth Direct into Moulds.

The rockers are each "a massive steel casting bolted to the underside of the furnace body, the rolling surface being curved and provided with rackwork, which keeps the furnace parallel without supporting any of the weight."

The pedestals or standards on which the rockers rest are "built up of steel plate and angles strongly framed together. On the top is fixed a flat steel plate, having recesses in which the rackwork of the rocker gears." The pedestals are, of course, built on very solid foundations.

The doors are three in number, and are operated by pneumatic cylinders through wire ropes, the leads being arranged in such a way that the doors remain closed when the furnace is tilted. The doors are water cooled, and radiate very little heat, thus allowing the small inspection hole in each door to be used without hardship to the men. "There is also a small door provided near each end of the furnace to facilitate repairing the end walls."

The tap hole "is so arranged as to be always above the level of the bath when the furnace is in the melting position. It is fitted with a heavy steel flanged casting securely bolted to the plates forming the sides of the furnace. In the outer flange holes are provided for readily attaching the fire hearth or the pouring spout as required for the various operations.

"The brickwork forming the ports is built up inside casings of steel plates," each port forming a separate self-contained structure carried upon four flanged wheels. The uptakes from the regenerators are strongly encased and tied, and are carried up to about the level of the furnace bottom, and across the top of each is laid a short track on which the wheels of the port rest. Round the upper ends of the two passages leading from the regenerators are two cast-iron water troughs, while round the corresponding openings on the underside of the port are fitted rings which project downwards into the water troughs, thus forming a water-sealed joint between the movable port and the fixed uptake. Sufficient clearance is given to the troughs to allow the port to be moved on its wheels a few inches towards or from the furnace end without breaking the seal. The joint between the ports and the furnace body is vertical, and is made by the cast-iron rings on the furnace abutting against the corresponding rings on the ports. The joint is efficient, and the leakage inwards and outwards is negligible. When pouring is about to commence, each port is drawn back a few inches to avoid friction between these faces and to allow free motion of the furnace body. The ports can be removed for repairs by an overhead crane, which lifts them from the track and deposits them in a suitable place, a fresh port being substituted. No joints require to be made or broken, and the change only occupies half an hour.

The regenerative chambers are placed two at each end of the furnace.

The Forehearth.—This arrangement is of great advantage in many cases, and in principle resembles the Casperson converter ladle described in connection with the Bessemer process. It is a small ladle-like arrangement attached to the tap hole, into which the metal can run when the furnace is tilted. It is provided with a hole and stopper like an ordinary ladle, so that the metal can be run from it into moulds—movable moulds, of course, being used—and the use of the ordinary ladle dispensed with. "It is a box-shaped casting, with a flanged opening on one side corresponding to the tap hole, to which it is bolted. It is brick-lined, and is provided with two pouring holes and stoppers."

Working the Furnace.—The furnace is charged in the usual way, either with a machine or with liquid metal, according to circumstances, and the charge is worked as usual. When the charge is ready, the forehearth—if such is being used—is fixed in position, the furnace rolled over, so that the metal flows into the forehearth, and is thence distributed to the moulds. The furnace is then rolled back to the melting position, and the furnace is settled as required round the slag line—which is, of course, above the level of the slag in the furnace. The forehearth is removed, and a spout substituted; the slag bogie is brought up, and the slag poured into it. The furnace is rolled back ready for a new charge.

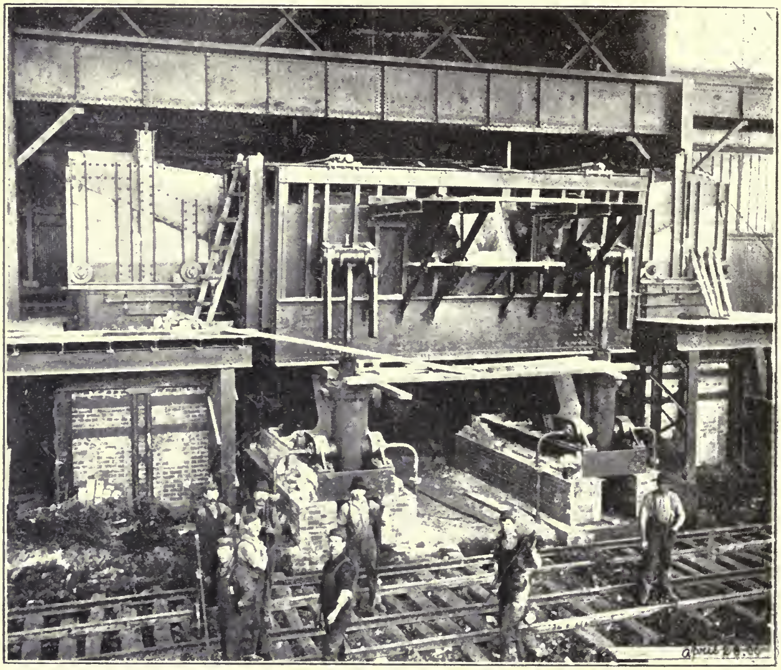

FIG. 179.—Wellman Tilting Furnace.

Advantages of the Rolling Furnace.—(1) "As the pouring hole of the furnace is above the level of the bath when in the normal or melting position, it is never closed up, but only loosely covered to exclude the air. Consequently, the time taken to open the hole before pouring, and to repair and close it after pouring—which is sometimes considerable in a fixed furnace—is saved, as well as the labour connected therewith. The interval between emptying the furnace and commencing to charge the new material is thus considerably shortened, and the material necessary for making up the tap hole in a stationary furnace is saved.

(2) "Since no injury is done to the pouring hole by opening and closing, the life of the furnace bottom is much prolonged. The occasional trimming of the hole can be done at any convenient time.

(3) "If the slag is too abundant—as is often the case in the basic process—it can be poured off at intervals during the melting.

(4) "In every fixed furnace small inequalities in the bed must exist in which pools of metal lodge and can with difficulty be removed. This leads not only to a waste of metal, but to a diminution of the capacity, and often to distortion of the furnace bottom. In the tilting furnace every particle of metal and slag can be removed after each charge.

(5) "The charge can be tapped at the exact moment it is ready, as no time is lost in opening the tap hole.

(6) "Should any hitch occur during pouring, the furnace can be instantly tilted back, and thus the pouring stopped."

Advantages of the Forehearth.—The forehearth has several decided advantages. There is much less cooling than when a ladle is used, so that the metal is tapped hotter. The metal is very easily distributed, and, should the stopper be leaky, the furnace can be at once rolled back, thus avoiding loss.

The pouring is said to be much quicker than from a ladle. "At Ensley the whole contents of a 50-ton furnace is poured into about 20 moulds in less than 12 minutes."

Modified Methods of Working.

The open-hearth process has many advantages over the Bessemer, but in output it falls far behind. A pair of 10-ton Bessemer converters working on the British system will make about 30 tons of steel an hour. A 30-ton steel furnace will take 10 or 12 hours, or perhaps more, to make the same amount. Larger furnaces, of course, reduce the difference to some extent, but not much, because the larger furnaces, whilst turning out more metal, take longer to work, though the output increases more rapidly than the time occupied. A 50-ton furnace, however, turning out, say, 50 tons in 12 hours, is still far behind the pair of converters in output.

Most modifications that have been made have had for their object the increasing the output so as to bring the open-hearth nearer to the Bessemer process.

Combined Bessemer and Open-hearth Processes.—Acid, basic, or the two combined, have frequently been suggested, the work being commenced in the converter, and the molten metal being transferred to the hearth for completion, it being contended that the speed of the Bessemer with the control of the Siemens process could thus be obtained. Such methods, however, have never come into use to any extent.

Within the last few years two important modifications of the open-hearth process have been devised, both of which are rapidly coming into use.

The Bertrand (or Bertrand-Thiel) Process.—This process was introduced at Kladno, in Bohemia, and once attracted public attention.

The essential point of the process is the use of more than one furnace, the process being commenced in one and completed in the others. Three or four furnaces have been recommended by some; but the best results seem to be attained by the use of two furnaces, these being preferably placed at different levels, so that the metal can be easily transferred from one to the other. The first furnace is called the "primary," and the second the "secondary" furnace, and both are basic lined. The pig iron is charged into the primary furnace, and is worked in the usual way, the temperature being kept low. The scrap to be used is put into the secondary furnace, and is heated up and oxidised; the hot, molten metal is poured from the primary furnace into the secondary, and, coming in contact with the hot, oxidised steel, a very vigorous reaction takes place, the temperature rises, and the elimination of the metalloids is soon complete.

The reactions are much the same as in the ordinary process. In the primary furnace the phosphorus and silicon are almost completely removed, and the manganese largely, but the carbon is only slightly reduced. Hence the vigorous reaction in the secondary furnace when the molten metal comes in contact with the oxidised scrap or ore.

The following figures are given by Mr. Bertrand:—

	C.	P.	Si.	Man.
Pig iron	3·8	1·6	1·0	1·0
Ingots from primary furnace	2·2	·4	·05	·5

The slag from the primary furnace contains a large quantity both of silica and phosphoric anhydride, whilst the slag from the secondary furnace contains but little phosphorus. In one case the slag from the primary furnace contained:—

Silica	19·60
Phosphoric anhydride	21·88
Ferrous oxide	8·15
Lime	35·40

The process is very materially shortened and the output considerably increased. The saving of time is apparently due to the fact that the bulk of the removal takes place under very favourable conditions, and that when the slag has become charged with silica and phosphorus, and is, therefore, much less efficient as a purifying agent, it is removed and replaced by fresh material of high purifying

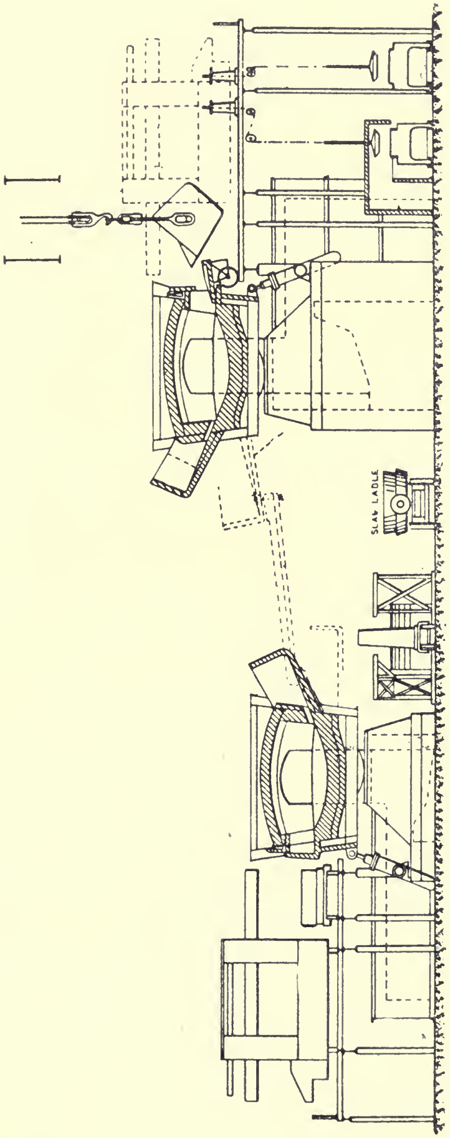

Fig. 180.—Arrangement of Rolling Furnaces for the Bertrand Process.

power. The removal of the last portions of an impurity is always more difficult than the removal of the first portions, and in the ordinary process this has to be done by a slag already highly charged with the constituents to be removed. On this subject Mr. Howe writes: "For the first washing of a very dirty object, relatively dirty water does pretty well; when the object has been washed nearly clean, we need clean water to remove the last traces of the dirt. To remove the first of the phosphorus of cast iron the slag need not be extremely basic: a moderately basic one suffices, like moderately clean water. To remove the last of the phosphorus needs a more basic one. Clearly, for a given quantity of phosphorus and silicon in the cast iron, and, hence, of phosphoric acid and silica resulting from their oxidation, the more basic slag the greater will be its quantity, since it is made basic by adding lime to it. If now we keep the slag in the furnace throughout the process, as is the common practice, the whole of that slag must receive additions of lime great enough to make it basic enough to remove the last of the phosphorus, and the quantity of slag must be correspondingly great. If, however, we wash out the first of the phosphorus and silicon with a slag which is relatively acid, and hence has had but relatively little lime added to it, divert that slag, and to the second slag alone add enough lime to make it basic enough to remove the last of the phosphorus, the total addition of lime will manifestly be much less, and hence the total quantity of slag formed will be just so much less."

This lesser quantity of slag leaves much more room in the furnace, and the slag, being less, requires less heat to meet it, and at the same time has less action in keeping the heat of the flame from the iron.

In the earlier form of the process the metal was charged solid, and was carried from one furnace to the other in ladles.

The introduction of tilting or rolling furnaces has greatly facilitated the process. Two rolling furnaces of 50 tons or more capacity are placed facing each other, *i.e.*, with the tap holes inwards, the one being at a little lower level than the other. Into the higher furnace 50 tons or so of molten pig iron is charged, and worked in the usual way. By means of the forehearth this is run, when sufficiently worked, into the second, where scrap or ore has been heated, and the first furnace is prepared for another charge.

The time of working in the primary furnace will be three or four hours, and rather less in the secondary furnace, and the yield will be somewhat more than the pig iron supplied. Allowing four hours, the pair of furnaces will turn out about 300 tons in 24 hours; or, if three hours only be occupied, about 400 tons, a very large output compared with the ordinary method of working, by which not half of this could have been obtained, and with larger furnaces the output could be still further increased.

Mr. Darby gives the output and costs of the process compared with the ordinary method of working in the table shown on the opposite page.

COMPARATIVE COSTS OF 100 TONS STEEL INGOTS.

	ORDINARY PROCESS.								BERTRAND-THIEL PROCESS. 70 per cent Pig Iron.								BERTRAND-THIEL PROCESS 100 per cent Pig Iron.							
	Total Quantity Used.				Price.	Amount.			Total Quantity Used.				Price.	Amount.			Total Quantity Used.				Price.	Amount.		
	t.	c.	q.	lbs.	s.	£	s.	d.	t.	c.	q.	lbs.	s.	£	s.	d.	t.	c.	q.	lbs.	s.	£	s.	d.
Pig iron	73	0	0	0	75	273	15	0	68	10	0	0	75	256	17	6	94	7	2	0	75	353	18	2
Scrap	34	10	0	0	70	120	15	0	29	10	0	0	70	103	5	0		....			..		....	
	107	10	0	0	..	394	10	0	98	0	0	0	..	360	2	6		....			..		....	
Ferro	0	15	0	20	17	10	12	6	0	13	1	16	17	11	6	8	0	13	1	16	17	11	6	8
Iron ore & lime		....			..	18	10	0	40	0	0	0	..	30	0	0	40	0	0	0	..	30	0	0
Labour		....			..	50	0	0		....			..	25	0	0		....			..	25	0	0
Moulds		....			..	7	10	0		....			..	7	10	0		....			..	7	10	0
Repairs		....			..	25	0	0		....			..	12	10	0		....			..	12	10	0
Fuel		....			..	27	10	0	25	0	0	0	10	12	10	0	24	0	0	0	10	12	0	0
						533	12	6						458	19	2						452	4	10
Less basic slag :		....			..	17	10	0		....			..	30	0	0		....			..	30	0	0
Quantity made .	100	0	0	0	..	516	2	6	100	0	0	0	..	428	19	2	100	0	0	0	..	422	4	10
Cost per ton ...		....			..	5	3	3		....			..	4	5	9		....			..	4	4	5

The Talbot Process.—This process was invented by Mr. B. Talbot, and was first put into use at the Penncoyd Steel Works, Pennsylvania, U.S.A., in 1899. It was described before the Iron and Steel Institute in 1900, and at once attracted general attention, and the erection of plant to work the process was soon started in English works.

The furnace used is a large tilting furnace, those at Penncoyd having a capacity of 75 tons, and is basic lined.

The furnace is started for the week's run on Sunday evening, and is charged with about 50 per cent scrap and 50 per cent molten pig iron, or any other proportions that may be required. At Penncoyd the iron is melted in cupolas, but where there are blast furnaces it could, of course, be supplied direct. The charge is worked down to steel in the usual way with ore and lime. As soon as the metal is of the required quality, about one-third of the charge is poured off, either into a ladle or direct into moulds, the furnace is turned back, and a considerable quantity "of oxide of iron, in a fairly fine state of division, is added to the slag ; and, as soon as this is melted, about 20 tons of molten cupola metal is run in to replace the steel tapped out. An immediate very active reaction takes place, during the continuance of which gas is cut off from the furnace. The reaction has all the characteristics of the Bessemer blow during the elimination of carbon, a large volume of CO being given off, which immediately ignites and burns with an intense flame, the heat thus produced partly raising the temperature of the bath, and partly being absorbed by the regenerators. After the metal has boiled vigorously for some 10 or 15 minutes, the slag, which is now almost deprived of its iron oxide, is partly poured off, and the bath worked down into finished steel by the help of fresh additions of ore and lime."* About one-third of the charge, *i.e.*, 20 to 25 tons of the steel, is again poured off, and the process is repeated, more pig iron being added to make up for the steel removed till the end of the week, when the furnace is emptied. It will be seen, therefore, that the furnace is never empty, and the fresh charge is always added to a hot bath of molten metal.

As the metal has to be poured off without the slag, the tap hole is stopped, the furnace is tilted till the slag is above the tap hole level, and then the metal is run out ; and as soon as sufficient is out the furnace is gently tilted in the other direction, so that the slag level is well below the tap hole, which is then stopped. After the removal of each portion of metal the slag line is examined, and any repairs seen to be necessary are made by "throwing raw dolomite or limestone, mixed with five per cent pitch or resin, on the banks, at a space from 6 in. to 9 in. above the level of the reduced bath." Any of the repairing material which falls down is dissolved in the slag. The time between the casts is from three to four hours, and at Penncoyd about 30 heats are made per week.

The hearth wears very slowly, as it is never emptied. The

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* Talbot, J. I. and S. I., 1900-1, page 36.

slag does not come in contact with it except just at the slag line. The temperature changes very little, and the bed is not liable to mechanical injury.

Scrap can, of course, be used as usual, but it does not accelerate the process, as the diluting action is more than counterbalanced by the chilling effect. Mr. Talbot contends that the use of cold scrap is wrong, as it leads to waste of iron, and suggests that all scrap should be put through the blast furnace, and thus be converted into pig iron.

Mr. Talbot gives the conditions of success in open-hearth steel making by this process as being: (1) The use of liquid metal; (2) the oxidation being entirely produced by oxides of iron; (3) utilisation of the heat of oxidation of the impurities, so as to obtain a high enough temperature to ensure the fluidity of the metal and slag.

Mr. Talbot claims the following advantages for his process:—

(1) The cost and delay in charging the metal is avoided.

(2) A saving in fuel in charging molten pig iron, and also through not cooling the furnace by charging cold material.

(3) The demand for a large and regular supply of good scrap, so important in ordinary practice, is altogether dispensed with.

(4) A regular supply of steel to the mills in any wished-for quantity and at frequent intervals is ensured.

(5) An increase of output.

(6) An increase of yield.

(7) Less repairs to furnace.

(8) Saving in labour charges, due to far less skilled labour being required per given quantity of steel.

(9) The possibility of using very large furnaces, with consequent reduction in cost of production, without the necessity for very large cranes and ladles.

The process is at present only in its infancy, but no doubt will be very largely used within the next few years. Much larger furnaces will probably be used—100 or 120 tons at least—and with works provided with blast furnaces and metal mixers a large continuous output will be secured.

The Monell Process.*—Limestone, and a large quantity of ore, are charged on to the hearth of the furnace, and when they have reached a high temperature the molten pig iron is run in; a violent reaction takes place, and as it subsides ore is added, and the process is continued in the usual way. The process is not likely to come into use.

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* J. I. S. I., 1900, vol. i.

COMPARISON OF THE FOUR STEEL PROCESSES.

This may be a convenient place at which to briefly compare the four leading steel processes.

The Bessemer.—This is, as already pointed out, the pioneer process, and the one by which mild steel was first obtained. It is very rapid. The output is very large, but the plant is costly, and the rapid output is obtained at the cost of the loss of a considerable quantity of iron. The variation allowable in the composition of the pig iron is not large, for the reasons already explained, and the iron is, therefore, likely to be costly. The end is determined by the drop of the flame, an external indication which may not always be relied upon. The steel tends to contain a little silicon. Of late years there have been many complaints of irregularity in the composition of Bessemer steel made to specification.

The Basic Bessemer Process.—This process has all the disadvantages of the Bessemer. The steel is apt to be irregular, as it is difficult, if not impossible, to always hit the exact end of the process, and the steel is likely to contain phosphorus. For many purposes basic Bessemer steel is still viewed with suspicion, and if it is to be judged, not by the quality of isolated and special heats, but by the average of a continuous output, the suspicion is well grounded. The one advantage over the ordinary Bessemer process is that a pig containing phosphorus can be used, but the allowable variation in the composition of the pig is not large.

The Siemens, or Open-hearth Process.—This process is somewhat more costly to work than the Bessemer, and the output is very much smaller. The allowable variation in the composition of the pig is much larger; indeed, almost any pig can be used, provided it be free from sulphur and phosphorus. Large quantities of scrap can be used, and steel of perfectly uniform composition can be made.

The Basic Open-hearth Process.—Resembles the Siemens process in all particulars, except that a much greater variation is allowable in the composition of the pig than in any other process. Any pig iron free from sulphur can be used, and by combination with Mr. Saniter's process that element can be got rid of, so that even white Cleveland pig can be used for steel making.

Up to the present the Bessemer process (in one or other of its forms) has been much more largely used.

In Great Britain alone is the output of open-hearth steel in excess of that of Bessemer. With the recent developments in open-hearth practice which have been described, lessening the cost and enormously increasing the output, it is almost certain that there will be a great development of the open-hearth steel industry, and that it will become the leading steel process of the world.

CHAPTER XXXVI.

APPLIANCES APPLICABLE TO ALL PROCESSES.

Once the steel is made, the apparatus necessary for its manipulation will be the same in principle for all the processes, though the details will vary much under different conditions.

The Ladle.—The steel from the converter or furnace, on its way to the moulds, is first run into the ladle. The ladle should be capable of holding the whole charge, so that there may be no interruption in pouring or tapping. The ladles used for the open-hearth process are, therefore, much larger than those used for the Bessemer process ; but with the introduction of tilting furnaces, and the increase in size of the furnaces, there is a tendency to dispense with the ladle altogether. The ladle is fixed to a suitable carriage, so that it can be moved as required.

The shell of the ladle is made of steel plate about 1 in. thick, well bolted together. For sizes below 30 tons the ladles are usually circular ; but for larger sizes they are usually elongated, as a round ladle would be inconveniently wide for the rails. Fig. 181 gives the dimensions of a 25-ton ladle.

The ladle is provided with trunnions, usually attached to a suitable trunnion band, and is carried on a carriage. It is so arranged that it can be tilted over to pour the contents when necessary. The method of tilting varies very much ; sometimes one end of a chain is attached to the bottom of the ladle, the other end being fixed to the jib of the crane, so that the ladle can be turned over, or a gearing mechanism may be used, as in the figure. As the ladle will, except in very exceptional circumstances, only need inverting to remove slag when it is nearly empty, the chain answers very well. The ladle is usually held in position when upright by strong rods attached to the carriage.

In the early attempts at steel making Bessemer poured the steel out of the ladle by tilting, but this was very inconvenient, and he designed the method of tapping, which is now universally used. At the bottom of the ladle is an opening, in which is fitted a fireclay nozzle. Over this is a vertical steel rod ; rigidly attached to a rod outside, working in guides ; and a lever, so that it can be raised or lowered. The rod is provided at the lower end with a fireclay plug or stopper, which fits into the nozzle, and thus stops it. The

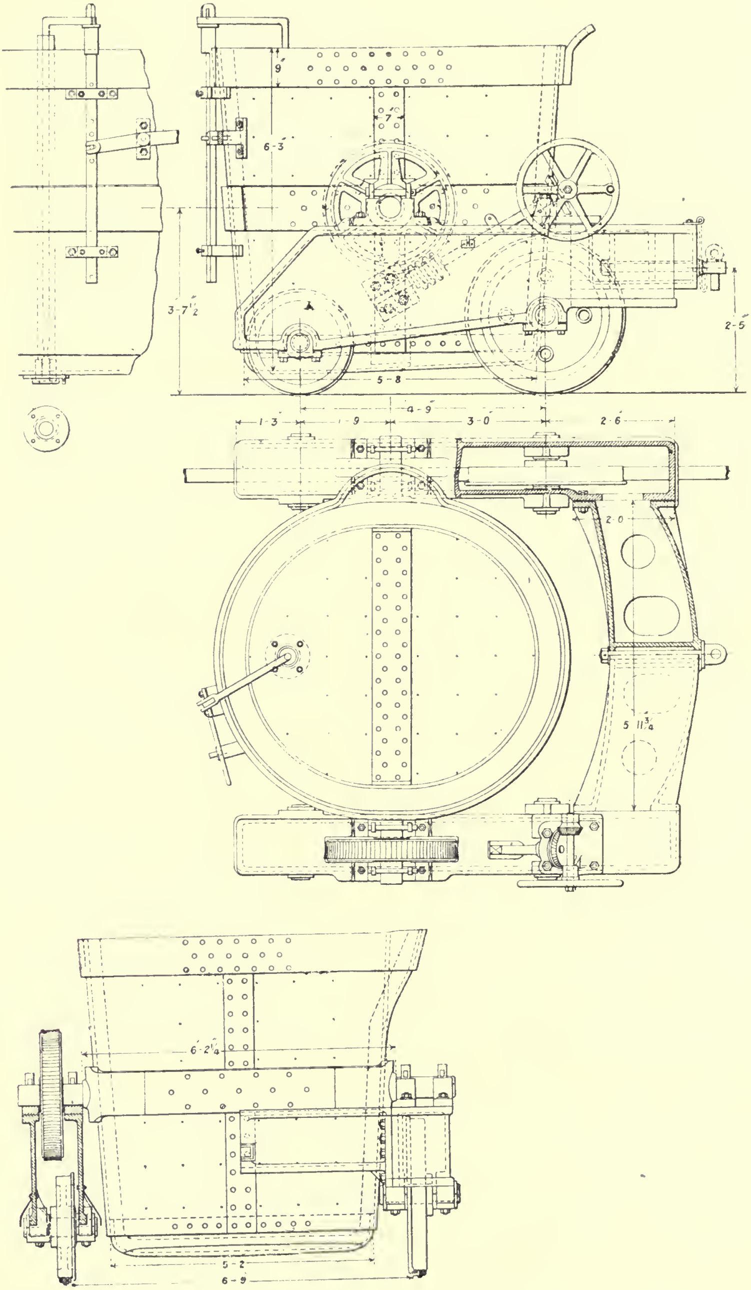

FIG. 181.—25-ton Steel Ladle.

rod itself is protected by cylinders of fireclay put round it and securely luted. When the end of the lever is raised the rod is forced downwards, and the plug closes the opening; when it is lowered the plug is raised, and the metal can flow. Difficulties from the sticking of the plug, which causes delay, and from failure to close, which causes loss of steel, are by no means uncommon, but nothing better has yet been devised.

In the Bessemer process the ladle is carried on the end of a rotating ladle crane, as already described, and is so arranged that it can be tilted over to pour out the slag. In the open-hearth processes the ladle must be carried on a carriage which can be drawn along rails, so that it can be moved over the moulds, and the same arrangement answers for the Bessemer process when a longitudinal casting pit is used. The gauge of the rails varies; 6 ft. to 7 ft. is common, but for large ladles it is often considerably more.

The ladle carriage is made of many forms; it is essentially a strong framework with wheels carrying the ladle.

The ladle is lined with refractory material, usually in the form of small fireclay slabs set in clay, but a lining of clay or ganister put in in the same way as the lining of a Bessemer converter may be used.

Before the ladle is used it must be thoroughly dried, or serious explosions may result. The drying is usually effected by lighting a wood fire in the bottom of the ladle, and keeping it up till the lining is quite dry, but in many works the drying is more rapidly effected by covering the ladle with a hood and burning a jet of gas in it.

In some works, where the steel is used for making castings, the ladle is lifted away bodily on its trunnions by an overhead crane and taken to the foundry.

Moulds.—The form of mould now used "was introduced, like so many appliances now in common use in the steel trade, by Sir Henry Bessemer in the course of his early struggles to make his process a practical success." It is cast in one piece, slightly wider at the bottom than at the top, so that it may be lifted away, leaving the ingot standing. These moulds are now made of any size required for making ingots. They are provided at the top with eyes, into which the hooks from the crane chain can be put, so as to lift them away. In using these moulds they are placed on thick iron plates and luted, and the metal is poured in at the top. As is well known, and for reasons to be explained later, the top of the ingot is often honeycombed and unsound, and therefore must be cut off and sent to scrap. Nevertheless this form of ingot mould has become nearly universal.

The moulds are always cast of Bessemer pig iron, so that when they crack they can be sent at once to the furnaces. An iron of fine grain should be used, so as to avoid liability to cracking. The mould should also be well proportioned, and the thickness of the metal should vary with the weight of the mould. Summersbach gives the German practice as being :—

Weight of Mould.	Thickness in mm.
20 to 30 cwt.	75 to 85
30 ,, 40 ,,	80 ,, 90
2 ,, 3 tons	95 ,, 105
3 ,, 6 ,,	110 ,, 120
6 ,, 10 ,,	130 ,, 140
11 ,, 13 ,,	165 ,, 180

The English practice, he says, is to make them somewhat thicker.

Many attempts have been made to improve the form of mould. Mr. Snelus* said : " At Guirs he found them using a solid topped mould inverted—that was, the smaller end was down at the bottom, and the metal was run into the larger end of the mould ; then they turned the mould over and threw the ingots out." Many methods have been suggested for casting with the large end of the ingot upwards, such, for instance, as providing the mould with trunnions so placed that when it was lifted from the pit it would turn over and drop out the ingot, as in a mould devised by Mr. James Riley. The mould was supported on standard bearings, and was inverted in the casting pit.

In another form of mould designed by Mr. Riley,† the widest part of the mould was cast with two V openings, which were filled up with wedge-shaped pieces of iron when the mould was to be used. As soon as the ingot had solidified sufficiently the wedge pieces were taken out, and the dogs grasped the ingot through the V openings and lifted it out of the mould.

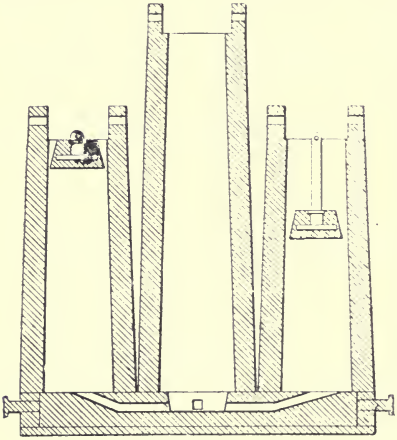

Fig. 182.—Group Casting for Small Ingots.

Group casting is sometimes used for small ingots. This method of working was devised by Mr. Holley at the Bessemer Steel Works, Troy, U.S. The ingot moulds (Fig. 182) are arranged round a larger central mould, being connected by channels at the bottom so that the metal is poured into the central mould—which also forms

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* J. I. & S. I., 1875. † J. W. of S. I. & S. I., vol. i., page 94.

an ingot—and thence passes into the smaller moulds, the ingots in which are thus cast from the bottom. The moulds all stand on a distributor, which is a framework containing loam in which the channels are cut. The top of each smaller mould is closed with a plug, which may be a mass of loam suspended on an anchor, dried, and perforated with small holes to allow of the escape of air. The position of this stopper determines the height to which the metal can rise, and thus the length of the ingot.

Movable Moulds.—When the movable ladle is dispensed with the moulds must be made movable. The iron plate on which the mould rests, instead of being placed at the bottom of the pit, is carried on a small truck running on a narrow rail track. (Fig. 183.) The body of the truck is so formed as to cover the wheels, so that they may not become clogged with metal. The plate is provided with edges or stops, so as to keep the mould in position. The mould, on its carriage, is brought under the ladle or fore-hearth, and is filled as usual; it is then drawn on, and another mould takes its place. The filled moulds are drawn away under a fixed ingot stripper, by which the moulds are lifted off, and the stripped ingots are dealt with, as usual, by the ingot crane.

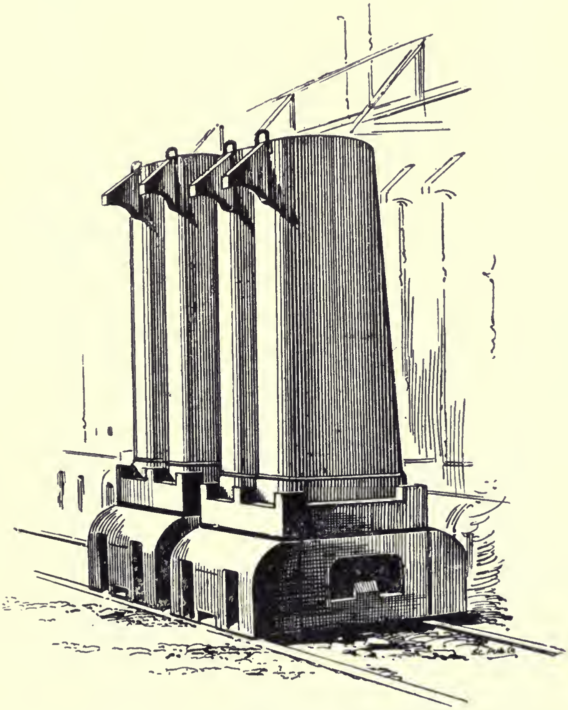

Fig. 183.—Ingot Moulds and Carriages.

Slag Ladle.—For dealing with the slag, a ladle is often used. This is somewhat similar to the metal ladle, but is very much smaller, and is not lined. The slag is poured from the metal ladle into it. When the slag has solidified, the slag ladle is carried by the crane to the slag heap or railway truck, as the case may be. The ladle is turned bottom upwards by a chain attached to the bottom, and is bumped till the slag comes out.

In some cases the slag is poured into a cavity in the ground—a sand mould—and, whilst it is soft, an iron rod with a ring or hook at the end is struck into it. When the slag solidifies, the lump is lifted away with a crane, and broken to liberate the iron hook.

Ingot Pusher.—Sometimes the ingot sticks in the mould, and comes up with it. A few sharp bumps are given on the bottom of the pit, and if that does not release it, it is passed over to the pusher. Many forms of pusher are used. Fig. 184 shows one of the horizontal type. It consists of a hydraulic ram. The mould, with its ingot, is brought up on a suitable truck, placed in front of a massive framework, against which the mould rests, whilst the ram pushes out the ingot. Inclined and vertical pushers are also used.

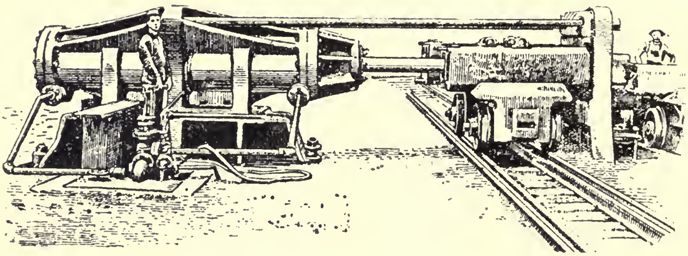

Fig. 184.—Ingot Pusher.

Cranes.—The design of cranes for various purposes is an engineering question which it would be out of place to discuss here. A few general remarks are all that is possible.

In the Bessemer process, with its circular casting pit, the cranes are arranged as already indicated, so that every part of the pit can be reached. Hydraulic cranes are almost universal, and they need not be of great size, since a 10-ton ingot is the largest that will have to be handled.

With the open-hearth process, with its extended casting pits, fixed cranes would be of little use, and locomotive cranes are, therefore, universally used. The ladle has to be drawn along over the moulds. This is sometimes done by a separate locomotive, but generally the crane is made to do the double duty.

Fig. 185 shows a combined locomotive and crane of a type built by Messrs. Dubs & Co. for the Steel Company of Scotland. It runs on the ordinary 4 ft. 8 in. gauge, and therefore can be used as an ordinary locomotive, and as a crane it is capable of lifting 6 tons.

The crane, with its central pillar and pedestal, is supported above, but clear of, the boiler by the main frame of the engine. The jib is capable of lifting, slewing, and lowering its load at any point within the circle of its radius. The load on the crane can be held in suspension by the pressure of steam on the hoisting cylinders, and conveyed by the locomotive to any distance required.

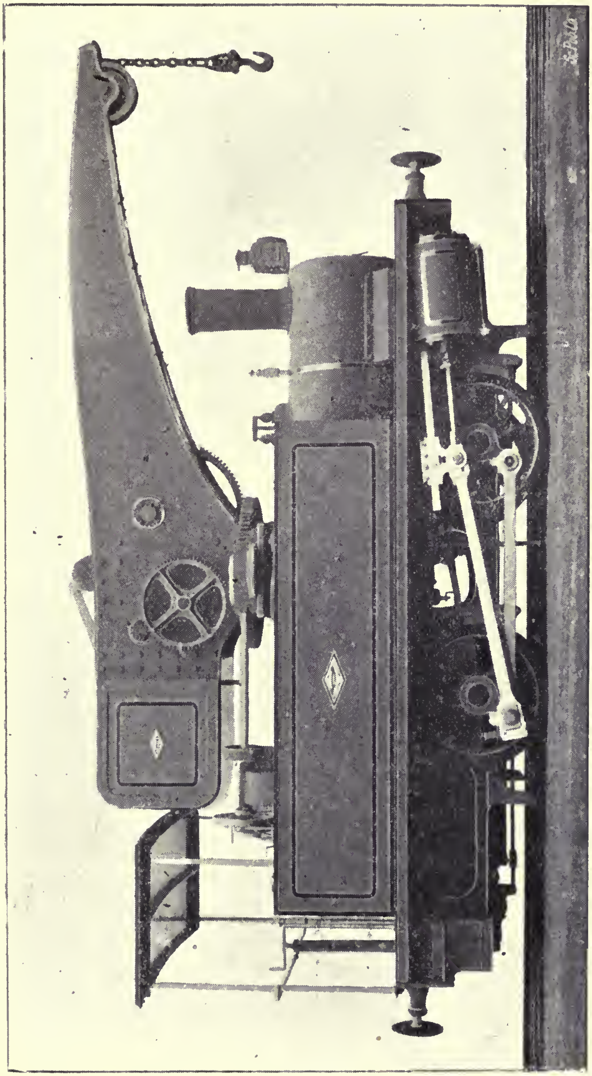

Fig. 185.—Locomotive Crane, Built by Messrs. Dubs & Co.

The slewing gear is worked by a small steam cylinder. All the movements of the locomotive and crane are under the control of one man on the platform.

This engine is very quick in action. It can lift a 5-ton load at the rate of 60 ft. a minute, and the crane makes a complete revolution in 30 seconds, and for work within its capacity is probably the most convenient form of locomotive crane yet designed.

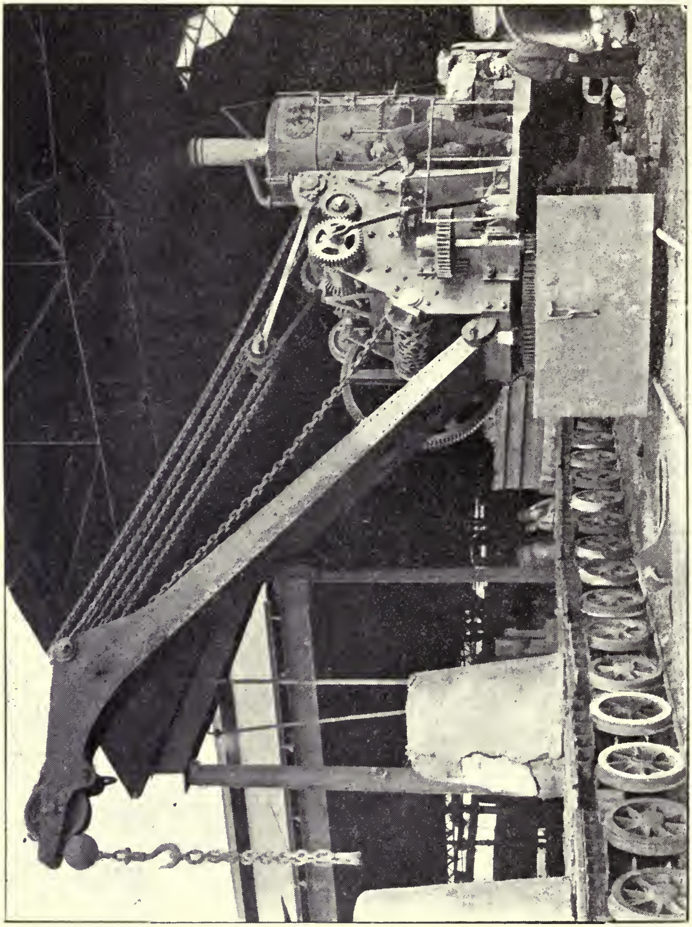

Fig. 186.—Large Ingot Crane.

Where larger cranes are required, those such as shown in Fig. 186 are often used. In this form of crane the engine and the crane are quite distinct, but are carried on the same platform, and the whole platform rotates with the crane. Such cranes, when used for hauling the ladle, usually run on a line of rails parallel to that on which the ladle runs, and are attached to it by a rigid iron bar.

Overhead cranes of the usual type are now being largely used, and have very many advantages. Those used in the steel works do not differ in any essential from those used in general engineering shops. They may be operated by steam or electricity.

The Heating Furnace.

As soon as the ingot has sufficiently solidified it is stripped, *i.e.*, the mould is lifted away, and the ingot itself is lifted out of the pit. It is, however, not in a suitable condition for immediate treatment. The outside is cool, but the inside is at a much higher temperature, or, if it be a large ingot, may probably still be quite liquid, and for rolling it is essential that the whole should be at a uniform temperature. Two methods of preparation may be used: (1) The ingot may be allowed to cool, and then be reheated in a suitable furnace to the required temperature; or (2) it may be so treated as to produce a uniform distribution of heat without complete cooling.

Prior to 1882 the former method was universal; indeed, cooling was thought to be essential, some even contending that the metal was improved by cooling or by standing some time in the solid condition before reheating.

The furnaces used were coal-fired, very like the ordinary mill or reheating furnaces used in the malleable iron works, but of larger size.

Whether or not the cooling of the ingots had any advantages, there was no doubt that it had one serious disadvantage, viz., that there was a large loss of sensible heat which had to be replaced.

Gjers' Soaking Pit.—The first attempt to dispense with the reheating was made by Mr. John Gjers, of Middlesbrough, in 1882, and his "soaking pit" was so successful that its use very soon became general.

The pit was simply a brick-lined cavity a little larger than the ingot it was to contain, and deep enough to hold it easily. The pit was lined with refractory firebrick about 9 in. thick; at the bottom was placed a layer of sand or broken brick, on which the ingot rested, and was provided with a well-fitting cover.

The pits were arranged in series of four, six, eight, or more, and were placed in some convenient position, so that the ingots could be readily transferred to them from the casting pit.

The ingot was placed in the pit; the heat travelling from the interior through the exterior layers of the metal was radiated to the brickwork, and this, becoming hot, radiated the heat back again, so that there was a thorough redistribution of the heat, and the pit and its contents assumed a uniform temperature; this, indeed, being the characteristic of "soaking."

If the pit is cold, it requires two or three ingots to bring it up to the required temperature; but once hot, it continues in operation with very little loss of heat. The ingot is left in the pit or "soaked" for about an hour. As combustible gas is given off from an ingot under these conditions, the atmosphere of the pit is reducing, and the excess of gas burns at the mouth of the pit as it escapes round the edges of the cover.

The soaking pit differs from the ordinary furnace in two points: (1) No fuel is used, the heat being supplied by the ingots themselves, so that there is considerable saving of fuel; and (2) the pits are placed below the level of the ground, and the ingots are placed in them vertically, both these conditions facilitating the handling of the ingots.

With the introduction of the soaking pit, also, it became possible not only to dispense with the first heating, but also with intermediate heating, and to roll rails or other sections at one heat. The advantages of the soaking pit were so obvious that, as already remarked, it soon became very general; but its use revealed weak points, which led to considerable modification.

In order that a soaking pit may work satisfactorily it is essential that it should be fairly continuously in use. Any delay will cause cooling, and thus lead to irregular "soaking" of the ingots, which is always most objectionable.

Vertical Soaking Furnace.—The modern soaking furnace, which has now generally replaced the original soaking pit, may be regarded as being a set of soaking pits which can be heated when necessary by solid fuel or by gas. Mr. Gjers himself in some cases added a fireplace to his pits, so that heat could be applied if the temperature fell too low, and thus the pit became practically a furnace.

The modern soaking furnace is a chamber capable of holding 12 or more ingots. It is placed below the level of the ground, and is deep enough to allow the ingots to stand clear of the masonry. The roof is provided with a series of openings corresponding to the number of ingots it is to hold, each opening having its own lid, and usually it is provided with a taphole leading to a slag pit, so that any slag can be readily removed. If the furnace is to be gas fired, there are two regenerator chambers at each end, and it is worked exactly as an ordinary regenerative furnace, the gases being reversed about every hour. In a coal-heated furnace the fireplace is at one end. The gas-fired furnace is the more general, and is to be preferred, "firstly, because it is possible to work with a reducing flame, thereby keeping the all-important furnace waste down to one-half of that occasioned by the 'flash' heat of coal firing; secondly, a more uniform heat is obtainable by reversing the flow of the flame, thereby diminishing the liability of the ingot to turn up or down in the process of rolling, with a consequent saving of rollers and gearing; and, thirdly, because a high heat is not desirable. The degree of heat can be kept under complete control."*

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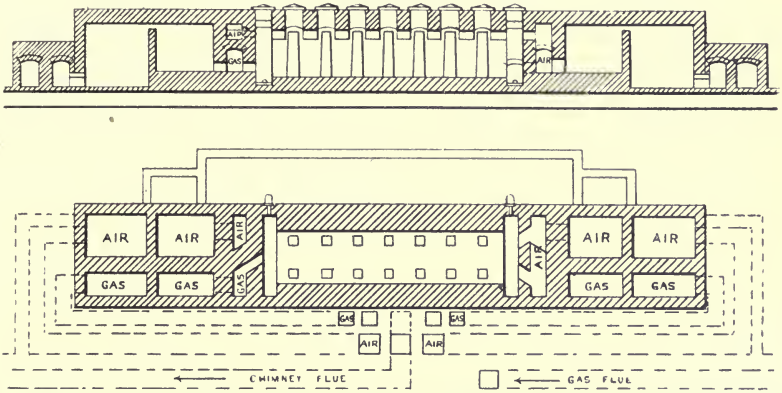
* Mills, J. W. of S. I. & S. I., vol. v., page 87.

The soaking furnace is thus a furnace proper, comparatively little use being made of the heat radiation from the ingots, but it resembles the soaking pit in so far as the ingot is put in hot, and in a vertical position.


Section.

Plan.

FIG. 187.—Vertical Soaking Furnace.

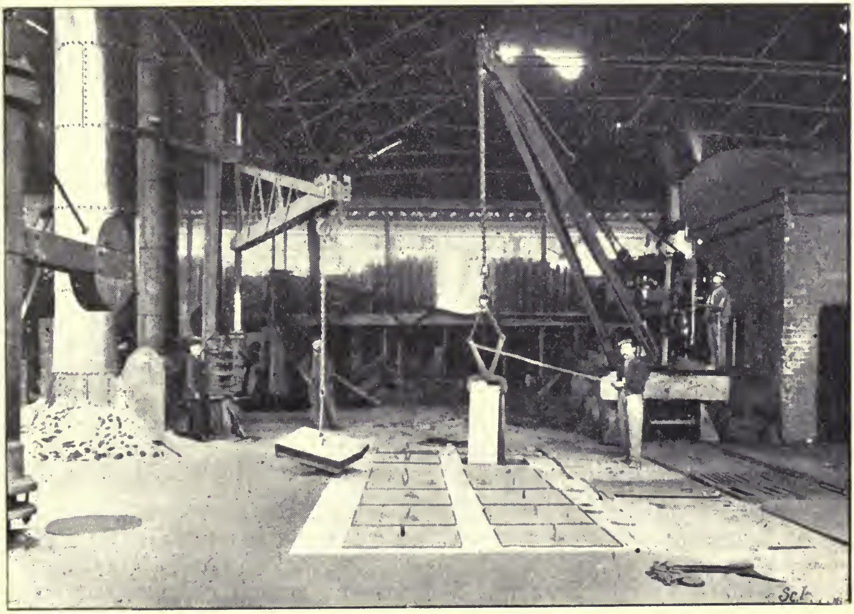


FIG. 188.—Vertical Soaking Furnaces.
(Cover lifted by small crane, and ingot being lowered in.)

The details and dimensions of the furnaces used vary very much.

Position of Soaking Furnaces.—As the ingots are to be transferred hot to the furnace, it is essential that the furnace should be near the casting pit, and the crane which lifts the ingot from the pit should deposit it at once in the furnace, preferably by only swinging the crane jib. To allow of this the soaking furnaces are often put in a line parallel to the melting furnaces, and separated from them by the casting pit and the crane rails. Where such an arrangement is not possible, the hot ingot may be lifted on to an inclined plane with rollers, put on to a truck, or carried, suspended by the crane. Any delay necessarily involves loss of heat, and where the soaking furnaces are not close at hand the ingots are often black on the outside before they reach them.

The covers of the soaking furnace are lifted by some mechanical appliance by which they can be quickly moved. The details necessarily vary with the arrangement of the furnaces. In Fig. 188 the cover is shown, being lifted by a small crane.

Plate-heating Furnaces.—Whilst the vertical or soaking-pit furnace has become general for heating the ingots, horizontal furnaces are more largely used for "soaking" plates, &c., that is, for heating them up to rolling temperature, when the whole operation cannot be concluded at one heat.

The conditions of such heating are, of course, very different, and the shape of the pieces to be heated is also different, and many forms of furnace are used for this purpose. The simplest is a reverberatory coal-fired furnace similar to that used in the malleable-iron mill, and next to that the ordinary Siemens regenerative furnace. As these types have been fully described in other connections, the mere mention here is all that is necessary. One of the most successful types of regenerative furnace for this purpose is the Siemens new form, which has been already described and figured. A description will be given of one or two recent forms of furnace which have been successfully used for "reheating" steel slabs, &c.

The Moor Furnace.—This furnace has been successfully used at the Moor Iron and Steel Works, Stockton. The furnace is a coal-fed reverberatory furnace, but is placed below the ground level like the ordinary soaking furnace, the slabs being charged through openings in the roof, which are closed by covers.

Mr. E. J. Bagley* claims the following advantages for this type of furnace over the overground horizontal furnace: "(1) No loss of heat by radiation; (2) saving half the fuel and half the labour, as it holds a double charge; (3) saving in furnace waste, as any air getting through the lids or openings found its way along the underside of the roof to the chimney without touching the slabs; (4) saving in first cost, as only half the number of furnaces were required; consequently (5) the distance to the rolls was reduced by half; (6) no obstruction above the floor line, and the mills were

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* J. W. of S. I. & S. I., vol. v., page 115.

consequently cooler." The indirect advantages were equally important: "(1) It was not necessary to have a gang of men to charge and draw the furnaces, as all this work was done by the crane; and (2) when the furnaces were situated with the crane road between two furnaces and leading direct to the rolls, the locomotive crane did the work of the bogey men. Both these advantages were greatly increased when dealing with heavy slabs.

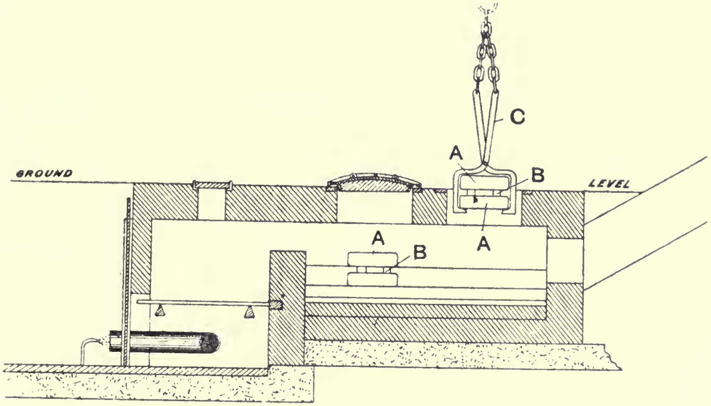


Fig. 189.—The Moor Heating Furnace.
A—Slab. B—Separating Bricks. C—Dog.

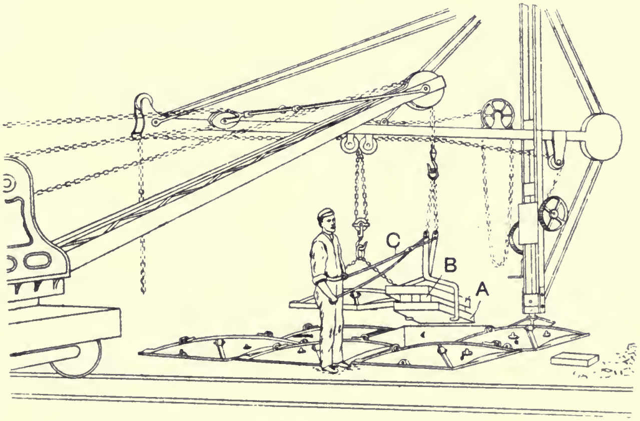
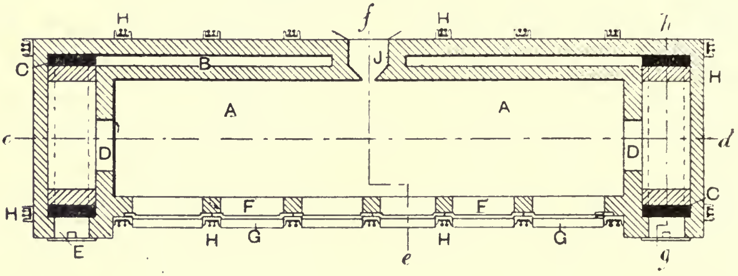


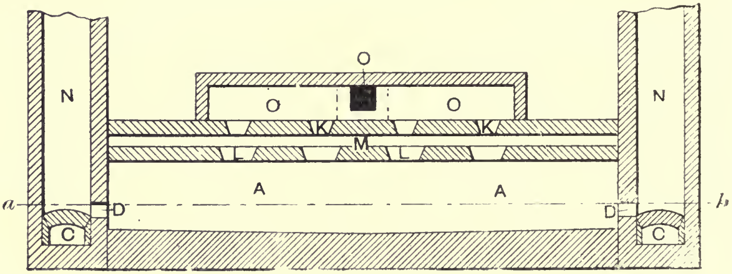
Fig. 190.—Lowering Slabs into Moor Furnace.
A—Slabs. B—Separating Bricks. C—Guiding Tongs.

At the 'Moor' they had three furnaces to one mill, turning out 900 to 1,000 tons of finished plates per week." Some furnaces of this type, erected at the Moor Works, are fired with gas instead of coal.

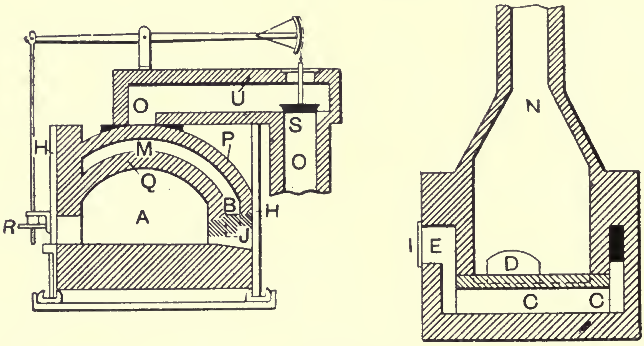
The Weardale Furnace.—This furnace, designed by Mr. H. W. Hollis, of the Weardale Iron and Coal Company, is based on an entirely different principle. It is a gas furnace, the gas being supplied direct from the producers at as high a temperature as

Sectional Plan on a b.





Longitudinal Section on c d.



Cross Section on f e. Cross Section through Air Flue on h g.

Fig. 191.—Weardale Furnace.

A, Furnace Body. C, Air Flues. D, Chimney Openings. F, Charging Doors. J, Slag Door. K, Gas Ports. L, Burning Openings. M, Heating Space for Air. N, Chimney. O, Gas Main.

possible without the intervention of regenerators. The air also is supplied direct to the furnace, and is heated in the furnace itself.

The furnace shown is 30 ft. long. The gas enters the gas main

O and passes through the gas inlet ports K in the upper arch of the roof. Here it meets the hot air. The air enters by openings into the flues C, and thence passes to the heating chambers M between the upper and lower arches of the roof. Ignition takes place as the gas and air meet, and the flame passes through the openings L into the furnace, where it spreads out and forms a sheet of flame. The flame passes away by the openings D, and may be used to raise steam or for any other purpose. The furnace has a row of working doors at the front, and a slag hole J at the back, towards which the bottom is made to slope. The mode of lighting the furnace is as follows : " After the whole of the brickwork of the furnace has been thoroughly dried by fires kept burning in the interior for a sufficient length of time—wood being the best fuel for this purpose—the gas is admitted ' by means of a valve,' and is ignited by the fire left burning for the purpose. The process of ' putting gas in ' is a little different from that adopted in starting a melting furnace. In the case of the new furnaces all the doors must be closed before the gas is admitted in order that a through draught from the air inlets to the chimney may be established. This effectually prevents any spreading of the gas between the roof arches, where it might cause an explosion. The gas invariably lights quietly and without the slightest ' puff.' "*

In one case given by Mr. Hollis, a furnace with a heating chamber 34 ft. 6 in. by 11 ft. heated 910 tons of slabs in a week, with a consumption of 2·37 cwt. of coal per ton of slabs, and in another case a furnace with a heating chamber 39 ft. by 7 ft. heated 600 tons of slabs, with a coal consumption of 2·4 cwt. per ton of steel. The waste heat was carried to Lancashire boilers, and gave an evaporation of 6·23 lbs. of water per pound of coal consumed.

Furnace Bottoms.—Various materials have been suggested for the bottoms of the furnaces. Basic slag seems to be the favourite material.

Arrangement of Furnaces.—The position of the furnaces is of the utmost importance. They must be of sufficient capacity to take the slabs as they come from the cogging mill, and hand them on without any delay. The number of furnaces required will, of course, depend on their capacity, and may vary from two to six or more. Some managers prefer a few large furnaces ; others a larger number of smaller ones. The furnaces should be between the cogging and finishing mills, so that the " carry " may be as short as possible. The usual arrangement is to have the furnaces in a single line or in two parallel rows, with rails along the front, on which locomotive cranes can run. The slab is lifted by a " dog " on the crane as it leaves the cogging mill, and is carried to the front of the open door of the furnace, when two men push the slab into the furnace, and it is lowered on to the hearth. In a similar way the slab is lifted out and passed to the finishing mill. A much more

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* J. and J. Hollis, J. I. & S. I., 1897, vol. i., page 64.

economical arrangement is in use at some works. The furnaces are arranged on the circumference of a circle, on which also are the ends of the live rollers of the mills. In the centre is a rotating crane carriage, the outer end of which runs on a circular rail. On the crane is an arm carrying a powerful pair of jaws, worked by hydraulic power, and so arranged that it can be tipped down to lift the slab; then the crane is turned, the arm is pushed forward, carrying the slab into the furnace, and depositing it on the hearth. The tipping motion, the opening and closing of the dogs, and the backward and forward movement are operated by separate hydraulic cylinders.

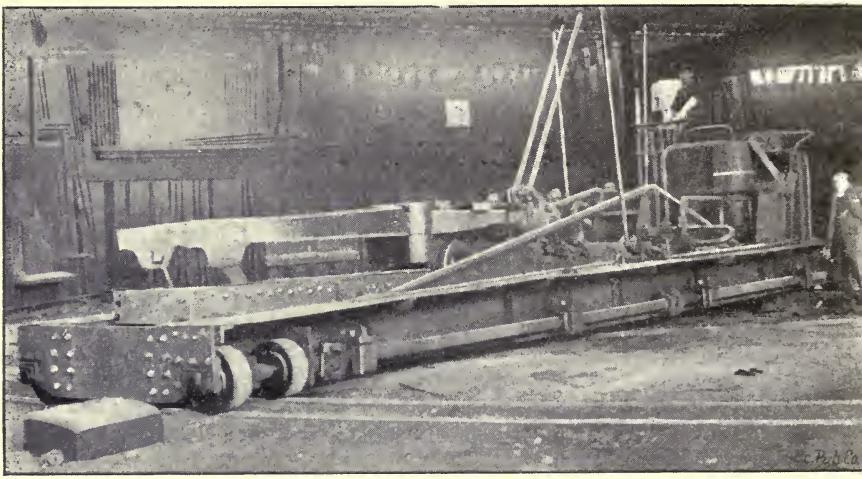

FIG. 192.—Hydraulic Slab Charger.

Electric Furnaces.—Many attempts have been made to use electricity as a source of heat for steel making, and there have been some so far successful, that "electric refining," as it is usually called, has become practicable.

The process as usually used is a finishing process; the charge is worked nearly to completion on an open hearth furnace or in a Bessemer converter, and is then transferred to the electric furnace for finishing, or the process of making steel from scrap and pig iron may be conducted entirely in the electric furnace.

The removal of the impurities in the electric furnace is much more complete than in the ordinary gas-fired furnace; this is due, no doubt, partly to the fact that the metal is not in contact with sulphur bearing gases, and partly also to the conditions set up by the method of applying the heat. Mr. J. F. Campbell* gives the following reasons for the easy removal of the sulphur, phosphorus, and oxygen from the molten bath of metal:—

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* J. I. S. I., 1910, vol. ii.

"(1) The intense heating of the slag, which is the place at which the refining takes place. Owing to this high temperature and the extreme fluidity of the slag the rate of the refining reaction is very great, because the velocity of the reaction rises very quickly for high temperatures, and not in direct proportion to the temperature.

"(2) The extremely basic slag that can be kept in a very fluid state, and the calcium carbide formed by the action of the arc on the calcareous slag are especially advantageous for desulphurisation.

"(3) The violent motion of the steel which results from the convection currents produced in the bath, due to the two intensely hot areas caused by the arcs below the electrodes, increases the volume of steel exposed to the hot and fluid slag area, and hence the rate of refining."

When Bessemer steel is used, the electric furnace is prepared by putting at the bottom, lime and oxide of iron in some form, and on this the metal is poured, the slag being kept back as completely as possibly. "On the bath of steel, carbon is thrown to carburise to any required degree, and then a second highly basic and desulphurising slag is added." Calcium carbide may be formed. As no gases enter the furnace no contamination is possible, and as there is no air, the atmosphere is strongly reducing. The procedure will be similar with open-hearth steel, but the details will vary with the amount of impurities to be removed.

The Furnaces.—As only the heating effect of the current is required, it may be applied in many ways, and as the best form of furnace is still under experiment, it will only be necessary to call attention to two distinct types, and one example of each.

Induction Furnaces.—In these furnaces the heating current is induced by a current outside the furnace itself. In the earlier types, such as the Kjellin furnace, the furnace body was more or less circular, with a hollow centre, and the metal was contained in an annular chamber. The primary coils carrying alternating current passed round the metal core in the centre of the furnace, and the alternating magnetic field in the core induced the powerful direct current in the circular ring of molten steel, and thus heated it to the required temperature.

In a paper read before the Iron and Steel Institute in 1909*, Mr. Rodenhauser (of Saarbürcken) described an induction furnace—the Röchling-Rodenhauser furnace—which differs from the earlier types of induction furnace, and with which he had attained good results. The furnace, as shown in Fig. 193, is a tilting furnace, the tap hole, therefore, being above the level of the charge. The primary circuits A are within the furnace, and there are two grooves or heating channels F in which the metal is melted. These grooves unite into a central working chamber D, which resembles the hearth of an ordinary open-hearth steel furnace. There is also a secondary circuit which terminates in steel plates embedded in

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* Vol. i., 1909.

the refractory material of the furnace, which becomes an electrical conductor at the high temperature of the furnace, so that the currents induced in this secondary winding also pass through the metal, and help to heat it. A single-phase or a three-phase current may be used. This furnace is said to have been very successful at the Röchling works, the capacity of the largest furnace worked being 8 tons. This is able to deal with the charge of ·75 per cent carbon rail steel from the basic Bessemer converters in about an hour after the recarburising, and reduce the sulphur and phosphorus content from ·1 and ·08 per cent to ·044 and ·023 per cent respectively.

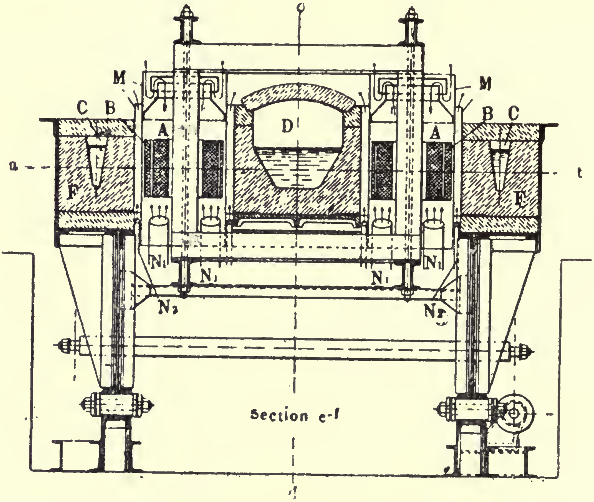

FIG. 193.—Eight-ton Röchling-Rodenhauser Induction Electric Furnace.

Arc Furnaces.—In this country the arc furnace of the Heroult type has been most used. The Girod furnace, described by Mr. W. Borchers* may be taken as the simplest and safest type of electrode furnace. The furnace is best arranged as a melting furnace, and the arrangement is shown in Fig. 194. The lower electrodes or contact pieces pass through the bottom of the furnace, and the upper carbon electrodes can be raised or lowered as required. The illustration shows a 12-ton furnace, the dimensions being in metres. The charge can be introduced melted for refining, or a scrap charge can be melted by the current, the movable electrode being brought down into contact with the scrap. In larger furnaces, of course, two or four carbon electrodes may be used, and these are run with alternating current carrying from 1,000 to 1,200 kilowatts, at 70 to 75 volts. The power required to make one ton of steel is about 800 to 900 killowatt hours, and the consumption of carbon electrodes varies from 12 to 15 kilogrammes per ton of steel. The furnaces are

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* J. I. S. I., 1910, vol. i.

worked with a basic lining (dolomite) which stands about 80 charges, which take from 6 to 8 hours to work, according to the purity of the raw material.

Advantages of the Electro-Thermic Refining Process.—Owing to the perfection of the refining, steel of the best quality can be made from impure materials; this, however, requires more time and power than pure raw material.

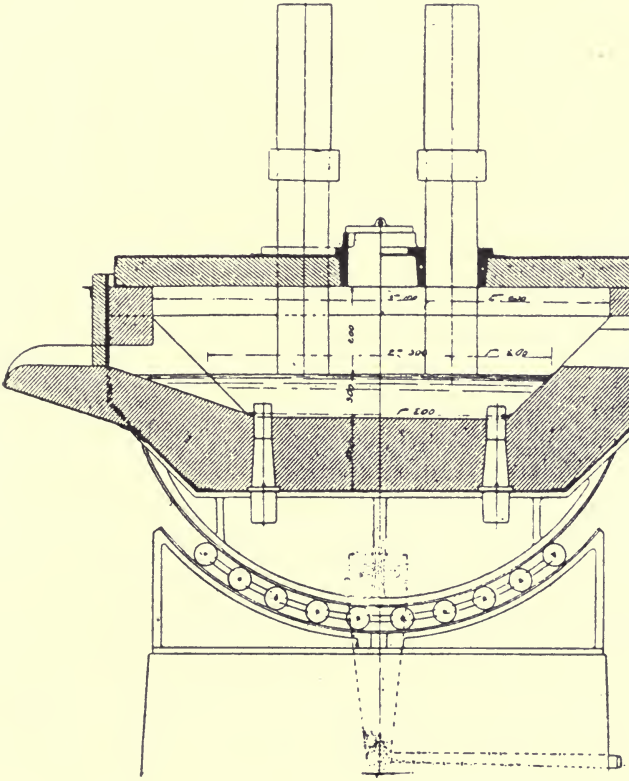

Fig. 194.—12-ton Girod Electric Arc Furnace.

The output of the plant can be maintained if the electric furnaces are used for refining, because the final purification takes place very rapidly.

The cost will of course vary considerably, being dependent on the efficiency of the furnace and the cost of electric power. Where power can be obtained cheaply, as from blast furnace gas or water power, the process will be cheap, and able to compete successfully with the crucible method of making special tool steels, but the question of the relative cost of this and the open hearth process for structural steel cannot yet be definitely settled.

Steel of very high quality can be readily produced, blow-holes are rare, the castings being very sound, and the quality of the steel is said by Campbell to be better than that of steel of the same chemical composition made in other furnaces.

"The adoption of electric refining will cause some readjustment in the steel trade. As soon as the Sheffield steel-melter has become acquainted with the process, and accustomed to the working of electric furnaces, electrically refined steel will largely replace ordinary crucible steel. This has already occured in Germany and America, where electric furnaces are used to make all classes of special and high-speed steels, the usual practice being to refine metal from a basic open-hearth furnace. Large crucible plants and small open-hearth furnaces engaged in the manufacture of small and intricate castings, such as motor car parts, &c., may be replaced by electric furnaces, because the high degree of fluidity and dead melt obtained is specially advantageous."

"In many cases manufacturers of axles, guns and tubes will abandon the use of Swedish raw materials, and refine steel made from low grade ores, thus reducing the value of high grade ore deposits and the quantity imported, for by the use of electricity Cleveland ore will produce a steel equal to the best hæmatite ores. The capacity of many Talbot and basic open-hearth plants will be increased, and the quality of the product improved, while much of the power that is now going to waste will be used for steel refining."*

The whole process is being rapidly brought into form, and great developments will probably be made within the next few years.

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* J. F. Campbell, loc sit.

CHAPTER XXXVII.

WORKING MILD STEEL.

The steel ingot is worked down into the form required—billet, rail, plate, sheet, or whatever it may be—by means of hammers or rolls, very much as already described under malleable iron. The essential difference is that the steel ingots, being much heavier than the iron blooms, the machinery required is much heavier and stronger.

Steam Hammers.—Following the example of the malleable iron-makers, the steel ingots were in the early days of the steel industry worked down first under a steam hammer, let cool, and then reheated and rolled.

In order to deal with the very large ingots, very powerful hammers were constructed ; 25 tons was a common size, and some of 100 tons and over were built. The large hammer at the Bethlehem Works was 120 tons. The steam hammer is now very little used for "cogging" ingots, as it has been found that for large masses of metal impact is less effective than pressure ; nor is the reason far to seek. In a steam hammer the compressive force is due to the momentum of the falling weight, and this is largely taken up by the outer portions of the metal, which yield somewhat, so that the energy is thus absorbed, and but little pressure reaches the interior. In the case of small blooms or ingots this is of little moment, and can be to a large extent overcome by turning, so as to expose each side successively to the impact ; but with heavy ingots this is not sufficient ; hence rolls and presses have replaced the hammers.

The steam hammer, usually of from 2 to 10 tons, is still largely used for the manufacture of steel forgings, axles, crank shafts, and the like. The ingot is cast in the usual way of the required size, or more often a large ingot is rolled down into a suitable billet, and this is forged under the steam hammer into the required form exactly as is done with malleable iron. Forged steel is much more homogeneous than malleable iron, and there is no piling of bars, &c., though in the early days of the steel industry, and to a small extent now, forgings are made of steel bars, sheared, piled, and hammered exactly as in the case of malleable iron.

Rolling Steel.

The rolling of steel differs from the rolling of iron mainly in the form of the plant used, this, as before remarked, being dependent on the weight of the ingots treated. Two types of rolling may be distinguished, bar and plate rolling, including under the first billets, rails, and all similar sections. The principle is the same in all cases, the difference being only in detail.

Rolling Mills.—As in rolling iron, there are three possible arrangements of mills.

(1) **Return Mills.**—These are worked continuously forward, the ingot or bar is passed between the rolls, and is then returned over the top. These are used only for light work, and are exactly similar to the mills used for rolling malleable iron.

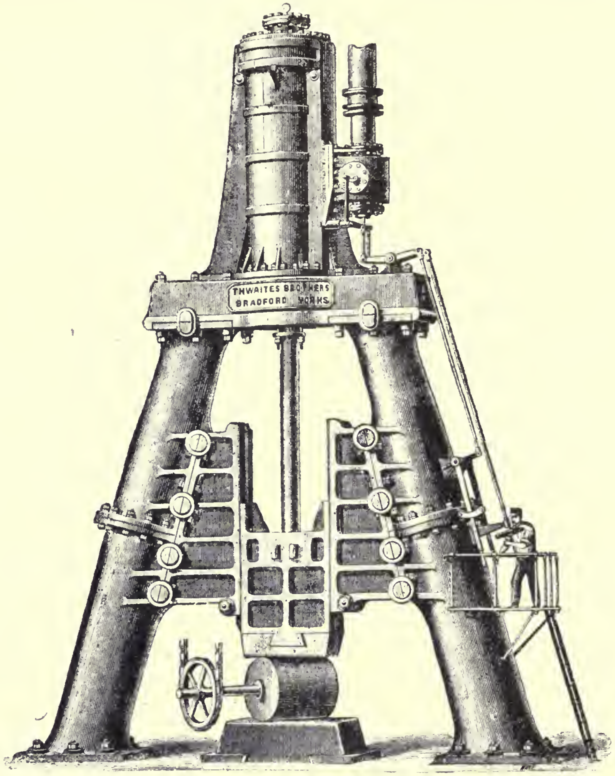

FIG. 195.—30-ton Steam Hammer.

(2) **Three-high Rolls.**—In these the bar is passed in one direction between the lower and middle rolls, and is returned between the upper and middle rolls, being therefore rolled in each direction. These mills are, of course, driven always forward. They are but little used except for very light sections, such as wire rods and similar work, though they are much more largely used in America than in this country.

(3) **Reversing Rolls.**—In these rolls the direction of rotation is reversed at each pass, so that the ingot is rolled in both directions.

Rolls of this type are now universal for all except the lightest work. Obviously, the reversal may be obtained either by driving the engine always forward, and using a reversing gear, or by reversing the engines at every pass. The latter method was introduced by Ramsbottom, and is now general.

With the introduction of heavy ingots the size of the mill engines has been greatly increased. Direct-acting horizontal engines are now almost universal, but electrically-driven mills are gradually coming into use, and they are often of great power—up to 3,000 H.P. or even more.

Cogging or Blooming Mill.—In this mill the ingot is reduced to a square bar of suitable size for future treatment. For billets, &c., the ingot will usually weigh from one to five tons—rarely more. The ingot is taken from the soaking pit by means of a crane, and delivered at once to the rolls. It is passed through the rolls two or three times, and is then turned on its side, and again passed; then again turned, and so on. The rolls are brought closer together each pass, till the ingot is reduced to a roughly rectangular bar of the required size. This is then passed through a groove in the rolls, and is sent to the shears.

The Mill.—This consists of a pair of rolls 6 ft. to 8 ft. long, and from 30 in. to 36 in. diameter, made of cast iron, or, more rarely, of mild steel. The rolls are not cut into grooves, as in the case of the blooming rolls of the malleable-iron mill, except that there is one groove at the end for giving the finishing form.

As the ingot must be reduced at each pass, the rolls are adjustable. The lower roll is fixed, but the upper one can be raised or lowered as required. The bearings of the top roll work in a vertical slot in the framework, and are carried by screws, the rotation of which will lower or raise the roll. In the smaller mills the screws are worked by hand, a large horizontal wheel being attached to the top of each, and being marked so that the workman may know when the two ends of the roll are exactly at the same level. In the larger mills the rolls are too heavy for hand working, and the screws are worked by steam gearing. When the rolls have only to be moved a short distance, these arrangements answer well; but where it is necessary to raise the upper roll considerably, as in cogging slabs (*q.v.*), the time taken is considerable. Hydraulic adjustments have repeatedly been suggested, and an excellent one has been devised by Messrs. Jardine and Jack.* (Fig. 196.)

The upper roll is supported on rods I from a cross-head attached to the balancing cylinder H below the rolls. Above the framework is a cylinder A fitted with a steel piston B attached to the housings of the roll. The upper cylinder is provided with a safety valve loaded to three tons per square inch, so that in the case of too great stress the cylinder may not be fractured; and also with an air valve. The two cylinders H and A are attached to the accumulator. To raise the roll, the exhaust valves of the cylinders A are opened,

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* J. W. of S. I. & S. I., vol. i., page 151.

and the pressure of the water in H raises the roll ; to lower it, pressure is admitted to the larger cylinders, and these, being of larger diameter than the ram H, will preponderate and carry the roll downward.

Both the rolls are driven from the engine, and the connection of the upper roll must be of such a character as to allow of it being moved from the line of driving. The connections are similar to those used in the malleable ironworks which have been already described.

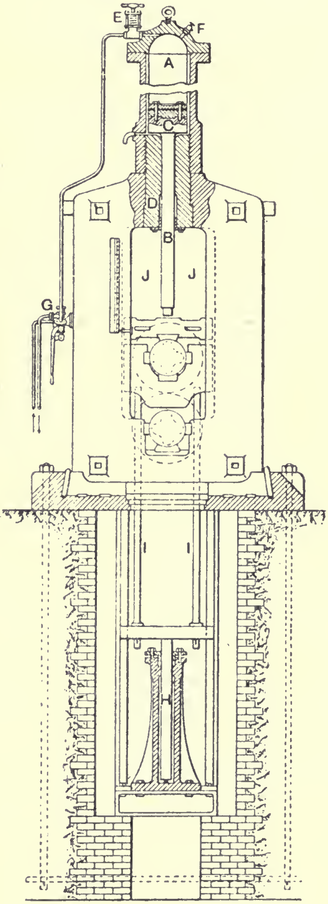

Fig. 196.
Patent Hydraulic Arrangement for Rolling Mills.

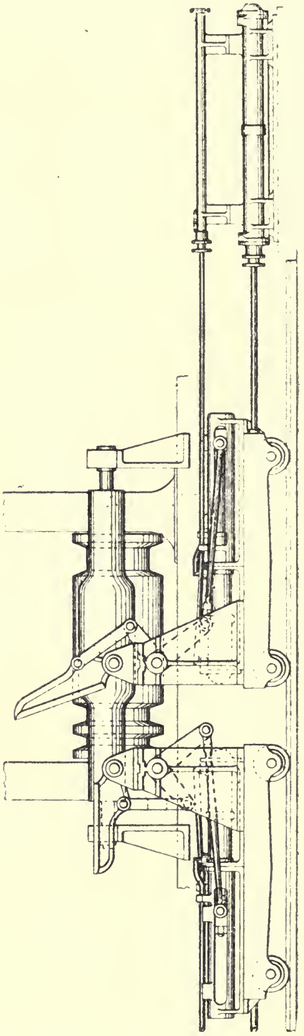

Fig. 197.—Tilting Gear for 40 in. Slab Cogging Mill.

The moving of a heavy ingot is always troublesome. In the ordinary malleable ironworks rollers are provided over which the bloom can be pushed by means of rods. These were once used in steelworks, but have now been superseded by live rollers. These are rollers coming a little above the level of the floor, which are rotated by an engine by means of bevel gearing, and as they rotate they carry the ingot forward to the rolls.

Guides, &c.—To guide the ingot to the right position, so that it may pass through the rolls at the right point, a pusher is provided. This consists of a pair of vertical arms, or a vertical plate, attached to a carriage below the floor which runs transversely on rails and which is usually operated by hydraulic power, so that the ingot can be pushed exactly into the required position.

The ingot will also need tilting, so as to turn it on to its side for passing through the rolls. Several forms of tilter have been devised. One form is shown in Fig. 197. It consists of two arms pivoted to a frame, so that they can be placed either in a horizontal or vertical position. They are actuated by means of hydraulic cylinders, and each is carried on a carriage which runs transversely beneath the floor, so that the ingot can be turned over and passed at once to any position on the "live rollers."

When the ingot has passed through the rolls for the last time it is passed to the shears, where the ends are cut off and sent to scrap, and the ingot is passed on to the roughing or finishing rolls.

These rolls are about 24 in. to 30 in. diameter and 6 ft. long. They are grooved so as to commence with the square billet and end with the article in the required form—bar, rail, or whatever it may be.

The finished bar will probably be far too long for the purpose for which it is required, bars up to 120 ft. long being frequently rolled; it will, therefore, be cut up into the required lengths and the ends will be cut off. This is almost always done with a circular saw; and as the cut must be at right angles to the bar, and it would not be easy to move a long bar transversely, the bar is kept in position against a guide plate which is graduated so that the length of the cuts can be adjusted as required, and the saw, carried on a swinging arm, is brought forward to the bar, and cuts it through. The bars are then laid on one side till required.

Unless for very small work, the bars are now rolled at one heat, so that they pass direct from the cogging mill to the roughing rolls, and then to the finishing rolls, and thence to the saw.

Plate Mills.—Plate mills do not differ very much from bar mills. The rolls of the cogging mill are, of course, plain, and they must be capable of a very wide separation—up to 3 ft. 6 in., or even more. The rolls are about 8 ft. long and up to 40 in. diameter. The ingot, which in this case may be much heavier than in the case of an ingot for bar, is passed through the rolls a few times. It is then turned round, and is passed through in the other direction till it is reduced to the required thickness, the object being to roll a thick rectangular bar. As it is important to keep the edges flat, the bar is turned on its side and passed through the rolls in that position. When the ingot is reduced to a slab about 8 in. thick, it is passed to the shears, where the ends are cut off, and it is cut into pieces of suitable size for the plate mill, and then passed to the reheating furnace.

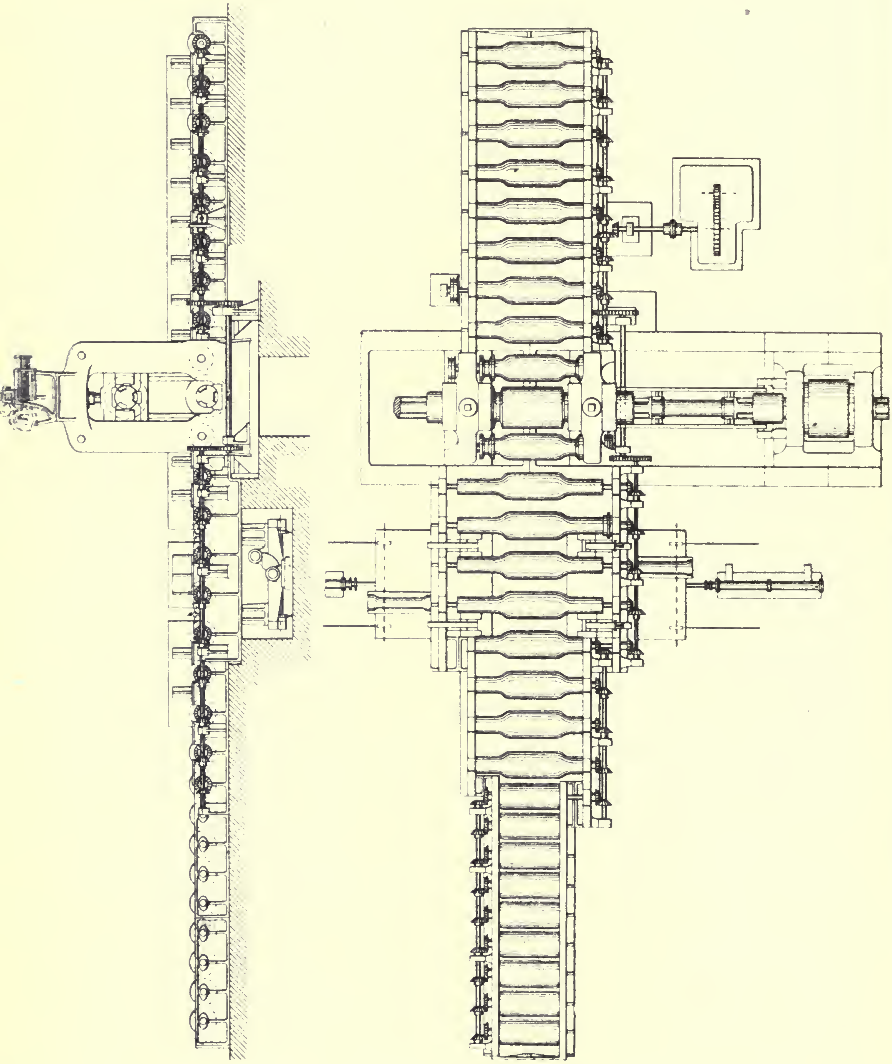

FIG. 198.—Side Elevation and Plan of 10 in. Slab Cogging Mill.

It would be possible to roll the plate at one heat, as is done with bar; but it is not advisable, as the metal has cooled considerably, and therefore is harder, and would have to be taken down at reduced draughts or the risk run of breaking the rolls.

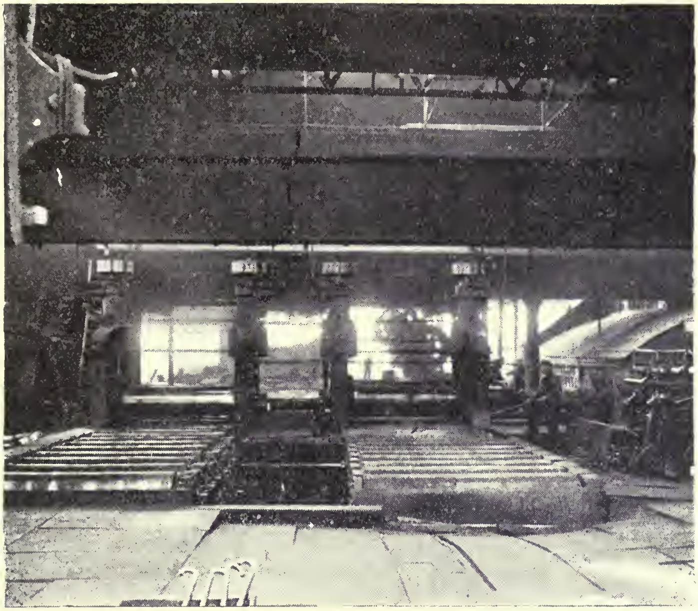

Fig. 199.—Plate Mill.

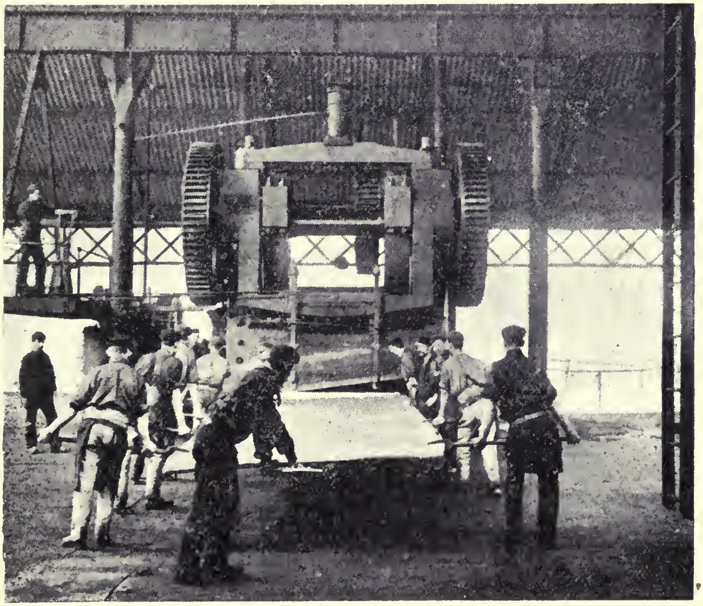

Fig. 200.—Plate Shears.

About half an hour in the reheating furnace brings it to uniform temperature well suited for rolling, and thus in the end saves time—that is, if suitable appliances are used for dealing expeditiously with the slabs.

The slab passes to the roughing roll, where it is reduced to a convenient size, and then at once to the finishing rolls, where it is finished.

The two pairs of rolls are placed side by side, and are coupled together, so as to be driven from the same engine ; and usually there is a movable table, running transversely on rails, by which the plate can be taken from one to the other.

The roughing rolls are adjusted in the same manner as the cogging rolls ; but in the finishing rolls only the bottom one is driven, the upper one resting directly on it, the rolls being adjusted by screws worked by hand wheels.

The roughing rolls are made of cast iron or steel. The finishing rolls are chilled. As the plate is passing through the finishing rolls, the surface is kept well watered, so as to remove scale, and, for the same purpose, the surface is kept well brushed with a bundle of brushwood.

The finished plate is sent forward at once to the floor of the mill ; there, as soon as it is cool enough, the dimensions of the required sheet are marked on it with chalk. It is carried to the shears usually by means of an overhead crane, and is sheared to the required size.

The handling of sheets or plates of large size is very troublesome, but gradually improved plant is being designed for the purpose.

Arrangement of the Mill.—The arrangement of the mill is of the utmost importance for quick work, and it is essential for large outputs that hand labour should be almost entirely replaced by mechanical appliances, and that all parts of the works should be so arranged as to allow of rapid moving and handling of the ingots, &c. Obviously, this is more easily done where the works produce only one variety of article, and there is, therefore, now a great tendency to specialise production.

The cogging mill must be so placed that the ingot can be readily delivered from the soaking furnace and passed to the shears, and then either to the reheating furnace or roughing mill, as the case may be, and it should be possible to pass the ingot on with no handling.

In modern, well-arranged mills all motions of the rolls, pushers, tilters, &c., are controlled from a bridge or platform, so that no one need be on the floor except in exceptional cases. Thus the work can be very quickly done, and is constantly under the oversight of the foreman in charge. Electric appliances are now being very largely used, and will, no doubt, be very much more extensively used in the near future.

Hydraulic Forging.—For dealing with articles of large size for which rolls are not suitable, hydraulic forging presses are now largely used. The method seems to have been introduced by Mr. Haswell, of Vienna, and one of the first hydraulic forging presses was erected for the Cyclops Works, Sheffield. Of late years presses of very much larger size have been erected, the largest probably being that at the works of Messrs. Beardmore and Co., Parkhead, Glasgow, which gives a pressure of 12,000 tons.

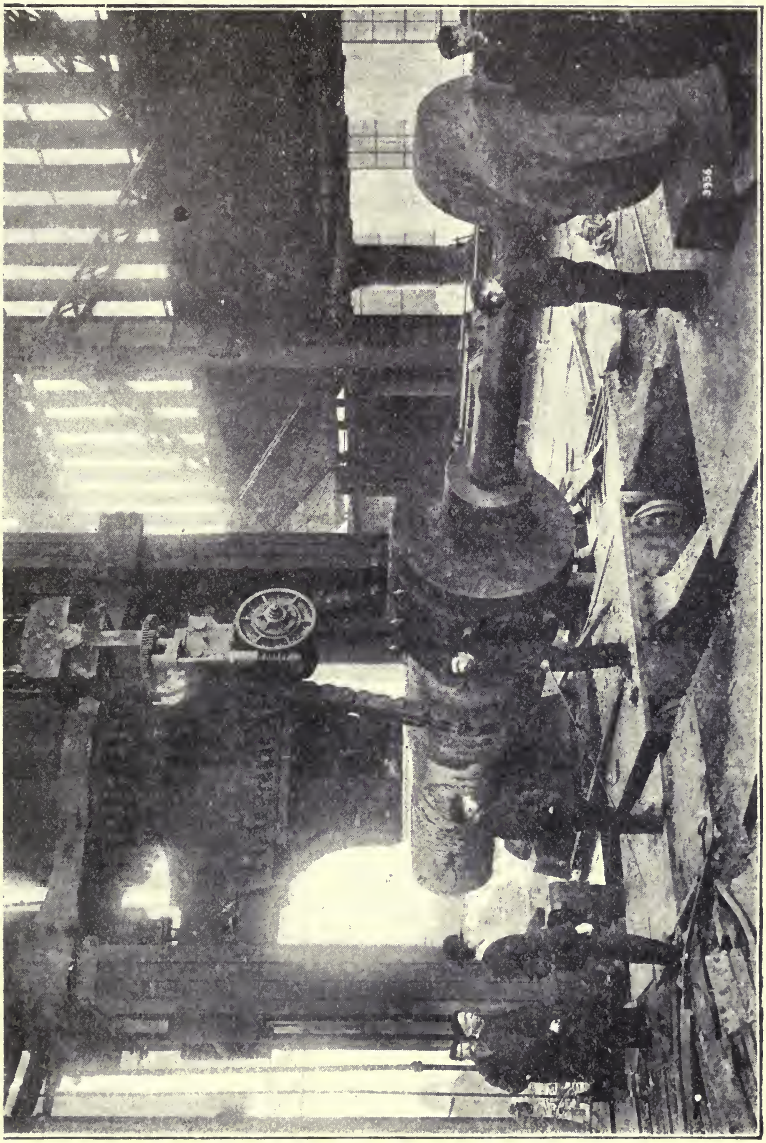

Fig. 201.—Hydraulic Forging Press at Messrs. Beardmore's Parkhead Works.

CHAPTER XXXVIII.

CASTING STEEL.

The methods of casting steel do not differ materially from those used in casting iron, but the temperature of the metal being much higher a more refractory sand must be used for the moulds. The metal is, of course, never melted in a cupola, but either in a crucible in the case of hard steel, or in an open-hearth furnace in the case of mild steel.

In the early days of the mild steel industry it was found to be much more difficult to obtain sound castings with mild steel than with cast iron or hard steel, and the milder the steel the greater was the difficulty. There are three defects that were met with in the castings of which notice must be taken, but these are not by any means exclusively confined to mild steel, viz.: Blowholes, pipes, and segregations.

Blowholes.—These are small cavities or bubbles, more or less regularly distributed through the metal, and varying very much in size. The blowholes near the surface of the ingot are more or less lengthened cavities, and lie with the long axis at right angles to the surface of cooling, sometimes coming so near the surface that on working they produce pits. Those nearer the centre are very much more irregular in position and in shape. "The surface of the blowholes is here smooth, there furrowed lengthwise: now metallic and silvery, now oxidised, now covered with an extremely thin enamel-like coating of a more or less greenish or yellowish-grey colour, and even brown according to Walrand. I have confirmed Walrand's statement that this coating is instantly removed by hydrochloric acid with the evolution of sulphuretted hydrogen. On the whole, the surface of rather more of the subcutaneous than the deeper seated blowholes seems to be oxidised, but the reverse is often true."* The blowholes near the surface, which form pits, are often oxidised.

The blowholes may vary much in size, from quite visible holes to mere microscopic cavities. Howe mentions some in a 14 in. ingot 3 in. long in and ·2 in. diameter. Sometimes they are very irregular in shape.

When the ingot is rolled these blowholes do not, as a rule, weld up, but become lengthened out into threads or cracks, which are a source of weakness, and when the surface of the metal is machined away they, of course, leave irregularities which spoil the surface of the metal.

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* Howe, "Steel," page 146.

Gases in Molten Steel.—Molten steel dissolves a considerable quantity of gas, the amount, as a rule, increasing with the temperature of the metal, and varying with its composition. This gas is to a large extent given off during solidification, and under certain conditions it may give rise to the formation of blowholes in the solid metal. The gas may be many times the volume of the steel, and it consists of hydrogen, carbon monoxide, and nitrogen, the first-named being present in much the largest quantity, usually more than the other two combined.

The source of this gas is not far to seek. The molten metal in the furnace is exposed to the action of the air, and therefore may dissolve some nitrogen therefrom. The oxygen of the air, and still more from the ore added, will combine with the carbon and form carbon monoxide, most of which will escape, but some may remain in solution. Moisture present in the materials or in the air may be decomposed, oxides formed, and hydrogen evolved, and this may partially remain in solution. In the Bessemer process, where the air is blown through the molten metal, such solution is more likely to take place than in the open-hearth process, where the air plays only on the surface. The proportion of gases in solution depends, obviously, upon the solvent power of the metal for each, and not on the quantity in which each is present, for nitrogen and carbon monoxide will be present in largest proportion, whilst hydrogen is the principal constituent of the gases dissolved.

When the steel cools towards solidification this gas is given off usually with a steady, gentle, continuous bubbling, but if the quantity be very large the boiling may be very vigorous and the metal may be "wild." As the metal approaches solidification the evolution of gas increases, and therefore is often much greater in the mould than in the ladle; indeed, sometimes the evolution of gas in the mould is so rapid that the metal "scatters," and a considerable portion may be ejected from the moulds. It is obvious that the gas which escapes whilst the metal is liquid cannot cause blowholes, but any that is retained may do so.

Consider the case of a large ingot of steel solidifying. Whilst the metal is very liquid the gas can escape freely, and thus produce boiling or bubbling, but this condition does not last very long, the metal becomes more and more pasty, and thus the gas is able to escape with less and less freedom. As the gas comes out of solution it will, of course, occupy increased space, and thus will increase the bulk of the contents of the mould. The metal will therefore rise in the mould, and this "rise" may be very considerable in amount. If all the gas could escape whilst the metal was perfectly liquid, the metal would sink back to its original volume, but this very rarely takes place.

As the top of the ingot becomes pasty the gas rising from below is less and less able to escape, but, becoming entangled in the more or less pasty metal, makes it porous and unsound. The head of the ingot is therefore always cut off and rejected.

Once the surface of the metal has solidified there can be but little escape of gas, only that which can pass, by diffusion, through the outer layers of the metal, and this not till after the ingot is stripped. If a cavity (pipe) is left as the metal solidifies this may be filled with gas, but otherwise the gas cannot be given off.

The ingot does not solidify all at once. The solidification is very gradual from the surface inwards. The metal is crystalline, and solidification takes place, not by the formation of one smooth layer of metal over the other, but by the development of crystals which grow out into the molten mass, and the spaces between which afterwards become filled by the growth of other crystals. As the metal solidifies the gas will be evolved, but the small bubbles may adhere to the solid surface, and may thus not rise at all, and may become entangled in the growing mass of solidifying metal. The presence of a minute bubble of gas may determine the separation of the next bubble, and so the bubble may grow inwards and form the lenticular blowhole so common near the surface of the ingot. Near the centre of the ingot cooling is less definitely from one surface, and the position of the blowholes is therefore not so markedly at right angles to the cooling surface, and the arrangement is much less regular.

Pipe.—The pipe is very different in character from the blowhole, but is often confounded with it. When an ingot which evolves no gas solidifies, it contracts, the solid metal occupying less bulk than whilst it was in the molten condition; therefore, since the metal solidifies first at the surface of the mould, the contraction will take place towards the centre, and if the top of the ingot solidifies last there will be a conical depression or pipe. This is well seen in hard steel ingots. Should the top of the ingot become solid the contraction still takes place, but since the whole outer shell of the ingot is now rigid it can only take place in the interior, and the pipe will therefore take the form of an internal cavity. As the solidifying metal will always adhere to that previously solidified, so as to make a continuous metallic mass, the position of the pipe will be determined by that of the last solidifying portion of the metal. Under ordinary circumstances it will be near the top of the ingot, but in certain cases—if, for instance, the ingot be thrown over or upended whilst the interior is still liquid—the position may be considerably changed.

Prevention of Blowholes.—Many suggestions have been made for the prevention of blowholes, and have been used with more or less success. They are either physical or chemical.

Physical Methods.—The physical methods depend on the removal of the gas, preventing its escape, or so modifying the conditions of casting that the gas may accumulate in some portion of the ingot which can be removed.

(1) Agitation facilitates the escape of the gas. Hence it has been suggested to keep the contents of the ladle well stirred by means

of agitators. This no doubt would facilitate the escape of the gas which was actually liberated in the ladle, but most of this would escape in any case, and it could have little influence on the gas evolved in the moulds on further cooling.

(2) Agitation of the moulds has been tried, but with little success, the plant required being too elaborate for ordinary steelworks. The most promising arrangement (that proposed by J. L. Sebenius) consists in freely suspending the mould, which is closed at the bottom, by means of projecting pins just above its centre of gravity when full, on an arm or table which can be set in rapid rotation. The mould is filled in the usual way, and the arm set rotating. By its centrifugal force, the mould gradually assumes a horizontal position, the heavy steel is forced against the end of the mould, whilst the lighter gas, being forced inward, can escape.

(3) **Pressure.**—When gas is in solution increased pressure will hinder if not stop its evolution, whilst if the pressure be reduced over a mass of steel in a state of tranquil fusion a vigorous evolution of gas may be produced. Casting under pressure was apparently first tried by Bessemer in 1856, but was reintroduced and rendered practicable by Whitworth in 1865.

Whitworth's apparatus is shown diagrammatically in Fig. 202. The steel is cast into the mould M, which is supported by very strong steel jackets, and is carried on a table T, attached to an hydraulic ram R, working in a cylinder C. As the mould is raised the boss D, attached to a solid crosshead L H, enters the mould and compresses the metal. The crosshead is fixed during the operation, but can be moved on the guide posts S by an hydraulic ram above. "The pressure on the steel is gradually increased till it reaches six tons, occasionally till it reaches 20 tons per square inch of horizontal section of the ingot. The press at Aboukoff exerts a total pressure of 10,000 tons. With a 45-ton ingot the maximum pressure is reached in about 35 minutes.

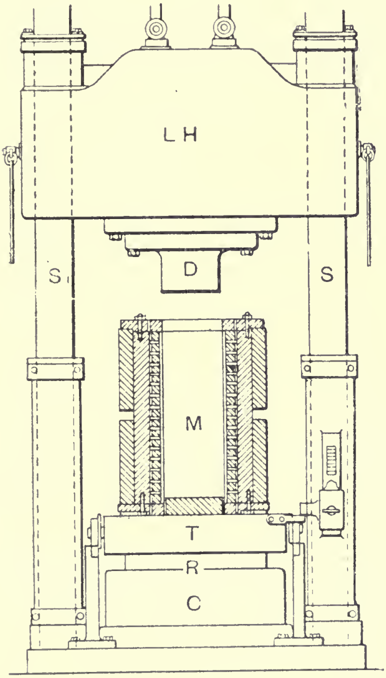

FIG. 202.—Whitworth Casting Press.

" During this time there is 'a continuous and violent' evolution of gas and flame, and the ingot is compressed about one-eighth of its length. A pressure of 1,500 lbs. per square inch from an accumulator is now substituted for the direct pressure of the pump, and is maintained until the 'metal is sufficiently cooled to ensure no further contraction in the mould' (which, taken literally, means till it is completely cold), so as to follow up the contracting steel and prevent the formation of external contraction cracks from local adhesion to the side of the mould or from other cause."*

What is the direct advantage of liquid compression is not very clear. It "cannot hasten the escape of gas bubbles, which would rise by gravity to the surface with or without compression, but it must tend to retard or even stop the evolution of gas, the solubility of which increases with the pressure, and thus to increase the quantity of gas retained by the steel.

"Plastic compression, however, may actually squeeze the blowhole gas out through the crust of the ingot as we squeeze water out of a sponge. It may cause the reabsorption of part or, indeed, all of the gas contained in the blowholes, and may squeeze and weld the sides of the pipe together; and if gas remain which is neither squeezed out nor reabsorbed the pressure will diminish the size of the cavities which contain it. The gas which is thus reabsorbed and compressed is not, indeed, eliminated, and it is possible that it may be re-evolved and may re-expand should plasticity without compression recur; but it could then hardly form in the relatively stiff pasty metal as large cavities as it would have caused at the higher temperature and in the less viscous metal of its first liberation."†

"Whitworth attacks the ingot at its strongest point, so that to accomplish given compression he has to expend the maximum of energy. To create even a slight pressure within the soft interior he must actually compress the most unyielding portion of the early freezing walls, and that too in a direction in which they resist most powerfully."‡

Many other methods of compression have been suggested; as, for instance, G. Krupp uses liquid carbonic acid, and is said to obtain a pressure of 5 tons on the square inch; Jones uses steam, and so on; but the difficulties in the way of the application of any of them are very considerable.§

(4) By the use of a sinking head (*i.e.*, a head of molten metal above the top of the ingot), or, what comes to the same thing, making the mould longer than is needed, the ingot proper solidifies under the pressure due to this head; and as the metal in the head remains liquid the gas bubbles will tend to rise into it, and the pipe may also be in it. The sinking head should be about 20 to 30 per cent of the entire casting, or, what comes to the same thing, it may be necessary to reject that proportion of the casting to ensure soundness. In ordinary cases the amount rejected will be about 10 per cent.

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* Howe, "Steel," page 156.

† Howe, "Steel," page 158.

‡ Howe, "Steel," page 186.

§ For further particulars see Howe's "Steel."

(5) In ordinary work, as soon as the mould is full, the ingot is filled up or stopped with sand and covered with an iron cover. This has the effect of slightly increasing the pressure without hindering the escape of gas, and also, by preventing radiation, and thus keeping the top of the ingot liquid as long as possible, so as to allow of the rising of the gas and the formation of the pipe as high as possible in the ingot.

Lateral Pressure.—Moulds in which a lateral pressure can be given have been suggested, the most successful process being that patented by Messrs. Robinson & Ridge, of Sheffield.

The moulds are made in halves, divided vertically, the two halves being separated by pieces of convenient size, which can easily be removed, and the moulds are arranged in a press so that the separating pieces in the moulds are at right angles to the direction of the pressure. The moulds are filled as rapidly as possible, and so that they are all filled at once. As soon as the metal is in the moulds, it will have solidified at the surface, the separating pieces are removed and pressure is put on, so that the halves of the mould are forced together, the pressure being continued till the metal is quite solid, and is gradually increased till it reaches about two tons per square inch. In the case of large ingots, the top may be kept open by means of a feed-rod, a clay cylinder being placed on the top of the ingot to receive extruded metal. Ingots cast in this way are said to be quite sound.

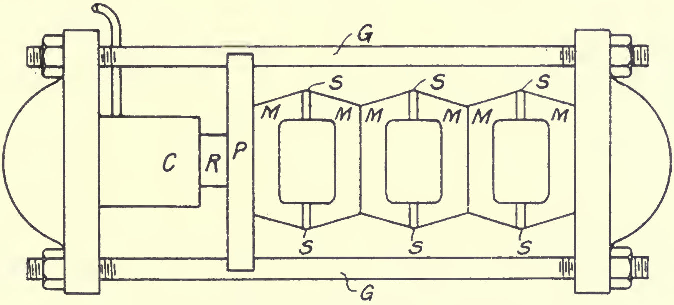

Fig. 203.—Plan of Robinson's Mould Press for Ingots.

M, Half Moulds. S, Side Spaces. P, Movable Pressure Piece. G, Guide Rods. R, Ram. C, Cylinder.

Chemical Methods.—The chemical methods for producing sound castings and the elimination of blowholes depend on the addition of some suitable material to the molten metal. Two substances are used: Silicon, either as silicon iron or silicon carbide, and metallic aluminium.

The effect of silicon is very marked. If a little silicon be added to boiling steel in a ladle, the metal at once quiets; and whilst, had it been teemed in its boiling condition, it would have given an ingot containing blowholes, after the addition of silicon it will give a perfectly sound casting.

The cause for this change produced by silicon has been much discussed. It has been claimed that it is due to a deoxidising action, the silicon combining with the oxygen present in the gas forming silica which enters the slag. As has been pointed out, however, the gases which are evolved consist largely of hydrogen and nitrogen, which certainly could not be reduced by the silicon. The real reason seems to be that silicon increases the solvent power of the metal for the gases, so that the gases, instead of being given off, are retained in solution as the metal cools and finally solidifies.

The action of aluminium is quite as marked as that of silicon, but the rationale of the action is not understood. The quantity of aluminium which it is necessary to add is very small, and of this only a small portion—hardly more than a trace—remains in the finished metal. There can, however, be no doubt as to the fact of the action of aluminium in producing sound castings, and its use in steelworks has now become very general. Howe suggests that "may it not be that the presence of oxygen diminishes the solubility of gas in iron, and that the aluminium, by removing this oxygen, indirectly raises its solvent power?"

It seems as if the action of these agents is not the same in all cases; indeed, it may be that the gases themselves vary in composition. Metals which contain excess of oxygen often give off a large quantity of gas.

Mitis Castings.—Castings of excessively mild steel, known as Mitis iron castings, are made commercially. Very mild, almost carbonless steel, such as that used for the preparation of these castings, evolves gas so copiously that it is impossible to obtain sound castings, but by the addition of ·1 per cent of aluminium, or less, the evolution of gas is prevented and sound castings are obtained.

It is sometimes said that aluminium lowers the melting point of the metal, and thus allows of the escape of the gases; but this does not seem to be the case, and it does not seem likely that the small amount of heat evolved by the oxidation of the aluminium could raise the temperature so as to give the increased fluidity necessary for casting. Only a minute trace of aluminium remains in the metal.

The castings are made by melting the metal in crucibles, adding a little ferro-aluminium, stirring and casting in the usual way.

Gases from Steel.

Mould Gases.—As might be expected, the whole of the gas in the steel is not given off whilst the metal is in the liquid condition. Of that which remains some will diffuse through the sides of the hot ingot and escape; so that whilst the ingot is kept hot it will be continually evolving gas. This was well seen in the Gjer's soaking pit, the gas from the soaking ingots escaping and burning round the cover of the pit. The gas has much the same composition as that evolved during solidification.

Boring Gas.—The solid metal still retains a considerable quantity of gas, partly perhaps still in solution, but the bulk of it contained in minute cavities or blowholes. If the metal be bored under water with a cutting tool, or broken up so that the pores become exposed, the gas can be collected and examined. The more finely the metal is triturated the more gas will it evolve ; and also the more porous the steel the more gas will it give. The gas obtained by boring consists almost entirely of hydrogen and nitrogen, carbon monoxide being absent, or present only in very small proportion. When a fine drill is used, gas is obtained up to 11 times the volume of the metal cut. It is hardly likely that any drill used would be fine enough to liberate the whole gas, and if there were any in true solution it, of course, could not be liberated by mechanical means. By heating solid steel in vacuo for several days, a considerable amount of gas may be obtained.

It is impossible to say how the gas obtained by heating in vacuo is related to that obtained by drilling.

The table of gases from steel given on page 434 is from Howe's stee .

SEGREGATION.

By segregation is meant the separation of the metal into portions of different composition during solidification. If the metal were a definite chemical compound it would crystallise or solidify so that all parts had exactly the same composition ; but steel is not a definite compound, and its solidification does not take place so uniformly. The less fusible constituents solidify first, and the more fusible later. To obtain perfect homogeneity these should be evenly distributed, so that the average composition of a portion from any part of the ingot would be the same ; but there is always a greater or less tendency for the more fusible portions to be ejected from the less fusible as this solidifies, and so for them to segregate or accumulate in masses usually in the portion that solidifies last.

Obviously, the slower the solidification the greater will be the freedom of motion of the molecules and the greater will be the tendency to segregation, whilst when the solidification is rapid the greater will be the likelihood of obtaining a homogeneous casting. There seems to be always a tendency in steel for pure iron, or iron low in impurities, to separate first, leaving the iron higher in those constituents to accumulate in the portions which solidify last. The purer the metal the less is segregation likely to take place, whilst the larger the quantity of other constituents the more marked it will be.

In ordinary ingot castings the segregation is not large.

Gases Classified According to their Time of Escape (Howe).

Mode of Escape.		Effect.	Percentage Composition by Volume.				Volume of Gas per Volume of Iron.				
			CO	H	N	CO_2	CO	H	N	CO_2	Total.
1. Escape while the metal is so liquid that the passages close....		Scattering	8·8—82·6	2·3—43·3	1·0—43·3	0—8·4	0—1·23	0—1·61	0—0·78	0—0·13	0—8
(A) Held as gas mechanically or by capillarity, or gasified during plasticity.	(1) Escapes gradually from blowholes through walls of ingot... (2) Redissolves in the metal	Rising, blowholes, &c.	12·9	20·47-27·21	59·91-66·63	..	..	..	..	..	..
	(3) Remains in pores and blowholes	..	0—2·2	52·2—92·4	5·9—48·1	..	0—·006	·03—9·76	·01—1·13	..	·06—11
(B) Remain dissolved after plasticity has ceased, and is reformed by reactions thereafter.	(1) May be extracted by heating in vacuo .... (2) Cannot be extracted by heating in vacuo	May affect physical properties.	7·9—63·65	22·72-57·3	11·36-34·7	2·27	·02—·43	·007—3·12	0·03—1·89	—·001	·031—5·45

The following figures, given by Campbell,* will give an idea of the segregation in plate ingot 10 in. thick :—

	Carbon. Per cent.	Phosphorus. Per cent.	Sulphur. Per cent.
Centre 6 in. from top	·187	·075	·065
,, 12 in. ,, ...	·150	·067	·054
,, 18 in. ,, ...	·179	·067	·054
,, 24 in. ,, ...	·183	·062	·049
,, 3 in. from bottom	·145	·058	·044

The question of segregation is of extreme importance, and many experiments have been made with a view to reduce it to a minimum. The most successful method, so far, seems to be the addition of a small quantity of aluminium. The quantity required is very small, only three or four ounces per ton, and it is best added when the mould is partly full. The steel so cast is freer from blowholes, and there is less segregation. The reduction in segregation is shown in Fig. 204, from a paper read before the Iron and Steel Institute, by Mr. B. Talbot, in 1905. The figures given only show the segregation of sulphur and phosphorus, but the segregation of carbon manganese is also considerably reduced. The steel seems to set more quickly, but it is not certain that its fluidity is increased.

Cracks, &c.—There are sometimes mechanical defects in the ingots due to various causes. Cracks may be horizontal or vertical, and may be produced in various ways. The steel in the ingot mould is much hotter than the mould itself, and the outer skin will solidify almost instantly. As the mould becomes heated it will expand, and may draw away from the wall of the ingot ; if the solidified metal is sufficiently plastic, it will follow it ; if not, the pressure of the molten metal within may cause a fracture.

As the shell solidifies it contracts over the still liquid interior. If cooling goes on so that the exterior cools and contracts more rapidly than the still liquid interior, this, being incompressible, will not yield, and the surface of the ingot may crack. It may happen that the ingot adheres to the mould at some spot, and is therefore not free to contract with the rest of the ingot ; and in other ways, due to irregular contraction, cracks may be formed and, as air finds its way in, the surfaces of the cracks are likely to oxidise, and therefore will not weld up by subsequent work.

If the solidified shell contracts less rapidly than the interior, internal flaws or cracks are likely to be produced : or " if a cold ingot be placed in a hot furnace, the surface may expand so rapidly

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* " Structural Steel," page 175.

that the expansion of the slowly heating interior cannot keep pace with it, when internal cracks may form, often with a loud report." To avoid cracks, ingots must be cooled and heated as uniformly as possible, and should be transferred to the "soakers" as soon after casting as convenient. Howe states that "the proportion of cracked, or 'second quality' rails, is greater when rail ingots are allowed to cool than when they are charged into the heating furnace while still hot from teeming."

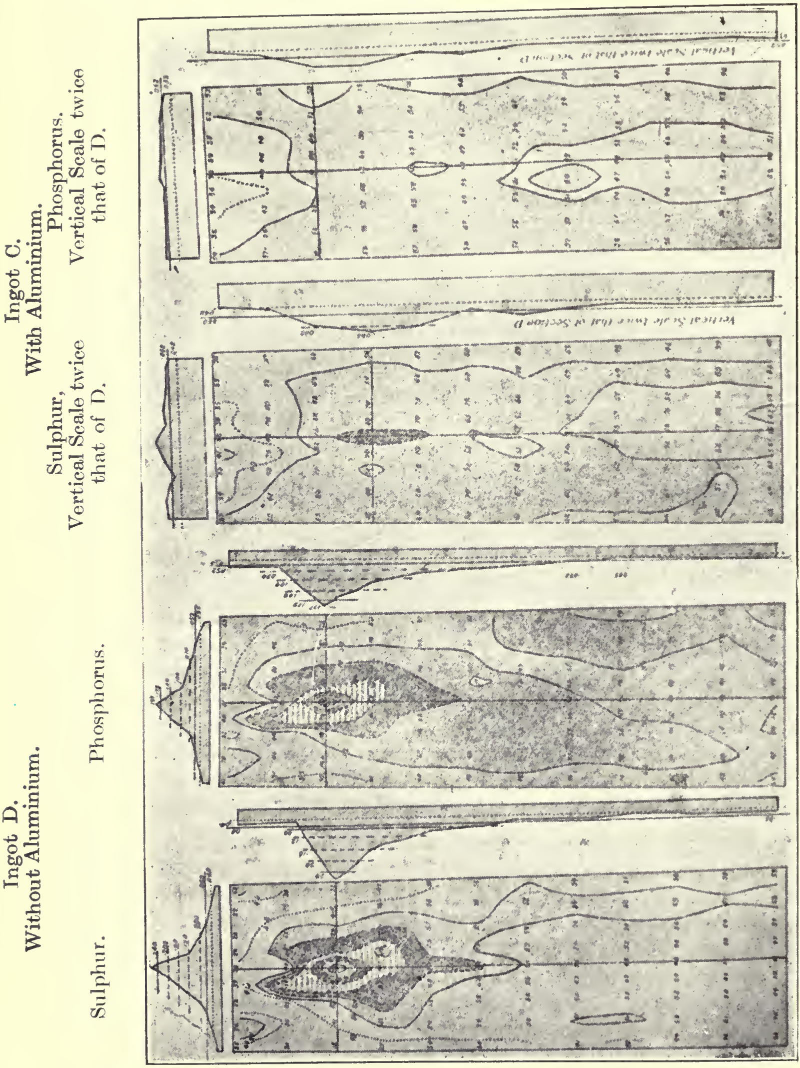

FIG. 204.—Segregation in Steel Ingots minimised by use of Aluminium.
4 oz. Aluminium to ton of Steel.

CHAPTER XXXIX.

AFTER TREATMENT OF IRON AND STEEL.

Removal of Sulphur.—As has been already explained, part of the sulphur in the materials finds its way into the pig iron, and this is not eliminated in the subsequent operations by which the iron is converted into steel, even the basic process only removing a portion unless the quantity present be very small. This limits the pig which can be used for steel making to that which is free from sulphur. Many attempts have been made to devise a process for the removal of sulphur either from the pig iron before treatment or during the process of conversion into steel. Only one of these (apart from electric refining) calls for description.

The Saniter Process.—This process was invented by Mr. E. H. Saniter, who commenced his experiments on the subject in 1880, and read his first paper on it to the Iron and Steel Institute in 1892. He found that while heating with lime removed a portion of the sulphur—as in the basic process—the removal was much more rapid and almost complete if the lime was mixed with calcium chloride. The process, therefore, consists in heating the iron to be purified—in the molten condition—with a mixture of lime and calcium chloride. The process may either be applied to the pig iron or during conversion in the basic furnace.

The method suggested by Mr. Saniter was to grind the calcium chloride and lime together in a mill, so as to mix them thoroughly and bring them to the condition of a coarse powder. "About equal parts of each are required as give the required fusibility." The mixture is placed in a suitable ladle, consolidated by the action of heat, and the iron is run on it. The mixture fuses, and, rising through the metal, removes the sulphur. About 25 lbs. of calcium chloride and the same weight of lime are sufficient to desulphurise one ton of iron.

Mr. Saniter gives * the following results of some experiments :—

Class of Iron.	Sulphur.		Silicon.	
	Before.	After.	Before.	After.
No. 5 hematite	·220	·060	1·6	1·2
Hard forge	·300	·060	1·7	1·4
Grey forge	·070	·008	2·2	1·6
Basic	·102	·032	·56	·32
Do.	·065	·026	·54	·46
Do.	·093	·016	·32	·09

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* Journal Iron and Steel Institute, 1893, vol. i., page 73.

And, as a result of a large number of tests, he gives :—

Sulphur elimination	73·6	per cent.
Silicon ,,	35·77	,,

The composition of the slag is about :—

Calcium chloride	39·1	per cent.
Calcium sulphide	5·8	,,
Lime	38·6	,,
Silica	12·9	,,

Mr. Saniter gives an account of the working of the process at the works of the Wigan Coal and Iron Company. He says : "The sand bed has been lowered to the ground level. On this level, and in front of the blast furnace, is a ladle on a carriage. The ladle is provided with a tipping gear."

"The ladle is heated before the first operation, the mixture put on the bottom, a small cast-iron plate being used to prevent the metal cutting under the mixture. The metal is then run in, and as soon as the reaction ceases is tipped into the lowered sand bed, and the slag raked out of the ladle, which is then ready for the next operation. This ladle takes from nine to 12 tons at a cast."

The process is now used in some steelworks where the basic open-hearth process is in use, the calcium chloride being mixed with the lime in the furnace.

Theory of the Process.—As the sulphur is in the slag as calcium sulphide, it is evident that it must have replaced either the chlorine in the calcium chloride or the oxygen in the lime. It seems probable that it is the lime which is attacked, the calcium chloride serving mainly to make a fusible compound with the lime, and thus bring it into contact with the molten iron. E. L. Rhead has suggested that the action is due to the silicon, this being oxidised by the oxygen of the lime, whilst the sulphur combines with the liberated calcium. There is always a considerable reduction of the silicon, much more than would be required for this reaction ; but this is, no doubt, partially due to the action of the moisture, which is always present. Other substances, such as fluor spar, can be used in place of calcium chloride, but the result is not so good.

High Carbon Steel by Mild Steel Processes.—It is impossible to produce steel of good quality containing up to 1 per cent of carbon by the Bessemer process, except under very special conditions, as the quantity of ferro-manganese that must be added to supply the necessary carbon would carry in an objectionable quantity of other impurities. With the open-hearth processes the difficulty is not so great, as with suitable iron the elimination of carbon can be stopped at any required point, and thus the amount of ferro-manganese necessary will be much reduced. Steels up to 1 per cent are now made by the open-hearth process for wire-drawing and other purposes, a little silicon-iron being added to give hardness.

There would be less difficulty in making hard steel by the open-hearth process if the carbon could be added in some purer form than ferro-manganese. A method of doing this has been suggested by Mr. Darby.

The Darby Process.—This consists in treating the steel with carbon in the form of wood charcoal, graphite, or coke. The steel, made in the usual way in a basic-lined open-hearth furnace, is either run through a small ladle, on its way to the large casting ladle, and into this small ladle is introduced a continuous stream of the carbonising material from a hopper above ; or the steel is run into the ladle in the usual way, and on its way from the ladle to the mould passes through a small funnel or ladle, into which the carbonising material is supplied in a continuous stream. In either case combination rapidly takes place, and the carbon is evenly distributed through the steel. Some of the carbon is, of course, consumed by contact with the air, the loss being about 15 or 20 per cent.

Mr. Theisen, in a paper read before the Iron and Steel Institute in 1890,* gives a number of examples of the composition of steel made by this process, and from this paper the following figures are taken :—

		Percentage of Carbon.	
		Desired.	Found.
Ingot I.	Section A	·25	·255
	Section B		·260
	Section C		·251
Ingot VI.	Section A	·45	·461
	Section B		·455
	Section C		·470

CARBURISED OPEN HEARTH CHARGES.

Desired Carbon per cent.	Before Carburising.	After Carburising.
·65	·069	·668 first. ·660 last.
·70	·076	·708 first. ·700 last.
·80	·070	·804 first. ·804 last.

This process is in use at some works in this country, and also on the Continent.

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* Journal I. and S. I., 1890, vol. ii., page 564.

M. Meyer has introduced a modified form of the process, which is used at the Dudelange Works (Luxemburg). Finely-powdered anthracite is moulded into bricks with 10 per cent of milk of lime, and these bricks are allowed to dry for some months. When the steel is ready, 90 lbs. of these bricks is thrown into the ladle, crushed by a hammer, and distributed uniformly over the bottom, and the metal is run in as usual. As the metal flows, the ladle is kept in motion by means of hydraulic mechanism. A violent reaction takes place when the metal meets the carbon, so that at first pouring must be slow. When the ladle is full it is teemed as usual. Steel with up to 1·5 per cent of carbon has been made in this way.

It is claimed that the process is very economical, 12 cwt. of spiegeleisen formerly used being replaced by 1 cwt. of anthracite, and the amount of ferro-manganese used is reduced by one-half.*

Calcium carbide, which is now made on a large scale, is also suggested as a carburising agent, but it is very doubtful how far it would be satisfactory.†

Case-hardening.—The method of carburising iron by heating in contact with charcoal has already been described under the cementation process for making steel, and it was there pointed out that the carbon gradually travels inward from the surface of the bar. It is, therefore, obvious that the surface of the bar will thus become steely or hard while the interior still remains soft. A similar process is frequently applied to articles of malleable iron or mild steel where a hard skin or surface is required, and is known as case-hardening. Bars of mild steel are often case-hardened, and they are then known as mild-centred steel.

The article to be hardened is embedded in some carbonaceous material, and is heated in an iron box for from 12 to 48 hours, or longer. The carbon travels into the iron, and converts the outer layers into steel. Charcoal is not usually used, as most workers prefer some material which contains nitrogen, such as leather or hoof parings, and for small articles potassium ferro-cyanide ($K_6 Fe C_6 N_6$), yellow prussiate of potash, is often used. Small articles are often hardened by making the ferro-cyanide into a paste with water, covering the article with it, and heating it in a furnace. As the surface of the article is required to be as hard as possible, it is usually quenched in water.

Giolitti has perfected a process of case-hardening all classes of steel by the use of carbon-monoxide gas under a pressure of about 200 lbs. per square inch. The articles are packed with carbon in vertical retorts heated by producer gas. The operation is complete in from two to four hours.

Harveyising.—This is simply the application of case-hardening to thick plates of mild steel to be used for armour-plates for ships of war.

The armour-plate, which may be of any thickness up to 18 in. or thereabouts, is made of ordinary mild steel, nickel steel, or similar

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*Journal I. and S. I., 1892-1, page 437. †Journal I. and S. I., 1893-2, page 523.

material, and is brought into the required form by means of a hydraulic press and rolls. The surface is then cemented, so that the face becomes converted into a high carbon steel with from 1 to 1·5 per cent of carbon, and is then hardened by quenching in oil or spraying with water.

Owing to the great weight of the plates, powerful appliances are required for handling them.

The plate is heated in a furnace of special construction heated by gas.

The furnace is of the car type, the bottom being carried on an iron truck so that it can be drawn away from the furnace. On the top of this truck is built up the furnace bottom, which consists of several layers of firebrick built so that flues pass through it for the passage of the burning gas. On this brickwork is put the plate, face upwards, resting on a layer of sand or dry clay. A wall of brick is built round the plate to a little above its upper surface. The plate is then covered with a layer of granular charcoal, which is well rammed; down over this is put a layer of sand, and above this is a heavy layer of firebrick; or, more generally now a layer of charcoal is put on the plate, and over this another plate face downwards, so that two plates are heated at once, the whole being covered with sand, to exclude air. The car is then drawn into the furnace, the doors closed, and the whole is heated strongly for a considerable period, varying from five days to a fortnight, according to the size of the plate and the depth of the hardening required.

At the works of Messrs. Vickers, Son, & Maxim, Sheffield, "the furnaces are 21 ft. wide and 30 ft. long," so that very large plates can be treated.

The amount of carbon taken up depends on three factors—the temperature of the furnace, the time of heating, and to some extent on the compression of the carbonaceous material against the plate. Loose granulated charcoal is usually used, but compressed slabs of peat charcoal have been tried. The thicker the plate the deeper can the hardening be allowed to go. As an example, the following is given by the *Iron Age :* " A plate 10½ in. thick, composed of steel containing ·35 per cent of carbon, may be charged with additional quantities of carbon varying in amount from 0·10 per cent at a depth of 3 in. beneath the surface of the exposed side of the plate to 1 per cent at the surface by a continuation of the process for 120 hours after the furnace has been raised to the required temperature."

When the process is judged to be complete the car is withdrawn, and the plate is allowed to cool. To give the required hardness it must be quenched, but before this is done the plate must receive any work that has to be put on it, as after hardening this could not be done. If it has to be bent, this is done by a powerful hydraulic press, the necessary holes are drilled through, and the edges are machined flat.

When the plate is ready for hardening it is heated to the required temperature in a furnace similar to that used for Harveyising, and when hot it is withdrawn from the furnace, lifted on to a table, and cooled by a spraying apparatus, which sends a fine spray of water over the surface to be hardened. Great care must be taken that the spray is uniformly distributed, or the hardening may be irregular. In some cases the plate is hardened by being dipped in oil. This is Krupp's modification of the process. Should it be necessary to drill the hardened plate it can be locally annealed by strongly heating the points where the holes are to be made with the electric arc.

Malleable Cast Iron.—The process, by which this is made, is apparently the converse of that of case-hardening, and consists in softening the surface of cast-iron articles by heating in oxidising material. The castings are made of a suitable iron, which must contain but little graphitic carbon, though the combined carbon should be fairly high, and there must be but little silicon. The metal is melted either in a cupola or a reverberatory furnace, preferably the latter, as the oxidising atmosphere will help the removal of the silicon, and is cast in sand moulds—usually green sand—in the usual way. The castings are well cleaned from adherent sand by any suitable means, according to the nature of the casting, by abrasion in the tumbling barrel, by scrubbing with wire brushes, or by pickling in dilute sulphuric acid. They are then carefully packed in iron boxes surrounded by iron scale, powdered hæmatite, or other suitable material, iron scale being the best, as the ore frequently contains earthy matters, which adhere to the castings and are troublesome to remove, and the boxes are carefully luted with sand and clay so as to exclude air. The boxes are then subjected to a high temperature—of course, below the melting point of cast iron—for a week or more, and then allowed to cool slowly.

The castings as they come from the boxes have a fine blue colour. They are well cleaned, and are ready for use.

An iron must be selected which contains but little free graphite, or the resulting material will be porous ; white iron or mottled iron are, therefore, used, and they must be as free as possible from other impurities. Hæmatite pig, or in America charcoal pig, are the materials usually used.

The boxes must be so arranged that a uniform temperature can be maintained. Coal furnaces are usually used, but Siemens gas furnaces are coming into use. The boxes vary in size with the size of the articles being treated, but are usually about 16 in. long and 13 in. wide and deep. "If carefully used they will last from five to 15 heats."

The depth to which the malleableising proceeds depends on the time of heating, which may vary from a day or two to two weeks. The conversion may be to only a small depth or entirely through the piece. The malleable casting has a higher tenacity than grey iron, but less than malleable iron or mild steel. It cannot be welded, and contains sufficient carbon to allow of it being hardened by quenching. At a moderate red heat it is possible to forge some of the best qualities, but if it is overheated it crumbles as soon as it is struck.

The process has been modified in various ways. C. Ross proposes to increase the rapidity of the action by bringing the surface into very intimate contact with the softening material. For this purpose the article is dipped in a pasty mixture of hæmatite, lime, and water, which forms an adhesive layer.

The action is apparently not a simple removal of carbon by oxidation, as is usually supposed, but rather a change in the condition of the carbon, it being to a large extent converted into very finely disseminated graphite.

Annealing.—Articles of steel and iron are more or less hardened by rapid, and softened by slow, cooling. When the metal is required to be very soft, it is, therefore, annealed by being heated to redness and cooled slowly. Ordinary articles are heated in a muffle or open fire to the required temperature; but very small articles which might suffer by oxidation are enclosed in iron boxes. There is for each grade of steel a temperature which is best. The temperature must be high enough to release the molecules from any strain that has been thrown upon them by work, and to allow of free rearrangement.

Many attempts have been made to use a non-oxidising atmosphere for annealing by filling the muffles with non-oxidising gas or sending a stream of gas through them.

Welding.—One of the most striking properties of malleable iron is its power of being welded, *i.e.:* If two pieces at a suitable temperature be brought together and hammered or pressed into contact a perfect union will take place. Whilst welding is a characteristic property of malleable iron, other metals can also be welded. Indeed, it seems that if, owing tc the softness of the metal, the two portions can be brought into such close contact that the molecules come within the range of molecular attraction, union will take place.

The weld depends on the perfection of contact, and this depends on three conditions :—

(1) The plasticity or softness of the metal as determined by its composition and structure.

(2) The temperature.

(3) The perfect cleanness of the surfaces.

The purer the iron the softer it will be, and the better it will weld, and the elements which harden the metal will tend to decrease its welding power. Carbon, therefore, will decrease welding power. As the percentage of carbon rises the welding power decreases, though steels with 1 per cent of carbon can be welded with care and skill. It is usually thought that the history of the metal makes a difference in the welding power, for instance, that malleable iron will weld much better than mild steel of exactly the same composition ; but evidence is so conflicting that it seems impossible to come to a definite conclusion on the point. There can, however, be no doubt that mild steel low in carbon will weld perfectly, and such metal is regularly used in the manufacture of welded tubes, and for other similar purposes.

There is another reason why carbon decreases the welding power, and that is that "it lowers the point to which the metal can be heated without danger of burning, but does not lower correspondingly the temperature at which plasticity sets in ; indeed, it seems to diminish the plasticity and adhesiveness for a given temperature."*

Sulphur is said to interfere very much with the weldability of the metal ; over ·1 per cent probably renders the metal unweldable. Phosphorus, arsenic, antimony, and copper are also objectionable, but the influence of silicon in small quantities is uncertain.

Temperature.—For welding malleable iron the articles are heated to a white heat, but for steel the temperature must be considerably lower. Only experience will enable a judgment to be formed as to the correct welding temperature for any given steel.

Fluxes.—In order that the surfaces of contact may be perfectly clean, fluxes are used. When the metal is heated the surfaces become covered with oxide, and this will prevent contact between the metal faces unless the temperature be so high that it will be liquid, and can thus be squeezed out. As malleable iron can be heated without injury to the temperature at which the oxide fuses, it is possible to weld this without the use of any flux ; but in other cases a flux must be added, so as to form a fluid compound with the oxide that can be squeezed out.

The fluxes used are : Borax, which melts very readily and dissolves the oxide of iron, and therefore can be used for steels which cannot be heated to a high temperature, and sand, which is the usual flux. The silica combines with the oxide of iron, forming a fusible ferrous silicate, which is squeezed out. Clay, a silicate of alumina, which combines with the oxide of iron and forms a double silicate of iron and alumina, and many other substances have been suggested. For ordinary welding, sand is invariably used.

Varieties of Weld.—The iron to be welded is heated in the forge. The pieces are forged into the required shape, sprinkled with flux, brought together, and hammered till union is perfect. Several forms of weld are used. The scarf weld is the commonest. The two pieces are sloped off, the one being widened and the other narrowed, as shown in Fig. 205. In the V weld one piece is pointed and the other is made with a V-shaped slit, into which the point

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* Howe, "Steel," page 251.

goes. In the jump or butt weld the two flat surfaces at right angles to the bar are united, and in the split weld the pieces are made to overlap. Many other forms are used for special purposes.

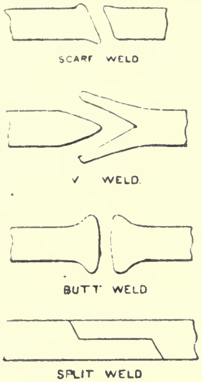

Fig. 205.
Varieties of Weld.

It is sometimes contended that the weld is stronger than the metal itself, but this is certainly not the case, and rarely, if ever, is the weld as strong. When a welded piece breaks, it usually breaks, not at the weld, but near it, but this is due, not to the greater strength of the weld, but to the fact that the iron near the weld has been weakened by the heating. Where strength is required the welded piece should always be annealed.

Welding of Different Metals.—Different metals and different grades of steel and iron can rarely be welded satisfactorily, because the welding temperatures are so widely different.

Electric Welding.—Electricity has been applied to welding, and two processes are in use.

The Thomson Process.—The only function of the electric current in this process is to heat the piece. It depends on the fact that if an electric current be passed through a metallic rod heat is generated, and the heat varies with the resistance of the rod and the strength of the current. The welding is always of the character of a butt weld. The ends to be welded are made convex, and a little borax is put on them. Wires fron the dynamo are attached to the pieces near the point to be welded, and these are brought together. As the current passes the temperature rises, and the two pieces, being softened by the heat, are pressed together and united.

The heat is proportional to the square of the current strength, and not to the tension, so that a current of low voltage can be used. As the resistance to the current, on which the heating power depends, decreases with increase of the sectional area of the piece, a much more powerful current is required for large than for small pieces. Howe states : " It is estimated that a 1 in. round bar can be welded with 12 H.P., but slowly ; to weld it in from 25 to 30 seconds 18 to 20 H.P. should be provided ; to weld a 2 in. round bar in one minute 40 H.P. are needed, and, say, 20,000 amperes." In any case the potential will be low, from 1 to 5 volts.

The process is therefore only suitable for comparatively small articles. Wire rods, small tubes, &c., can be welded end on, and metals of very different character can be welded—iron to brass, for instance, though in this case it may, perhaps, rather be called a melting together. The weld seems to be as strong as the original metal, and different metals can be welded together.

The Bernardos Process.—In this process the heat is applied, not by the resistance of the piece to the passage of the current, but by the application of the electric arc. A carbon point not unlike that used for the arc electric lamps, carried on a suitable handle, is attached to the positive pole of the dynamo, whilst the article is attached to the negative pole. The heat of the arc is intense, and the metal is readily softened or melted. As the glare and heat is very intense, the workman must be protected by a screen.

This process is, obviously, only applicable in certain cases. It has been used for uniting plates. The edges are feathered, chips of the metal put between them and melted by the arc, thus uniting the plates. It is also used for repairs, filling in holes in castings, &c. If required, holes can be melted through metal plates. The current required has a much higher voltage than that for the Thomson process, up to 400 volts being used, and therefore is much more dangerous.

It has been stated that the metal becomes seriously deteriorated, tensile strength and ductility being lost, the metal being burned, and also that carbon may be taken up from the point used. This, however, does not seem always to be the case. Electric welding has, at present, only come into use for some few special purposes.

Oxy-Acetylene Welding.—The oxy-acetylene flame has been successfully used for welding, the flame is easily controlled, and a temperature of 3,500 deg. Cen. can be obtained. Both mild and high carbon steels, and even cast iron, have been successfully welded by it.

HARDENING AND TEMPERING.

When steel containing over ·5 per cent of carbon is heated to redness and suddenly cooled by quenching in oil, water, or mercury, it becomes intensely hard. The hardness acquired depends on the amount of carbon present in the metal, and on the rate of cooling, or rather the rate of cooling over a certain critical temperature. Mercury produces the most rapid cooling, and therefore the greatest hardness, provided the quantity of mercury be sufficient, because mercury is a very good conductor of heat; water stands next, because, though not a conductor of heat, it has a very high specific heat, and is very mobile, so that the heat is carried away by convection, whilst oil stands last. Experiments with alcohol indicate that it cools more rapidly even than mercury. The less rapid the cooling the less the hardening, and therefore, the tougher will be the resulting metal. In practice, water is almost invariably used, the article being either dipped into the water or sprayed. The sudden cooling not only hardens the metal, as tested by its power of resisting abrasion, but it also increases the tensile strength, and this increased tensile strength can be detected in cases where the carbon is so low that there is no sensible hardening. The elastic limit is increased and the ductility and specific gravity are decreased.

Great care must be taken in quenching that the rapid cooling does not produce distortion or even fracture. In practice this is done by dipping the article in such a way as to ensure as uniform cooling as may be, or, in special cases, other precautions may be taken.

Tempering.—The hardened article is usually too hard and brittle for use, and the hardness is reduced by tempering. This consists in heating the article to a temperature far lower than that to which it was heated before quenching, and then cooling it usually by plunging it in water. The sudden quenching has retained a condition of things which existed at a high temperature, and, by gentle heating, a temperature is attained at which there is a certain molecular freedom ; rearrangement can to a certain extent take place, and thus the hardening may be to a certain extent destroyed. The higher the tempering temperature the more hardness is removed and the softer the metal becomes. It need hardly be said that for any purpose a steel of suitable composition must be selected, as it would be impossible otherwise to obtain the required properties.

The efficiency of tempering depends mainly on the accurate adjustment of the temperature to which the piece is heated, and as the process was in use long before there were accurate instruments to measure the temperature, some method of hitting the point with sufficient accuracy had to be found. Three methods are used—

(1) When the metal is heated in an oxidising flame it becomes covered with a film of oxide ; this film is very thin and transparent, and gives by interference a series of colours which change as the thickness of the film increases, from pale yellow to dark blue. The skilled workman, always working under suitable and similar conditions, can judge when the right temperature is attained. This is, however, a matter of skill and practice, since too long an exposure to a low temperature would give the same colour as shorter exposure to a higher temperature.

(2) The article is heated in an oil bath, the temperature being judged by the appearance of the oil.

(3) The article may be heated in a bath of an alloy of known melting point.

The first method is almost always used. Howe* gives a table (shown on page 448) of tempering colours with the corresponding temperatures.

Many attempts have been made to devise methods by which the metal could be obtained of the required hardness at one operation, and thus the tempering dispensed with, but they have not been attended with great success.

The details of working must necessarily vary with the form and size of the article being treated.

The theory of hardening and tempering will be discussed later.

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* "Steel," page 23 (slightly abridged).

HOWE'S TABLE OF TEMPERING COLOURS WITH THE CORRESPONDING TEMPERATURE.

Oxide Tint.	Temperature.		Uses of the Steel.	Per cent of Carbon or Steel for which the Temperature is Used.
	C°	F°		
White	..	..	Tungsten steel.............. HARDEST.	Tungsten steel.
Pale yellow	220	428	Lancets	
Straw	230	446	Razors, surgical instruments, taps, dies, &c.............	1·5
Golden yellow .	243	469	Razors, penknives, hammers, taps, reamers, and dies, cold chisels for cutting steel .	1·3
Brown	225	491	Cold chisels, shears, scissors, hatchets	
Brown, dappled with purple ..	265	509	Axes, planes, lathe tools for copper	
Purple	277	531	Table knives, large shears, wood turning and cutting tools, cold chisels for soft cast iron	
Violet	..	..	Cold chisels for brass	0·9
Bright blue ...	288	550	Swords, coiled springs	
Full blue	293	559	Fine saws, augers...........	
Dark blue	316	600	Hand and pit saws, cold chisels for wrought and copper	0·8
Just visibly red in the dark ..			Spiral springs, clockmakers' purposes .... SOFTEST.	

CHAPTER XL.

ALLOY STEELS.

When any other metal is added to molten iron containing a small quantity of carbon—such as mild steel—the name steel is still retained for the alloy, the name of the added metal being prefixed. As the addition of small quantities of some metals largely modifies the quality of the steel, and improves it for some purposes, these alloys are now made in considerable quantity.

The Literature of these steels is now very extensive; only the barest outline of their properties is given here. The student desiring fuller information must refer to the original papers.

Nickel Steel.

This is probably the most valuable of the iron alloys. It was first described by James Riley in a paper read before the Iron and Steel Institute in 1889. Iron and nickel alloy quite readily, and a natural alloy occurs in meteoric iron, which almost invariably contains a considerable quantity of nickel, varying from 2 to 14 per cent.

Preparation.—Nickel has such a high melting point that it cannot be added to the steel in the ladle. The metallic nickel is therefore added to the molten metal in the open-hearth furnace, or mixed with the steel and melted in crucibles, and where great uniformity is required the metal made in the open-hearth furnace may be remelted in crucibles. It has been suggested to add nickel oxide to the open-hearth charge, so as to avoid the necessity for the separate reduction of the nickel, but this involves considerable loss of nickel, and is unadvisable. The nickel may be alloyed with iron in the electric furnace, and then the alloy added to the steel.

Properties.—Nickel very considerably modifies the properties of steel. The table shown on next page, from a paper by Mr. Hadfield,* will indicate the nature of the influence. It will be seen that up to about 20 per cent of nickel, and this range includes all the alloys used in the arts, the tensile strength increases with the increased percentage of nickel, a steel with ·27 per cent of nickel

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* Proceedings of the Institution of Civil Engineers, cxxxviii., page 12.

having a tensile strength of 31 tons; and with 11·39 per cent a tensile strength of 65 tons. The elastic limit is also increased,* and the elastic limit increases more rapidly than the ultimate strength, so that the ratio of elastic strength to ultimate strength increases. "Tests made by Mr. Colby show that in forgings of mild steel, annealed, the ratio between elastic limit and ultimate strength is 44, in medium hard steel annealed 46·2, and in medium hard nickel steel 58·7 per cent." The elastic limit is usually taken as being, in mild steel, about 50 per cent of the ultimate strength, and Mr. Beardmore states that it may be 63 to 74 per cent in a 3 per cent nickel steel.

Analysis.		Unannealed. Load in Tons per Square Inch.				Annealed. Load in Tons per Square Inch.			
C.	Ni.	Elastic Limit.	Breaking Load.	Elongation.	Reduction of Area.	Elastic Limit.	Breaking Load.	Elongation.	Reduction of Area.
·19	·27	19	31	35	56	20	28	37	52
·14	·51	20	30	36	62	21	27	41	63
·13	·95	25	33	31	53	20	27	41	63
·14	1·92	26	34	33	55	22	31	36	53
·19	3·82	28	37	30	54	25	33	35	55
·18	5·81	28	41	27	40	28	37	33	51
·17	7·65	31	49	26	42	30	45	26	41
·16	9·51	42	85	9	18	32	56	2	2
·18	11·39	65	94	12	24	45	89	12	26
·23	15·48	55	94	3	2	..	68	1	1
·19	19·64	47	91	7	6	45	87	5	4
·16	24·51	32	77	13	14	25	78	14	8
·14	29·07	25	38	33	44	16	37	48	51
·16	49·65	No	test	made	..	15	36	49	53

As tensile strength increases elongation diminishes, but the diminution is not serious till the percentage of nickel becomes considerable, and the reduction of area is also necessarily diminished. In this respect, therefore, nickel acts in the same direction as carbon; but the reduction of elongation is less when the increased strength

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* By elastic limit in the table is understood the point at which stress and strain cease to be proportional.

is produced by nickel than when it is the result of increased carbon. In illustration of this, the following figures are given by Mr. Browne :—

C Per Cent.	Ni. Per Cent.	Elastic Limit. lbs. per sq. in.	Ultimate Strength. lbs. per sq. in.	Elongation.	Reduction of Area.
·20	3·5	45,000	85,000	26	50
·40	None.	43,000	85,000	25	40

It will be seen that 3·5 per cent of nickel has about the same effect on tensile strength as ·2 per cent of carbon, but that the elastic limit and the ductility are somewhat higher.

Another character of great value in nickel steel is what may be called its high vibrating strength, that is, the power of resisting a large number of small stresses each well within the actual breaking strength. Mr. Browne* states that under conditions where a piece of mild steel, suitably annealed and loaded, will stand 100,000 applications of the pressure without rupture, a similar bar of nickel steel with 5 per cent nickel will stand about 1,000,000.

Nickel steel is more rigid and tough than ordinary carbon steel. "Under impact tests, in which a heavy weight is allowed to fall upon a steel bar supported at its extremities, nickel steel with about 3 per cent of nickel shows 48 per cent greater stiffness and 45 per cent greater toughness than carbon steel. The word stiffness refers here to amount of deflection produced by the blow, while the word toughness refers to the number of blows required to produce rupture."† When the quantity of nickel is large the compressive strength is greatly increased, and the shearing strength is also increased.

The influence of the nickel seems not to be much affected by the percentage of carbon where this is low, but is greater in high carbon than in low carbon steels.

Heat Treatment.—Nickel alone, *i.e.*, in the absence of carbon, imparts to steel the power of hardening and acquiring increased strength on quenching, and in carbon steels nickel increases this power.

Nickel steels do not weld well, except when the percentage of nickel is low.

When nickel steel is cooled there seems to be only one point of

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* Transactions American Inst. Mining Engineers. Vol. xxix.

† Browne loc. cit.

recalescence, and this is at a considerably lower temperature than in the case of ordinary carbon steel. The annealing temperature of nickel steel is, therefore, lower than that of ordinary steel, and it hardens when quenched from a lower temperature.

When the percentage of metal reaches about 10 per cent, the metal is no longer hardened by quenching ; indeed, with between 10 and 20 per cent, neither quenching nor annealing seems to have any effect, but when the percentage rises above 20, quenching distinctly softens the metal.

Segregation.—Nickel tends to prevent segregation in steel, and therefore nickel steels have a very fine grain, this effect being, perhaps, due to the formation of double carbides of high melting point. Nickel does not prevent the formation of blowholes, and and these if once formed are not readily welded up on rolling. A small quantity of nickel, say 1 per cent, does not seem to diminish the welding power of the steel, but any increase acts deleteriously, and with above 3 per cent the metal will not weld.

Magnetic Properties.—The magnetic properties of nickel steel are peculiar. A steel with 25 per cent of nickel shows no magnetic properties till cooled to—40 deg. Cen. ; then it remains magnetic as the temperature rises ; but the magnetic power is destroyed at 600 deg. Cen. This phenomena is known as non-reversible transformation, and is shown to some extent by all nickel steels. It may be defined as the capacity for existing at ordinary temperature in two distinct forms, characterised by the presence or absence of magnetic properties. Chromium lowers the temperature at which the change takes place. The whole of the properties vary with this change in magnetic condition. The magnetic steel elongates comparatively little, and only shows deformation near the fracture, the remainder of the bar remaining smooth and bright, but it has the higher tensile strength ; the non-magnetic steel elongates over its whole length, and elongates more than the non-magnetic form. This is shown by the following table :—

State.	Analysis per cent.				Tons per sq. in.		Per cent.	
	C.	Mn.	Cr.	N.	Tensile Strength	Elastic Limit.	Elongation.	Contraction of Area.
Magnetic	·16	·13	..	15·92	56·5	48·5	19	54·5
Non-magnetic	·53	·83	302	16·05	49·	21	23	68·0

Nickel steels containing more than 25 per cent of nickel are magnetic but lose this magnetism on heating ; as, however, they recover it on cooling over the critical temperature, this change is reversible, the maximum effect being obtained with a 36 per cent nickel steel. When a 36 per cent nickel steel has undergone this reversible transformation, it acquires the property of not being changed in volume by change of temperature, so that such an alloy is of value in making articles that have to be subjected to changes of temperature, where change of volume is objectable.

The expansion of 18 per cent nickel steel is abnormal. On cooling a bar from 200 deg. Cen. it contracts uniformly till the temperature falls to 130 deg. Cen. Then it expands whilst the temperature is falling to 60 deg. Cen., when contraction is again resumed as the temperature falls. If the bar be now heated to about 130 deg., it will expand normally, and contract on cooling to 100 deg., when it begins to expand till 60 deg. is reached.

Condition of Nickel in the Steel.—With low carbon steels nickel "seems to form a homogeneous alloy, much tougher and stronger than either pure nickel or pure iron. When the quantity of carbon is larger, the influence seems to be partly direct and partly indirect, owing to a tendency to convert the carbon into the hardening condition, or in the presence of very large quantities into the condition of graphite."

Corrosion of Nickel Steel.—One of the claims that has been made for nickel steel is its power of resisting atmospheric corrosion. An alloy of iron with 18 per cent of nickel is said to be practically incorrodible. With less nickel corrosion goes on, but less readily than is the case with ordinary steels, but if the amount of nickel is less than 4 per cent the difference is not very marked.

Electric Properties.—Nickel steel has a high electric resistance. With 1·92 per cent of nickel the conductivity is given by Mr. Hadfield as being 8 per cent, and with 24·51 per cent about 3 per cent that of copper.

Uses of Nickel Steel.—Nickel steel has been used for various purposes—boilers, shafting, general forgings, railway axles, and tyres, structural beams, hydraulic cylinders, piston rods for steam hammers, and it is being largely adopted for armour-plates, it being generally recognised that it is superior to ordinary carbon steel for this purpose on account of high tensile strength and great hardness. A ·8 carbon steel with 3 to 5 per cent nickel is an admirable tool steel, and an alloy with 36 per cent of nickel is replacing German silver for many purposes. Steels low in nickel ($1\frac{1}{2}$ to 2 per cent) and with little carbon (·1–·15 per cent) are largely used for cranks, &c., in motor cars, and generally where high resistance to shock is required.

MANGANESE STEEL.

Manganese is always present in steel in small quantity, and seems to have little influence when under 1 per cent.

As the quantity of manganese is increased, the metal becomes hard, till, with 5 or 6 per cent, it is very hard, and brittle enough to be pounded. As the percentage of manganese is increased to from 8 to 15 per cent, an alloy of remarkable properties, called manganese steel, is obtained.

Preparation.—Manganese steel is made by the addition of ferro-manganese to steel in the open-hearth furnace in the usual way. As it is important to keep the carbon as low as possible, the richest ferro-manganese obtainable should be used, and this is usually prepared in the electric furnace. Manganese steel cannot well be made in crucibles, as the metal takes up carbon from the graphite.

Properties.—When the manganese is between 2·5 per cent and 7·5 per cent, the metal is excessively brittle in the cast condition, and it is so hard that it is impossible to turn it. The most brittle alloy is that containing about 5 per cent. Mr. Hadfield says: "Another singular point to be borne in mind is that the carbon in such brittle samples is not more than about 0·3 per cent or 0·4 per cent, or very little more than in mild steel; in fact, it has been noticed that the more purely the alloy consists of iron (Fe) and manganese (Mn) the more brittle is the product. It is apparently as hard as dead-hardened steel, and no tool of any kind will touch or face it in the slightest degree."*

It is highly crystalline in structure. When hammered or forged it is increased in strength, and remains too brittle to be of any commercial use, but attempts have been made, with some success, to make turning tools of it.

"Under the Hadfield patents, Messrs. Miller, Metcalf, and Parkin, of Pittsburg, U.S.A., have experimented with this self-hardening manganese steel, obtaining good results, against other steels, for nailers' knives, dies, and other purposes. The best results were secured by forging the bars at a yellow heat and grinding the tools dry, as if ground wet the edges were liable to split. The Americal steel, however, differs from that made in Sheffield, being not only high in manganese, but containing as much as 2·75 per cent of carbon."†

When the manganese exceeds 7·5 per cent the properties of the alloy are very different. In the cast condition it is very hard, and so tough that it can be used for tools. Mr. Hadfield calls the hardness peculiar, and says it is difficult to describe. The metal is hard (14 per cent Mn), so hard that it can only be drilled with extreme difficulty, has a tensile strength of about 67 tons, elongation 44·5 per cent before fracture, therefore it is ductile, and it can be indented by a blow with an ordinary hammer.

The alloy can be forged, but care must be taken not to overheat.

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* Proc. Inst. C.E., xciii., p. 10. † Hadfield loc. cit.

The following table, abridged from Mr. Hadfield's paper, will give an idea of the properties of forged manganese steel :—

		(1) Natural State.		(2) Air Toughened.		(3) Water Toughened.	
C Per Cent	Mn Per Cent.	T. S. Pounds per Square Inch.	Elongation on 8in.	T. S. Pounds per Square Inch.	Elongation on 8in.	T. S. Pounds per Square Inch.	Elongation on 8in.
·20	·83	73,920	31	..	..	..	..
·40	2·30	125,440	6	..	..	..	..
·52	6·95	56,000	2	47,040	2	51,520	2
..	7·50	87,360	4	..	..	..	..
·95	10·11	85,120	5	87,360	14	..	..
1·10	12·60	87,360	2	82,880	11	120,960	27
·92	12·81	87,360	5	107,520	20	136.640	37
·85	14·01	80,640	2	107,520	14	150,080	44
1·24	15·06	109,760	2	105,280	2	136,640	31
2·10	21·69	80,640	9	76,160	12	..	..

(1) The metal simply cooled after forging. (2) After cooling the metal was reheated to a yellow heat, and then let cool slowly in air. (3) After forging it was slowly cooled, then heated to a yellow heat and quenched in water.

The limit of elasticity is very low, as the metal begins to take a permanent set with a stress of about 35,000 lbs., its ultimate tensile strength being 125,000 lbs., so that the ratio is only about 28 per cent, though in many cases it is higher, and may reach 50 per cent. The high extension is somewhat deceptive, as the bar in testing behaves very differently from a bar of ordinary steel, stretching almost uniformly over the entire length instead of contracting only at one point.

Heat Treatment.—The metal is made very brittle by work, but its ductility is restored by annealing and quenching. It is made tough and strong by cooling from whiteness. With steels of about 14 per cent manganese the ductility and strength are increased by heating to whiteness and slow cooling, but very much more by quenching in water or oil, its behaviour being, therefore, very unlike that of carbon steel. Small pieces do not crack on sudden cooling. Forging is said to reduce the strength of the metal ; but

Howe says : " Mr. Hadfield informs me that his experience indicates that it is not the forging that injures the metal so much, but the slow cooling which habitually follows forging. The injury due to slow cooling may, however, be removed by again quenching from whiteness. Still, the matter is obscure."* Microscopic investigation shows that the manganese retains the iron in the gamma condition.

Manganese steel casts well, shrinks much, and pipes, but does not form blowholes. On cooling, the cooling is continuous, there being no point of recalescence.

Electric and Magnetic Properties.—The electric resistance is very high, and it is almost, if not quite, unmagnetisable.

Uses.—Manganese steel is likely to be used only for purposes where great hardness is required, such as car wheels, the wearing parts of crushing and grinding machines, &c., or where high electric resistance is required, as in wires for resistance coils.

Chrome Steel.

Alloys of iron or chromium are not easily prepared, but those containing over 60 per cent of chromium are made in the electric furnace, up to that they may be made by reducing chrome-iron ore in crucibles with charcoal and suitable fluxes, and with 30 or 40 per cent of chromium they are now made in the blast furnace.

Chrome steel is made by melting mild steel in crucibles with rich ferro-chrome, but the refractoriness of the ferro-chrome makes the process difficult. It may also be made in the basic open-hearth furnace, the steel being reduced to the required carbon content, and ferro-chrome then added, allowing for about 20 per cent loss of chromium, and no ferro-manganese being used.

The steels made contain 2 per cent of chromium or under, but chromium can alloy in all proportions with iron. With low carbon the metal is forgable even when it contains as much as 12 per cent of chromium.

The tensile strength rises with increase in the percentage of chromium till with about 5 per cent it is about 74 tons unannealed, or 55 tons annealed, the elongation being 13 per cent in the latter and 8 per cent in the former case. The limit of elasticity was 40 tons in the first, and 20 tons in the second case. As the quantity of chromium is increased the metal becomes harder, and with about 9 per cent can hardly be touched with the file. In the absence of carbon its hardening influence is not so marked, so that it may harden the metal indirectly by its influence on the form in which the carbon is present. Forging makes the metal hard and brittle, but the latter property is removed by annealing, and it is rendered excessively hard by quenching. It has a high resistance to shock, and is therefore suitable for the manufacture of armour plates, projectiles, &c.

Low carbon chrome steels with up to ·12 per cent of carbon can be forged, but as the carbon increases forging makes the metal hard and brittle.

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* "Steel," p. 633.

M. Osmond comes to the conclusion that chromium can exist in iron in three states :—

"(1) In the state of dissolved chromium.

"(2) In the state of a compound of chromium iron and carbon in the form of isolated globules.

"(3) Also in the same condition in the form of a solidified solution.

"The triple compound in the form of isolated globules is very hard. When incorporated with the more malleable matrix it naturally communicates to it a certain degree of hardness, combined with the relative plasticity of the metal itself. The same compound dissolved owing to the introduction of carbon into the molecule . . . hindering the molecular transformation of the iron, and maintaining the metal in the condition of β, from which results the general or partial hardness of the whole."*

Chrome steel is being largely used for purposes where hardness is desirable, such as dies and shoes for stamp milling, tools, &c., and with 1·5 to 2 per cent of chromium and 1 per cent of carbon it can be used for tools where great hardness is required.

SILICON STEEL.

Silicon combines readily with iron, and silica is always reduced in the blast furnace, the silicon passing into the pig iron. It is, however, completely removed during the conversion of the iron into steel.

The effect of silicon is to harden the metal, but to a far less extent than carbon ; and silicon does not give the property of water hardening, which is the characteristic of carbon steels.

Silicon steel is made by melting the steel either in crucibles or in the open-hearth furnace and adding silicon-iron. It casts well, contracts on casting, and pipes, and when the silicon reaches 2½ per cent has a largely crystalline structure, and with up to 5 per cent of silicon the metal forges well.

As the silicon is increased, the carbon remaining low, the tensile strength increases from about 33 tons (2·4 per cent Si) to about 49 tons (4·49 per cent Si), the extension falling from about 16 per cent to almost nil, the limit of elasticity rising from 22 tons to 45 tons. With up to 2 per cent of silicon, the metal does not harden on being quenched, with higher percentages some stiffening, but no true hardening takes place.

"Silicon steel has a certain kind or degree of softness, or lack of body, compared with carbon steel, which is especially brought out in the compression tests, where one sample, 'although apparently very hard and brittle, crushed up to 38 per cent of its length under a compression load of 100 tons per square inch. A corresponding hard temper of carbon or tungsten steel would not shorten more than 20 per cent, or if hardened would remain unaltered. A very mild steel, containing not more than ·20 per cent of carbon, would

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* J. I. & S. I., 1892, Vol. 2, page 127.

not shorten much more than this sample, containing over 2½ per cent of silicon.' "*

Silicon is often added to steel for wire drawing, but the principal use of silicon steels with about 1·5 per cent Si and ·5 per cent C, is for springs and motor gearing. It requires extremely delicate heat treatment.

ALUMINIUM STEEL.

Aluminium is added to steel to quiet it, but only a trace remains in the metal. When a larger quantity is added it seems to slightly increase the tensile strength and elastic limit, but reduces the extension and contraction of area, the effect being the more marked the higher the carbon.

TUNGSTEN STEEL.

Tungsten may be combined with iron in all proportions. Tungsten steel is always made in the crucible, ferro-tungsten or the pure metal being added to the molten steel.

The principal effect of tungsten on the metal is to make it intensely hard. Howe speaks of one sample containing 7·81 per cent of tungsten as being the hardest he has met with, indenting hardened chrome steel and scratching glass readily. Steels containing tungsten are not softened by slow cooling or hardened by quenching, whence they are called self-hardening steels. Many such steels are made. Howe gives the following analyses :—

	W.	C.	Si.	Mn.	P.	Tensile Strength Pounds per Square Inch.
(1) Mushet special	9·99	1·24	·33	1·04	·04	..
(2) .. ,, ...	7·81	1·99	·09	·19	..	146,400
(3) Crescent (Pittsburg) ...	6·73	2·06	·05	2·06	..	76,100† 94,000‡
(4) Imperial ,, ..	6·38	1·6	·16	2·11	..	..
(5) Styrian	6·45	1·20	·21	·35	..	190,000

There was no elongation except in No. 5, which gave ·75 per cent.

Tungsten steel can be forged at a suitable temperature (between cherry-red and low yellow), but then only with difficulty. Some makes are said to be weldable. It is very retentive of magnetism.

The annealing of tungsten steel considerably increases both its elongation and contraction, and with 3·5 per cent of tungsten an elongation of 34 per cent and a reduction of 53 per cent has been obtained, but with higher tungsten the ductility especially decreases.

The fracture of tungsten steels is peculiar. With between

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* Hadfield, J. I. & S. I., 1889, 2—235.

† As received from the maker. ‡ Quenched in oil from dull redness.

1·5 and 2 per cent of tungsten the grain is extremely close, but not silky, unless the carbon exceeds 1·25 per cent.

Tungsten steels containing high carbon, have a high magnetic retentivity and an alloy with ·62 per cent carbon, ·55 per cent manganese and 5 per cent tungsten is suitable for the manufacture of permanent magnets. The highest magnetic power and greatest retentivity is reached when the tungsten is between 4 and 7 per cent, but low carbon steels, whatever the amount of tungsten they contain, do not show great retentivity.

Molybdenum Steel.

Like tungsten, molybdenum imparts the property of red-hardness to steel, but it requires less to do so, only about 4 per cent being sufficient with medium carbon, although the best high-speed cutting results are obtained with about 10 per cent of molybdenum. This element forms a soft and brittle carbide which renders the tool useless, unless it is raised to a high temperature (above 1,200 deg. Cen.) to destroy this carbide and leave the steel in the Austenitic condition. Difficulties with the heat-treatment have now been overcome, but molybdenum steels are not so commonly used as those containing tungsten.

Vanadium Steel.

Ferro vanadium prepared in the electric furnace is added to steel usually containing about 1 per cent of carbon.

Guillet classifies vanadium steels into three groups :—*

(1) Vanadium up to 1 per cent. The tensile strength and elastic limit increase with the percentage of vanadium, with an elongation, or contraction, of area higher than in steels of the same carbon content, but with no vanadium. These alloys are very hard, but are not more brittle than the corresponding steel free from vanadium ; they have a very high resistance to shock and to alternating stresses, and have an extraordinary normal strength.

(2) Vanadium from 1 to 3 per cent. Tensile strength and elastic limit diminish as vanadium increases, the elongation and contraction both remaining high. These alloys are not more brittle than carbon steel, but are not so hard as those of the first series. Quenching has less and less effect as the percentage of vanadium increases.

(3) Vanadium over 3 per cent. These steels have a low tensile strength and elastic limit, which remain practically constant as the vanadium is increased. The elongation and contraction of area are high, but the steels are brittle. They are not very hard. The fracture often shows large crystals. Quenching produces little change. Apparently, in these steels, the carbon is all present, as a hard, double carbide of iron and vanadium.

All vanadium steels are hardened by quenching ; but if the heating be continued long enough to cause the separation of graphite, the steels become very brittle.

The only vanadium steel in use commonly is that containing

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* Journal I. and S. I., vol. iii., 1905.

about ·7 per cent of vanadium, and this is used in the motor car industry for shafts, cranks, and parts to stand high alternating stresses.

TABLE OF MECHANICAL TESTS MADE WITH VANADIUM STEELS.

Analysis.		Normal.*				Quenched.				Annealed.			
Per cent.		Tons per sq. in.		Per cent		Tons per sq. in.		Per cent.		Tons per sq. in.		Per cent.	
C.	V.	T.S.	E.L.	Σ	C.	T.S.	E.L.	Σ	C.	T.S.	E.L.	Σ	C.
·11	·29	28	19	24	63	34½	31	23	67	26½	18	22	58
·13	·60	31½	26	20	69	43½	26½	20	63	..	..	..	..
·14	·75	37	27½	16	58	46½	31	18	61	33	26½	13	53
·11	1·04	39	29	15	71	61	39	12	60	..	..	..	..
·13	1·54	36	28½	19	73	39	33	14	67	35	28½	16	63
·20	2·12	32	25	15	68	35	26½	12	60	..	..	..	..
·19	2·98	30	17	26	74	29	18½	21	61	..	..	..	..
·38	5·37	29½	16	17	61	28	16½	27	58	27½	15½	13	58
·13	7·34	28	16	30	63	27	16½	30	65	..	..	..	..
·12	10·27	29½	16	31	53	30	16½	22	56	..	..	..	..
·82	·25	56	28	8	20	73½	67	6	12	54½	28	6	19
·73	·60	58	30	8	22	75	70	9	20	56	30½	7	19
·89	·80	61	36	4	19	83	72½	3	10	..	..	..	..
·67	1·15	55½	37	8	26	76½	65	5	6½	53½	36	8	25
·62	1·58	60	42	9	31	72½	65	13	13	..	..	..	..
·95	2·89	58	30½	9	34	70	47	11½	18½	..	..	..	..
·67	3·06	54	37	16	29	63	43	3	6½	52½	34½	10	22
1·08	4·99	63	35	14	25	65½	37	11	41	..	..	..	..
·74	7·85	32½	18½	20	34	29	22½	27½	41	31½	18½	15	34
·89	10·25	40	20	12	38	37	27	17½	33	..	..	..	..

* The normal steels were heated to 700 deg. C., and slowly cooled.

T.S., Tensile Strength; E.L., Elastic Limit; Σ., Elongation on 100 parts; C.=Contraction, *i.e.*, percentage reduction of area on ·3 sq. in.

Quaternary Steels.

These special steels contain two chief elements in addition to the iron and carbon present, and have lately come much into vogue for engineering and tool making purposes.

Chrome-nickel steels are largely used in the motor car industry, and shafts and journals are often made with medium carbon, 5 per cent nickel and about 1 per cent of chromium. Quenching raises their elastic limit to nearly 70 tons (about 85 per cent of the tensile strength), and their mechanical properties are much ameliorated by quenching in air from 850 deg. Cen. Krupp armour plate offering high resistance to shock, contains low (·25 per cent) carbon, 1·5 per cent chromium, and 3·25 per cent of nickel. Rock-drills and crushing machinery jaws and dies are now often made of this material.

Chrome-tungsten steels are largely used for high-speed cutting tools, of which the edge is not destroyed by working at a red heat. Tungsten imparts the property of red-hardness, and chromium adds to the tensile strength, and allows the steel to be forged readily. With only medium carbon content, the highest efficiency of cutting is got with tungsten between 6·5 and 8·75 per cent, when associated with about 5·0 or 6 per cent of chromium, but different makers vary the composition within fairly wide limits, *e.g.*, carbon ·3 to ·6 per cent; tungsten, 6 to 12 per cent, and chromium, 3 to 6 per cent. These steels are not so sensitive to variation in the heat-treatment as most of the other high-speeds steels, and it suffices to quench them from a lower temperature, say 1,250 deg. Cen., in a bath of molten lead at 800 deg. Cen., and then dip into oil to complete the cooling. The subsequent annealing at 800 deg. Cen. requires to be carefully done.

Chrome-vanadium steels have been much used for axles, springs, gearing, and parts which have to resist torsion and alternating stresses. With medium carbon, and low chromium (1 per cent) and vanadium less than ·2 per cent, a very high yield point (about 70 to 80 per cent of the ultimate strength, which varies from 50 to 60 tons per square inch) can be attained, by quenching in oil from about 950 deg. Cen., and then tempering for a time in a lead bath at 500 deg. Cen.

Vanadium, if less than 1 per cent, increases the strength of the pearlitic nickel steels, *i.e.*, those containing under 10 per cent of nickel with low carbon, and 5 per cent or less with high carbon. The vanadium nickel steels are less sensitive to heat-treatment and mechanical work than the pure vanadium steels; Guillet reports both manganese and silicon steels to be improved by vanadium. For high-speed steels, vanadium has also been added to chrome-tungsten and chrome-molybdenum steels with advantage, and sometimes both molybdenum and tungsten are used in conjunction with chromium to produce tool steel for making very heavy cuts.

Most valuable information upon the properties of these steels is contained in the several volumes of the *Iron and Steel Institute* for 1905 and 1906.

CHAPTER XLI.

TESTING IRON AND STEEL.

The purposes for which iron and steel may be used are so many, and the qualities required for various purposes are so different, that it has become customary to specify certain properties in the metal, these to be determined by suitable tests. The tests will necessarily vary with the purpose for which the metal is to be used.

The following tests may be required :—

(1) Tensile strength.
(2) Compressive or crushing strength.
(3) Transverse strength.
(4) Hardness.
(5) Torsional strength.
(6) Impact tests.
(7) Cold working.
(8) Hot working.

Of these, the first is the most generally used, and is therefore the most important.

Tensile Strength.—A test piece is prepared of suitable form and size. This is fixed by the two ends in a testing machine, and the ends are pulled apart until the piece breaks. The force required to produce the fracture is the breaking weight of the sample, and this, calculated to one square inch of section, gives the ultimate breaking or tensile strength of the metal.

The Test Piece.—The test piece must be cut from the plate or turned down from the bar to the required size, and, of course, must not receive any hammering, rolling, annealing, or other work that is not put on the whole sheet or bar.

The test piece may be rectangular or circular in section, the former being general for plate tests, and the latter for bars, In the case of plate tests, the piece is the thickness of the plate, and of such width as to give the required area, usually from ·5 to 1 square inch. In the case of rod the diameter is usually from ·75 in. to 1 in. About half a square inch is a convenient area, though 1 square inch is often used. The test piece should be as long as is convenient, the usual length in this country being 8 in. or 10 in. between the shoulders. If a short test piece is used, it should be cut straight without shoulders.

The actual length of the test piece is important; and as the tests can only be regarded as being comparative—*i.e.*, as giving the strength and elongation under the conditions of the tests—the test pieces should always be of the same size and form. The length of the test piece has but little influence on the ultimate tensile strength, but considerable on the amount of elongation which takes place before fracture, which is always stated as a percentage of the original length of the test piece. It is essential that the sides of the test piece should be parallel for the whole length between the shoulders. Any irregularity fixes a weakest spot, and there fracture will take place. If a groove be cut round the test piece, the area being taken at the bottom of the groove, the tensile strength found will be too high. The form of test piece usually used for testing steel plates in this country is shown in Fig. 206. For rods or bars the test pieces are similar, but are round or square.

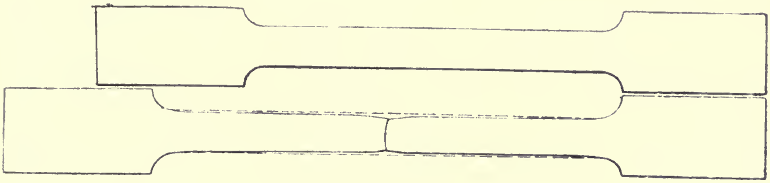

FIG. 206.—Test Piece, before and after Fracture.

Behaviour of the Test Piece in the Machine.—Two dots are punched on the face of the test piece 10 in. (or 8 in.) apart just below the shoulder, and the piece is firmly fixed in the grips of the machine. As pressure is applied it produces a stress in the metal, the stress being the resistance set up within the metal, which will be equal to the pressure or force registered by the testing machine; and at the same time a stretch or strain is produced, the metal elongating somewhat. The stress is measured in pounds or tons on the square inch of section; the strain is measured in inches, or rather in fractions of an inch.

As pressure is put on the test piece elongates more and more, the strain or elongation being proportional to the stress, *i.e.*, double stress produces double strain.

Taking a bar of mild steel 10 in. long and 1 square inch in section, a stress of one ton will produce a strain of about ·00075 of an inch. If the bar could continue to stretch uniformly as the stress was increased till it had doubled its length, the stress applied would be about 13,300 tons, or 30,000,000 lbs. This number is called the modulus of elasticity, or Young's modulus. It need hardly be said that no bar of metal can be stretched to double its length without fracture, but the number is a convenient expression for the extensibility of a metal within the limit of elasticity.

If p = the stress per square inch, e the strain per inch of length, and E the modulus of elasticity, then $E = \frac{p}{e}$.

As the weight on the machine is increased, a point is reached when the stress and strain cease to be proportional, and at this point, on removing the load, the bar would not return to its original length, but would show a small, but decided, permanent set; this is the elastic limit, or limit of elasticity, of the metal. It is one of the most important points in the determination of the qualities of the metal, and therefore is one which always needs to be known.

As the pressure is increased, each addition increases the permanent set; and after a little the bar suddenly elongates, the elongation being so marked that the drop of the lever of the testing machine can be seen. This point is called the breaking-down point, or, better, the yield point, and it is very frequently confounded with the elastic limit, which is always lower. Indeed, "when elastic limit is specified to a steel manufacturer it is usually the yield point which is determined." The yield point is supposed to be due to the giving up of the additional resistance obtained by the molecules by the work put upon the metal.

As further pressure is put on the resistance to elongation increases, "the molecules begin to draw and elongate, but they still retain a firm grip of each other, any change of position being extremely slight." "A point is ultimately reached, however, at which the adhesion of the molecules is overcome, and they roll over each other as in a fluid, and local contraction begins. This point is termed the 'point of fluidity,' or, more simply, the fluid point."

At the fluid point the steel is at its greatest strength, as is shown by the fact that though the area is decreased by contraction the bar does not break. As the pressure continues the molecules still continue to roll over one another, the bar still further elongates, and ultimately breaks at the point of contraction. The softer and better the steel, the longer will the condition of flow continue, and the greater will be the contraction of area before fracture.

The elongation is usually measured, and is stated as a percentage of the length of the test piece; but as the elongation during the period of flow takes place mostly in the neighbourhood of the fracture, it is obvious that the longer the test piece the less will be the percentage of elongation; and it is not possible to calculate the percentage of elongation on a bar of given length from that of one of another length. It is obvious that test pieces of uniform length must always be used, and this length must be stated. Even then the results are only strictly comparative when the pieces break nearly in the middle.

The contraction of area is sometimes specified, but this is so difficult to measure accurately that the figures obtained are of little value. The points thus determined which are of value to the steel user as indicating the quality of the metal are :—

(1) The ultimate or statical breaking strength, that is, the weight per square inch of original section required to produce fracture.

(2) The yield point, which will be about 50 per cent of the ultimate breaking strength.

(3) The extension before rupture.

(4) The modulus of elasticity.

There are other points in the strength of steel to which attention may be called. If a bar of steel be fixed in a machine, and a weight be applied from time to time very rapidly, it is found that if the weight exceeds a certain amount, far below the ultimate breaking strength, the bar will ultimately break. Mr. A. Wohler has made many experiments on this subject, sometimes applying the stress as many as 130,000,000 times. "He concludes that iron or steel will bear an unlimited number of repetitions of stress alternately put on and removed if the maximum stress does not exceed one-half of the statical (ultimate) breaking strength. This is termed the primitive strength." If, however, the stresses be applied alternately in extension and compression, the pieces would break after a time with a considerably less stress. This he calls the vibrating strength, and it is about one-third of the ultimate breaking strength.

These results may be tabulated :

Ultimate breaking strength	S.
Primitive strength	$\frac{1}{2}$S.
Vibrating strength	$\frac{1}{3}$S.

The elastic limit in tension is also about half the ultimate strength. If a bar be stressed beyond its elastic limit in tension, its elastic limit in compression is reduced, and vice versâ. If a bar be repeatedly stressed in tension and then in compression, a point is ultimately reached when the elastic limit remains constant. At this point the elastic limit is about one-third of the ultimate breaking strength.

Compressive Strength.—When a piece of metal in the form of a cube of 1 in. side, or a cylinder 1 in. high, is put into the machine, and subjected to compression, it gradually yields, and for a time, if the pressure be removed, it will return to its original length. From the compression the modulus of elasticity in compression can be calculated, and this, in the case of steel, is the same as the modulus in extension. As the pressure is increased, the piece ultimately yields. If hard, it may break into fragments ; but if soft, as the fluid point is reached, it will spread out till the increased area can support the load. In such a case there can be no distinct strength in compression unless it be the fluid point, and no metal can have a compressive strength beyond that. In the case of steel, the fluid strength is about $1\frac{2}{7}$ the ultimate tensile strength.

Hardness.—The hardness is an important property which is not usually estimated directly. Mr. Brinell has, however, devised a method by which it can be practically tested.

By this method, a hardened steel ball is pressed into the smooth surface of the metal to be tested, so as to make an indentation the size of which can be measured.

For iron and steel, the pressure is applied for 15 to 30 seconds, and the hardness is obtained from a table, or may be calculated from the formula—

$$A = 2 \pi R \left\{ R - \sqrt{R^2 - \frac{D^2}{4}} \right\}$$

H = Hardness.
K = Pressure on ball in kilos.
A = Area of concavity.
R = Radius of ball in mm.
D = Diameter of depression in mm.
H = K/A.

The hardness is rapidly determined, and Mr. Brinell states that it is possible from it to arrive at a close approximation to the tensile strength.

Other Tests.—Of other tests but little need be said. As a rule they are strictly comparative, and vary widely with the purpose for which they are applied.

Bending Tests are frequently used, the bar or test piece being bent in some specified way without fracture, the nature of the bend depending on the character and form of the metal.

Dead-weight and Drop Tests are used for rails and similar articles. A rail is placed on bearings a suitable distance (often 3ft.) apart, and a weight of, say, 10 tons is suspended at the centre. It must not take a permanent set or show more than a specified deflection. Then a weight of about 10 cwt. is allowed to fall on to the centre of a rail from a given height. The amount of permanent set that may be produced is specified, and the number of blows that may be given before the rail breaks.

Hot Forge Tests are sometimes used, especially for malleable iron, the test being punched and forged at a red heat.*

Classification of Steel.

Steels are usually classified according to the purpose for which they are to be used. The chemical composition—at any rate, as far as the percentage of carbon—is often specified; also the tensile strength, percentage of elongation, and such other properties as may be thought necessary. In some cases, also, the process of manufacture is specified.

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* For further particulars see Skelton's "Economy of Iron and Steel."

The following classification, according to the percentage of carbon, gives the principal purposes for which the various grades of mild steel may be used :—

Carbon	·05 to ·07 per cent.	Wire rod for making wire for electric conductivity, &c.
,,	·09 to ·12 per cent.	Soft wire rod. Tin bar for the preparation of sheet iron for tin-plates, &c.
,,	·14 per cent.	Rivets.
,,	·13 to ·18 per cent.	Boiler-plate.
,,	·15 to ·17 ,,	Ship plate.
,,	·17 per cent.	Girders.
,,	·25 to ·3 per cent.	Axles (railway).
,,	·30 to ·50 ,,	Hard wire rod.
,,	·30 to ·40 ,,	Rails.
,,	·45 to ·5 ,,	Locomotive tyres.

These figures will be, of course, varied considerably under varying circumstances, and with the other constituents present in the metal, and are only given as being those most generally used.

The following examples of the tests required for special purposes will give an indication of the general practice :—

Admiralty Test for Ship Plates.

(1) Strips cut crosswise or lengthwise shall have an ultimate tensile strength of not less than 26 or exceeding 30 tons per square inch of section, with an elongation of 20 per cent in a length of 8 in.

(2) Strips cut crosswise or lengthwise $1\frac{1}{8}$ in. wide heated uniformly to a low cherry red and cooled in water about 80 deg. Fah., shall stand bending double in a press to a curve of which the curves' radius is $1\frac{1}{2}$ times the thickness of the steel tested.

The pieces of plate cut out for testing shall be of parallel width from end to end, or for at least 8 in. of length.

Lloyd's Register: Ship Plates.—Open-hearth steel only to be used. At least one tensile test shall be made from each charge, and when the quantity of material at the thickness tested exceeds 25 tons, a second tensile test will be required ; also additional tensile tests for every variation in thickness of $\frac{3}{20}$ ths of an inch in the plates or bars made from each charge. A temper bend test or a cold bend test is to be made from each plate or bar as rolled, and these bend tests shall be in about equal numbers from each charge ; but a cold bend test shall be made from all plates which are to be cold flanged.

(2) The tensile tests are to be made upon strips cut lengthwise or crosswise from the plate or bar. They are to be machined to a

parallel for a length, of at least 8 in., and are to have an ultimate tensile strength of not less than 28 tons and not more than 32 tons per square inch of section. The elongation is to be at least 20 per cent on 8 in., in samples $\frac{8}{20}$ths of an inch and above in thickness, and 16 per cent in samples below that thickness. Steel plates intended for cold flanging, if specially marked for identification, may be tested to within a minimum limit of 26 tons tensile strength per square inch. Steel angles, channels, and bulbs may have a maximum tensile strength of 33 tons per square inch of section.

(3) Bend tests to be made upon strips sheared lengthwise or crosswise of the plate or bar. The sharp fin caused by shearing may be removed for all cold bend tests and for temper tests on samples $\frac{10}{20}$ths of an inch in thickness and above. They must stand bending double round a curve of which the diameter is not more than three times the thickness of the strip.

(4) The cold bend tests are to be made from samples as sheared from the bar or plate without annealing.

(5) For the temper bends, the samples are to be heated to a low cherry red, and cooled in water at 82 deg. Fah.

Lloyd's Register: Boiler-plates.—Open-hearth steel only to be used. At least two tensile tests shall be made from each charge, and an additional tensile test for every variation in thickness of $\frac{1}{8}$ in. in the plates, angles, or tee bars, and of every variation of $\frac{1}{2}$ in. in the diameter of stay bars made from each charge. When plates are $1\frac{1}{2}$ in. thick, or above, a tensile and a cold bend test are to be made from each plate. A temper bend test is to be made from *each* plate or bar as rolled, and a cold bend test is to be made from each plate or bar tested for tension.

(2) The tensile tests are to be made upon strips cut lengthwise, or crosswise of the plate or bar. They are to be machined to a parallel width for a length of at least 8 in. The material of longitudinal stays and of plates intended for the cylindrical shells of boilers is to have an ultimate tensile strength of not less than 27 and not more than 32 tons per square inch of section. If the shell plates are to be flanged or welded, the ultimate strength is not to exceed 30 tons per square inch. That of screw stays and all other plates is to have an ultimate tensile strength of not less than 26 nor more than 30 tons per square inch of section. In all cases the elongation is to be not less than 20 per cent in a length of 8 in.

(3) Steel used for rivets is to be of special quality, soft and ductile, having a tensile strength of not less than 26 tons nor more than 30 tons per square inch, and an extension of not less than 20 per cent in a length of 8 in., and samples of the rivets are to be tested by being bent both hot and cold by flattening down the heads and by occasional forge tests, in order to satisfy the surveyors of their thorough efficiency.

(4) Bend tests are to be made upon strips sheared lengthwise or crosswise of the plate or bar. Where the thickness is $\frac{1}{2}$ in. or

above, the sharp fin caused by shearing may be removed ; and where the thickness is 1 in. or above, the cold bend test may be made with planed edges. They must stand bending double round a curve of which the diameter is not more than three times the thickness.

(5) The cold bend tests are to be made on samples cut from the bar or plate without annealing.

(6) For the temper bends the samples are to be heated to a low cherry red and cooled in water of 82 deg. Fah.

Lloyd's Register : Malleable Iron.—The iron shall be of good malleable quality, capable of withstanding a tensile strain of 20 tons per square inch, and with 18 tons across the grain.

Plates shall stand bending cold through an angle depending on the thickness :—

Thickness of Plate.	To Bend Cold through an Angle of	
	With the Grain.	Across the Grain.
	Degrees.	Degrees.
$\frac{9}{16}$	25	8
$\frac{8}{16}$	30	11
$\frac{7}{16}$	37	13
$\frac{6}{16}$	47	15
$\frac{5}{16}$	55	17
$\frac{4}{16}$	65	20
$\frac{3}{16}$	70	25

Steel Rails.—"The rails to be of the best description of steel in Bessemer, Siemens, or other equally approved process. Holes to be drilled, not punched."

Each rail shall bear a weight of 40 tons suspended midway between bearings 3 ft. apart without a greater deflection than $\frac{3}{8}$ in., and without any permanent set after the load has been on one hour. Also two strokes from a ball 1 ton weight let fall from a height of 12 ft. without breaking or more deflection than 1 in. for each blow.

Locomotive Boiler-plates (Siemens Steel).—Strips cut lengthwise from each plate as rolled to have an ultimate tensile strength of from 26 to 28 tons per square inch of section, with a minimum elongation of 27 per cent in 8 in.

The strips when cut lengthwise from each plate, and with the sharp edges removed, must stand bending to a curve the inner diameter of which is the thickness of the plate either when hot or cold. In the first case the plate will be bent at a bright red heat, and in the second case will at a similar heat be plunged into water of 80 deg. Fah., and cooled down before being bent.

Crank Axle Forgings (Siemens Steel)—No hammering must take place after the forgings are at a red heat.

The tensile strength to be from 29 to 32 tons per square inch, with an elongation of not less than 25 per cent on 2 in.

A piece 1¼ in. square, cut from each crank web—with the throw—after having the sharp edges removed, must stand to be bent cold double without breaking.

Carriage and Wagon Axles (Siemens Steel).—The tensile strength must not be less than 35 tons per square inch, with a minimum elongation of 25 per cent in 3 in.

Each axle must be guaranteed to stand the following test without fracture, viz.: Five blows from a weight of 2,000 lbs. falling from a height of 20 ft. upon the axle, which shall be placed upon bearings 3 ft. 6 in. apart. After the fifth blow the axle to be broken.

Steel Tyres (Engine and Tender).—To have a tensile strength of 45 tons per square inch, and an elongation of 20 per cent on 2 in.

A bar 1¼ in. square to be bent cold through an angle of 55 deg. without fracture.

To bear an hydraulic compression test deflecting 2 in. per foot of inside diameter without fracture.

CHAPTER XLII.

RUSTING AND PROTECTION OF IRON AND STEEL.

When iron is exposed to ordinary atmospheric influences it rusts readily. Brown hydrate first appears in spots; these gradually extend until the entire surface is covered. The action proceeds with increasing rapidity. The film of rust may remain adherent or flake off, and ultimately the whole mass may be oxidised. Thus masses of iron, on long exposure to the air, may completely disappear. Whilst iron, therefore, is in one sense a very durable metal, in another it is not. Exposed to the air unprotected, it is much more rapidly destroyed than many other metals, and except in very dry and protected situations it must always be covered with some protective coating.

Iron Rust.—Since the stable oxide at low temperature is ferric oxide, Fe_2O_3, it is this which will be likely to form, and rust consists almost entirely of the hydrate of this oxide, having approximately the formula $2\ Fe_2O_3, 3\ H_2O$; but as this is very hygroscopic, much more water is usually present. There is, however, always present a small quantity of magnetic oxide (Fe_3O_4), or of ferrous oxide (FeO); probably the former, as the latter is very unstable in air.

The following analyses will give an idea of the composition of iron rust. They are of the rust of the Conway Bridge, and from Llangollen, by the late Prof. F. Crace Calvert, the samples being dried:—

	Conway Bridge.	Llangollen.
Ferric oxide	93·094	92·900
Ferrous oxide	5·810	6·177
Ferrous carbonate	·900	·617
Silica	·196	·121
Ammonia	Tr.	Tr.
Calcium carbonate	..	·295

Assuming the ferrous oxide to be present as magnetic oxide, the figures would be :—

Ferric oxide	80·322	79·174
Magnetic oxide	18·582	19·903

Conditions of Rusting.—Oxygen alone, either wet or dry, has no action on iron at ordinary temperatures. When iron is exposed to the air, the conditions are much more complex, for there is always present, in addition to oxygen and moisture, carbon dioxide ; but even under these conditions rusting will not take place unless water actually condenses on the surface of the metal.

Three conditions are necessary in order that rusting may take place : (1) The presence of oxygen, (2) the presence of carbon dioxide, and (3) the presence of liquid water ; the presence of all three at the same time being essential.

The chemical reactions involved in rusting seem to be somewhat as follows : Carbon dioxide dissolves in the water, forming carbonic acid, this combination not taking place between the gas and water vapour, but only between the gas and liquid water, thus $CO_2 + H_2O = H_2CO_3$. The carbonic acid then attacks the iron, forming ferrous carbonate, $Fe + H_2CO_3 = FeCO_3 + H_2$, which dissolves as bicarbonate in excess of the carbonic acid $FeCO_3 + H_2O + CO_2 = FeH_2\ (CO_3)_2$. This bicarbonate is very unstable, being oxidised in presence of air to ferric hydrate, thus $4FeH\ (CO_3)_2 + H_2O = 2\ Fe_2O_3\ 3\ H_2O + 8\ CO_2$. It will be seen that the reactions form a cycle, the carbon dioxide used in the first stage being liberated in the last, and is thus ready to start operations again, so that a very small quantity of carbon dioxide can convert a very large quantity of iron into hydrate.

At the same time, the reaction evolves heat, which facilitates still further change. The hydrate also is hygroscopic, and, by absorbing moisture from the air, tends to keep the spot where rusting has commenced continually damp, and so hastens the action, and the rusting will continue in an atmosphere not saturated with, and therefore, under ordinary circumstances, not capable of depositing moisture, and the action, once started, may continue indefinitely.

Action of Water on Iron.—In pure water iron is not acted on, but as ordinary waters contain both oxygen and carbon dioxide in solution, iron will rust under water, though not so rapidly as when exposed to moist air ; but when, as in the case of sea water, the water is charged with salts of various kinds, the action becomes much more complex.

If the iron were perfectly homogeneous, it might be a case of simple chemical solution ; but it never is so, and the irregularities in consequence may cause the setting up of feeble electric currents by which electrolysis is brought about and the iron dissolved. Nearly pure iron exposed to sea water may be completely dissolved, and cast iron may be so acted on as to leave a spongy graphitic mass containing but little iron. This influence of distributed impurities on the corrosion of iron has been but little studied. In presence of acids the action may be very much more rapid, as soluble salts may be formed and dissolved away. The small quantities of sulphurous and sulphuric acids in the atmosphere of towns greatly accelerates the rusting of iron; and in mine shafts, where the waters are often acid, and in railway tunnels, where the air is more or less charged with acids from the combustion of the fuel, corrosion is always rapid.

Corrosion of Various Forms of Iron.—The relative corrodibility of the various forms of iron has been frequently discussed, but the results obtained by experimenters and observed by observers have been so conflicting that it is impossible to make very definite statements on the subject. It is certain that some constituents, such as nickel, retard rusting; and others, such as aluminium and manganese, seem to accelerate it; but no general statement as to the influence of foreign constituents can be given.

Cast iron seems to corrode less readily than malleable iron or steel, and this is specially the case if it is left with the "skin" on; but if this is removed by filing or otherwise the difference is less marked.

The question of the relative corrosion of malleable iron and mild steel has been much discussed. There is a very prevalent opinion among users, that mild steel corrodes much more rapidly than malleable iron, and for this reason malleable iron is still used for some purposes for which steel would otherwise be used. It is very uncertain whether the difference—which has been undoubtedly noticed in certain cases—is at all a general one, or whether it was merely an accident due to the composition of the metals used and the circumstances to which they were exposed. The two metals are different in structure, and malleable iron contains intermixed slag and oxide, which may have a mechanical protective agency. Mild steel often contains more carbon, and almost invariably more manganese, and these may have some influence in determining corrosion. It has been suggested that the rapid corrosion of some forms of mild steel may be due to the irregular distribution of the manganese, added as a deoxidising agent, particles of manganese-iron alloy acting as centres for the beginning of oxidation.

Dr. Howe has examined the question of the relative corrosion of wrought iron and mild steel, and as the result of his experiments he found it difficult to come to any very definite conclusion. He says: "I do not find that wrought iron as a whole corrodes more than soft steel as a whole, nor do I find the reverse to be true. Taking all common classes of wrought iron and soft steel together, and all conditions of exposure to oxidation to which engineering structures are commonly exposed, except perhaps in marine boilers, I find it extremely difficult to say that either wrought iron or soft steel on the whole excels the other in resistance to oxidation; but while we find no marked difference between these two classes of iron taken as a whole, we often find moderate and somewhat constant differences in certain specific cases, and we sometimes find great differences." He states, for instance, that in fresh water mild steel corrodes less than wrought iron, but that in sea water the reverse is the case.

He sums up his results thus :—

"The inference which I have drawn is as follows :—

"(1) That the difference in the rate of corrosion between wrought iron and soft steel is rarely enough to be of great moment, except perhaps in marine boilers.

"(2) That the ratio of the corrosion of given soft steel to that of given wrought iron may vary greatly with the conditions of exposure.

"Of the apparent discrepancies between the results not only of different observers, but even of the same observers, I suggest two chief causes :—

"(1) The quasi-accidental variations, individual peculiarities, &c.

"(2) The susceptibility to corrosion of soft steel taken as a whole, does differ somewhat from that of wrought iron taken as a whole ; but that this difference is of such a nature that wrought iron as a class corrodes on an average faster than soft steel under certain conditions, but slower than soft steel under others."

He gives the following table of relative corrosion. Wrought iron = 100 :—

	Sea Water.	Fresh Water.	Weather.	Average.
Wrought iron	100	100	100	100
Soft steel	114	94	103	103
3 per cent nickel steel	83	80	67	77
26 per cent ,, ,, ...	32	32	30	31

Mallet gave the comparative corrosion in moist air as being : Cast iron, 100 ; wrought iron, 129 ; steel, 133. Taking wrought iron as 100, as above, this would give cast iron, 77·5 ; steel, 103·1.

Mr. Thwaite gives the following formula and table :—

C = Coefficient of corrosion during one year's exposure in pounds avoirdupois per square foot.

W = Weight in pounds of 1 ft. length of section exposed.

L = Length in feet of the perimeter exposed. If both inside and outside perimeters are exposed both must be included.

Y = Number of years life of the metal.

$$Y = \frac{W}{CL}.$$

Value of C. Corroding Agents.

	Foul Sea Water.	Clear Sea Water.	Foul River Water.	Pure Air or Clear River Water.	Air of City or Sea Air.
	lb.	lb.	lb.	lb.	lb.
Cast iron	·0656	·0635	·0381	·0113	·0476
Wrought iron	·1956	·1285	·1440	·0123	·1254
Steel	·1944	·0970	·1133	·0125	·1252
Cast iron (skin removed by planing)	·2301	·0880	·0728	·0109	·0884
Cast iron, galvanised .	·0895	·0359	·0371	·0048	·0199

If painted once a year, multiply by 2.
If painted once in two years, multiply by 1·8.
If painted once in three years, multiply by 1·6.

Removing Rust.—The removal of rust once formed is a matter of considerable difficulty; and not only so, but when it is removed the surface of the metal will always be more or less pitted and rough. The methods are: (1) Scraper and file, very tedious, and always more or less unsatisfactory; (2) the sand blast, much more efficient as a cleaning agent, fine quartz sand being used with an air pressure of about 10 lbs. per square inch; and (3) pickling in dilute acids, which is only applicable to small articles. As a rule, once any considerable quantity of rust has formed, it is impossible to remove it.

Protection from Rust.

The only way to protect the metal from rust is to keep it from contact with rusting agents, *i.e.*, from moisture and carbon dioxide. As it is impossible to keep the air dry, the only available method is to cover the article with a layer of some impervious material.

The following methods are used:—

(1) Coating with metallic films, tin, zinc, nickel, &c.
(2) Coating with oxide films.
(3) Painting.
(4) Varnishing.
(5) Dipping in various mixtures.
(6) Enamelling.

Which will be used will depend entirely on the character of the object to be protected.

Tinning.—This consists in coating the object with metallic tin. The layer of tin is flexible, and the plates are almost invariably "tinned" before they are made up into the articles which are to be made. The tin-plate industry is a large and very important one.

The tinning of plates seems to have been invented about 500 years ago, and to have been introduced into this country by A. Yarranton about 1665, and the first works was established in 1720. The plates at first were prepared by hammering; but rolling was introduced in 1728. For more than a century malleable-iron plates were used, the plates being usually prepared in charcoal fineries. Bessemer steel was first tried in 1856, and by about 1880 Bessemer and Siemens steel had completely replaced malleable iron as the material for tin plates.

In the manufacture of black plates for tinning, steel billets are rolled hot into flat bars from 6 in. to 12 in. wide and from $\frac{3}{8}$ in. to 1 in. thick. The bars are cut up into lengths, each length being the width of the plate to be rolled. They are heated in a furnace, and two bars are rolled sidewise, one right after the other until of the required length, when they are put one on the top of the other and again heated; they are rolled down (drawn out) again, doubled and heated, and again rolled and doubled, so that there will be eight thicknesses of metal. This "pack" is heated, rolled down to the required size, the rough edges trimmed off, and cut either into two pieces 20 in. by 28 in., or four pieces 14 in. by 20 in., and the plates are separated. The plates are then passed to the pickling-room, where they are treated with dilute sulphuric acid (pickled) to remove scale, &c., and are cleansed with water to remove all traces of acid. Machines are now usually used for pickling, the plates being placed in a frame which is kept in motion in the acid.

The plates are then packed in an iron box provided with a cover, luted to exclude air, and heated to redness, after which they are allowed to cool slowly.

The annealed plates are passed three or four times through rolls "cold," the rolls being highly polished, so as to give a smooth surface to the plates. They are then again annealed in boxes, as before, but at a lower temperature, and are again pickled, each plate being separately examined to see that the surface is perfect.

The plates are taken to the tin-house in troughs of clean water mounted on wheels.

Two processes of tinning are used—the "palm oil" and "acid" processes.

By the oil process a batch of plates is boiled in palm oil for about 20 minutes, thus evaporating the water and acid which might possibly still adhere.

The sheets are next passed to another pot containing molten tin or terne, the latter being the name given to a mixture of tin and lead, the surface of the molten metal being covered with a layer of oil. From this pot they are taken to a second pot of metal, where they soak for some time, and are taken from this pot by the tinman, who lays them on the hob, a space between the second and third metal pots, covered with iron plates, where they are brushed thoroughly with hemp on each side to remove any oxide or dross which might adhere. The plates then go to the third metal pot, which contains metal of extra purity. From this last metal pot they are taken to a pot containing rolls running in oil, by which the surface is smoothed, and any excess of metal squeezed off.

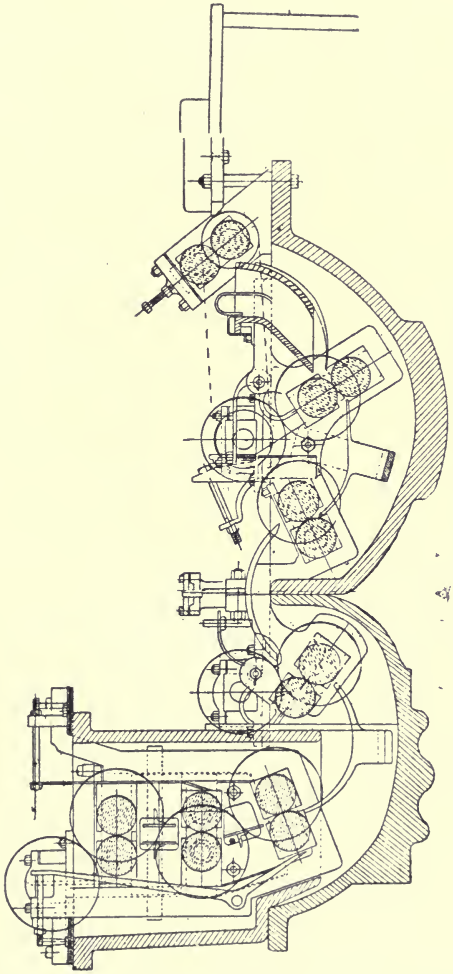

Fig. 207.—Wyndham-Thomas Tinning Machine.

The plate enters at right hand side and leaves at left.

In the acid process fused zinc chloride is used as a flux, a layer covering the surface of the molten tin, the plate being cleaned and dried by passing through it. The tin pot is divided into two parts, so that the zinc chloride can cover the metal in the one part, and the metal in the other part can be covered with oil. The plate is guided through the pot by suitable rolls, so that it enters through the zinc chloride and leaves through the oil, and any excess of tin is squeezed off by the last pair of rolls.*

For the acid process, as will be seen, machines are always used : of these there are many types. One of these, that of Mr. Wyndham Thomas, is shown in Fig. 207. The plates are guided by rolls through the flux and metal, and are delivered through a bottomless tube, the surface of the metal in which is covered with grease.

Tin plates are coated with pure tin, the thickness of the tin varying, the thicker, the better the plate ; whilst terne plates are coated with an alloy of tin and lead.

The term "charcoal plates" was at one time understood to mean that the tin was on plates made in charcoal fineries ; now the name only indicates that the plates are more heavily tinned, the metal being the same in all cases.

The tin alloys with the iron, and makes a perfectly firm and coherent coating. If the plates have been well coated they can be stamped into any form without the tin breaking, and they can be easily soldered ; hence, tin plate is largely used for making utensils of all kinds. The tin retains its brightness and protects the iron perfectly till the surface is broken, after which rusting goes on more readily than in the absence of tin. The layer of tin seems often to crack, and so to allow air and moisture to get beneath it and rust the iron.

Galvanising.—This is coating the iron with zinc. Two methods are used. In the one the iron is dipped into molten zinc ; and in the other the zinc is deposited by an electric current from a solution.

Hot Galvanising.—The method of applying the coating is very similar to that used in tinning, the article being dipped in molten zinc. Zinc is, however, very much less ductile than tin, and the coated article will not, therefore, bear much work, so that the article must always be completed, and then coated as a whole. The principal exception to this is the corrugated, galvanised-iron plates so largely used for building purposes, which are corrugated in a press—one corrugation at a time after galvanising.

Galvanising is applied to many classes of articles, from small tacks to large tanks, and the details of the method used must depend on the size and character of the article being treated.

The articles are first thoroughly cleaned, small articles often by tumbling in barrels, and are then pickled in dilute sulphuric or hydrochloric acid. They are then dried and are immersed in

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* See paper by W. C. Cronemeyer, "Iron and Coal Trades Review," August 25th, 1899, from which some of these details are taken.

molten zinc contained in a suitable kettle, the surface being covered with a layer of ammonium chloride (sal ammoniac), which acts as a flux.

The temperature of the article must be raised to that of the bath. Cast iron articles are left considerably longer in the bath than those of malleable iron or sheet metals, sometimes up to 30 minutes. The work is carefully withdrawn, tapped to remove excess of zinc, and either dipped into water or cooled in air.

The zinc must not be too hot. It alloys with the iron, forming a perfectly coherent coating, and some iron is dissolved by the zinc, thus gradually rendering the bath impure.

Large articles are dipped singly, smaller ones are wired together, and very small ones, such as tacks, are contained in wire baskets, being well shaken on removal to prevent adhesion. Plates are passed through the bath by rollers as in tinning.

The size of articles that can be galvanised will, of course, depend on the size of kettle available.

Galvanised iron is very durable if not exposed to acid fumes, but zinc is so easily acted on by acids that it does not stand well in the air of towns. It is quite unsuited for domestic utensils which are liable to come in contact with soap.

Cold Galvanising.—In this process the zinc is deposited from solution by an electric current. The article is thoroughly cleaned, usually by pickling. It is then washed and brushed, and immersed in a bath of lime water, to neutralise any acid that may be left, and is then transferred to the depositing vat.

The depositing solution is a slightly acid solution of zinc sulphate (about 40 oz. to the gallon), which is kept circulating through regenerating tanks in which the zinc removed by deposition is replaced. The best amount of acid, according to Mr. Cowper-Coles, is $\frac{1}{10}$oz. of free acid per gallon. The article is attached to the pole of a dynamo, giving a current at about 6 volts, and current density being of 10 amperes by suitable rods so as to form the cathode. The coating is dull and crystalline in structure, and is firmly adherent. The layer of zinc is very thin. Electro-galvanising is mainly used for articles which cannot be dipped in molten zinc without injury.

Sherardising is a new process of dry galvanising by which articles are coated with a layer of zinc by annealing for an hour or so in contact with zinc dust or " Blue Powder " at a temperature of about 300 deg. Cen. Although not molten, the zinc alloys with the iron and forms a very thin, uniform coating. The articles must be free from scale and rust but grease need not be removed. The process is highly economical, as no flux is needed and there are no skimmings dross, or hard spelter produced.

Deposition of other Metals.—Coatings of copper, nickel, and other metals deposited by electrolysis are sometimes used for protecting small articles. Electro-deposited metals are, as a rule, too crystalline and porous to be much protection.

Coating with Oxide Films.—When iron is oxidised at high temperatures magnetic oxide F_3O_4 is formed. If the oxidation can be conducted in such a way that the film of oxide remains adherent, it forms a very effective protection against corrosion. As, however, the oxide is brittle, the coating must be applied after the article is completed, and it must not be subjected to rough usage, or it may chip.

This method was first introduced by Prof. Barff, in 1876; and the next year Messrs. Bower patented a similar process. In the Barff process, the articles were heated in a muffle to about 600 deg. Fah., and steam, superheated to about 1,100 deg. Fah., was blown in. In the Bower process, the articles were first heated in the products of combustion of coal mixed with excess of air, and then in carbon monoxide. The two processes are now combined under the name of the Bower-Barff process.

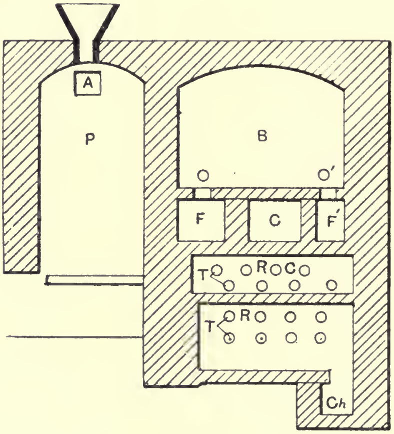

FIG. 208.—Furnace for Bower-Barff Process.

The articles are heated to the required temperature in a closed chamber by the flame of ordinary producer gas; the gas is then turned off, and superheated steam is sent into the chamber for one or two hours.

The apparatus used is shown in cross section in Fig. 208, which will give an idea of the arrangement, though it is impossible to show the various valves in one view. The operation consists of two stages. During the first the articles are being heated, and during the second they are being oxidised with steam. Gas is generated in the producer P, which is of the ordinary bar-bottom type, passes away by the opening A, and is brought by a suitable passage to one end of the combustion chamber C, into which air is also admitted, so that the gas is burned; the products of combustion pass from the other end of the chamber C into the flue F, thence by the opening O into the large chamber B, in which the articles to be oxidised are placed, and thence by a flue, not shown, to the regenerative chambers R C, which are crossed by a large number of tubes T, which thus become intensely heated, and away to the chimney by the flue *Ch.* When the chamber and its contents are hot enough, the gas supply is stopped by means of a damper, and steam is blown through the tubes T, in which it becomes strongly superheated, to the flue F^1, thence by the openings O^1 to the chamber B, and finally through the chamber R C away to the chimney. When oxidation has been going on sufficiently long the articles are drawn. and the chamber is heated up again ready for the next charge.

Cast-iron articles are heated to a temperature of about 900 deg. Fah., whilst for wrought iron or steel a much higher temperature is used. The film of oxide deposited is dead black, smooth and coherent, and forms a perfect protection against corrosion, whilst it remains unbroken. The articles must, of course, be coated after they are completed, as otherwise the film of oxide would be broken by the work, and, then being negative to the iron, would cause rapid corrosion. The process is principally used for articles of small size.

Gesner Process.—In the Gesner process, patented by Mr. G. W. Gesner, of New York, ordinary gas retorts are used, two being placed side by side in each furnace, and being heated to about 1,000 deg. Fah. to 1,200 deg. Fah. by fires. Fig 209.

The articles are introduced into the retorts, which are closed, and left until the temperature of the whole is uniform. Steam is then introduced by a pipe which runs along the bottom of the retort, and opens at the further end. After about 35 minutes half a pint of naphtha is let flow into the retort for 10 minutes; this is then stopped, and steam is continued for another 15 minutes, the whole time occupied being thus 1 hour 20 minutes. Any excess of gas escapes by a pipe which dips into water, so as to form a seal of about 1½ in.

Many other forms of applying the oxides have been suggested.

Paint.—This is the most general method of protection, as it can be used under almost all conditions.

Paint considered only as a protective agent consists essentially of two parts—the vehicle and the base.

The vehicle is almost always linseed oil, raw or boiled. Such oil dries readily on exposure to the air, forming a resinous solid layer, which, however, has a great tendency to crack. The base is a solid substance incorporated with the oil, so that when it dries, the dried layer of oil only unites and binds together the particles of base; and it is essential, therefore, that the base should be a material which binds well with the oil, and which has no action on the metal.

There is very great difference in behaviour between the different bases, depending both on their chemical and physical nature. As a rule, the base must be in an extremely fine uniform powder, and it should be amorphous, not crystalline. The best base from this standpoint seems to be pure oxide of iron, but this is only available for shades of red, brown, or black, and next stands good white

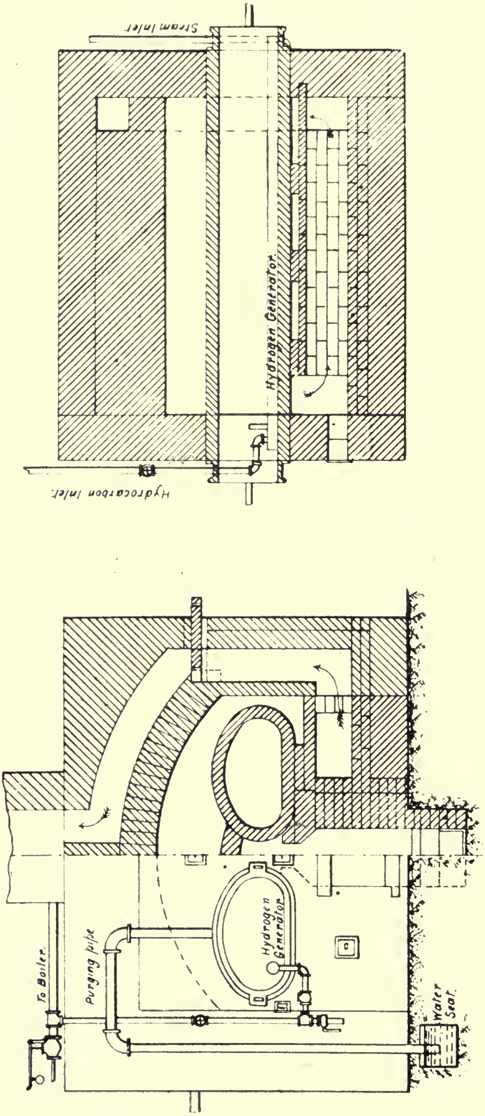

FIG. 209.—Furnace for Gesner Process.

lead. Oxide of iron paints are, however, often not by any means pure, as is shown by the following analyses :—

	1	2	3	4	5
Oil and volatile matter	13·35	30·67	..	26·30	16·23
Ferric oxide	4·83	27·13	18·5	51·16	75·46
Barium sulphate	57·95	..	..	..	..
Calcium carbonate	18·77	..	..	..	..
Calcium sulphate	4·17	..	..	..	..
Alumina	·67	..	..	..	3·10
Siliceous matter	..	42·20	..	25·51	5·13
	99·74	100·00	..	99·97	99·87

On trial, it was found that No. 5 was much better, and No. 1 much worse, than ordinary red-lead paint for protecting iron from rust.

Three plates were experimentally painted : *a* with red lead, β with No. 1 oxide, γ with No. 4 oxide. *a*, the plate was slightly attacked, only showing slight traces of corrosion, though under the microscope it was seen to be pitted ; β, had almost entirely lost its colour, and the plate was corroded in several places ; whilst γ was intact, and the plate in good condition.

It is obvious that for paints exposed to the weather all carbonates should be absent, since they are all (even lead carbonate) dissolved by water containing carbon dioxide, and they must be free from the alkaline earths (lime, magnesia, &c.) which would absorb water and carbon-dioxide and become centres of rapid rusting.

Iron oxide base has somewhat fallen into disrepute, on account of the extreme impurity of the paints often sold as oxide paints. Lead oxide, or lead carbonate, is far less suitable as a protective paint, though white lead—the basic carbonate—is the base of almost all paints used for decoration. The lead paints seem to tend to crack off ironwork, though a mixture of pure lamp black and red lead with boiled oil is strongly recommended by some engineers, and a little zinc oxide may be added without harm.

Whatever be the nature of the paint used, the surface should be well cleaned, preferably by a sand blast—for it is difficult, if not impossible, to make hand cleaning efficient—before the paint is applied.

Rusting seems to commence under paint in spots, round which the oxidation continues, and the expansion of the rust forces off the paint. Any little inequality seems to be a cause of rusting, and the smoother the metal the less liability is there to rust.

Varnishes.—Paint is opaque, and therefore hides any irregularities or rust patches. Varnishes have the advantage of being transparent. As a temporary protection, the article is often rubbed over with a non-drying oil, and this is quite satisfactory for shop purposes, provided the oil be one that does not turn acid. A coating of drying oil, viz., boiled linseed oil, is often used, but this is very inefficient, as the oil cracks on drying, and does not form a continuous impervious film. Ordinary varnishes are of little use. Few experiments have been made on the protective power of varnishes in general.

Tar Mixtures.—Various mixtures are used for protecting cast-iron pipes and other similar articles. These are used hot, and the article is dipped into them. Perfect dryness is thus assured, and this is a great matter in the application of all protective coatings. Dr. Angus Smith's mixture consists of coal-tar pitch with 5 or 6 per cent of linseed oil, and sometimes a little resin, and is used at about 300 deg. Fah. For the best work the pipes should be heated above 300 deg. Fah. before they are immersed, but this is often omitted. They are left in the mixture a few minutes, and are then lifted out and allowed to cool in a vertical position.

Enamelling.—This is only used for small articles and consists in covering the article with a layer of porcelain-like glaze or enamel, which may be applied dry, the powder process, or the article may be dipped, as in pottery glazing. An opaque layer or body of porcelain is first applied, and the article is fired. This may be repeated. Then a transparent glaze is put over, and another fire is given. In some cases only one layer—an opaque enamel or glaze containing tin—may be used.

The protection is perfect, except when the enamel cracks off (as it is very apt to do), and no work can be put upon the article after enamelling.

CHAPTER XLIII.

MICRO-STRUCTURE OF IRON AND STEEL.

When a piece of iron or other material is fractured the appearance of the fractured surface will give some idea of the internal structure of the metal, so far, at least, as it is coarse enough to be detected by the eye. If the substance be perfectly homogeneous it will break with a fracture all parts of which will be identical; if it be not, the fracture will be more or less irregular, and may vary from coarsely crystalline, as in grey pig iron, to very finely granular, as in the case of steel.

Iron and steel are never homogeneous, but vary much both in composition and structure. A body of complex chemical composition may be homogeneous if it be a definite chemical compound, or even if it consists of one body in solid solution in another; but this is not the case with iron in any of its forms. It is always a mixture of various substances which have separated during or after solidification, and which remain intermixed, the mixture usually being so complete that the eye cannot detect any heterogeneity.

Ultimate chemical analysis gives information as to the elements which are present, but only in very exceptional cases, as to the way in which they are combined, since the compounds are mostly broken up by the action of the reagents used for preparing the solution for analysis. It seems obvious that structure must depend far less on ultimate composition than on the way in which the constituents are combined or mixed, that is, less on the ultimate than on the proximate composition.

By chemical methods the proximate analysis of iron and steel has been carried a certain length, and some constituents have been isolated. The graphite in pig iron can be seen by the unaided eye, a definite carbide of iron, $Fe_3 C$, has been separated, as also have silicides of iron and manganese, $Fe Si$, $Fe_2 Si$, $Mn Si_2$ and phosphides such as $Fe_3 P$. The present methods of proximate analysis are altogether dependent upon the isolation of the more stable compounds, by the breaking up and solution of the less stable, by the reagents employed.

Microscopic Examination of Metals.—The finer mechanical structure of the metals, and especially of iron and steel, has within the last few years been investigated by means of the microscope, and many earnest workers in this and other countries are still engaged upon it.

The use of the microscope for the examination of metals was first suggested by Dr. Sorby in 1864, in a paper read before the British Association in that year. Speaking of this, in a later paper, he says : " This attracted no attention for 22 years, but in 1875 the Iron and Steel Institute requested me again to take the matter up, and appointed Dr. Percy, Sir Henry Bessemer, and myself to decide what was the best way of illustrating a complete paper on the subject."

Since then methods have been perfected, a vast amount of information has been accumulated, and the new science of Metallography has arisen, and a large amount of light has been thrown on the structure of iron and steel and other metallic alloys.

Method of Examination.—Small pieces, about ½ in. cube, of the metal are taken, being cut by hack saw from the mass of metal. One of these is ground down on emery wheels or coarse emery cloth, till an approximately smooth surface is obtained ; is then polished with finer emery paper, till at last the very finest is used ; the polishing is continued with fine alumina prepared by calcining ammonium-alum, and washing the calcined residue. Finally, the specimen is polished on selvyt cloth, parchment, or kid skin, on which the finest rouge is rubbed, and the excess is washed off with running water. The sample is then perfectly smooth and free from even microscopic scratches.

The Microscope.—The microscope is, of course, the most important item in a metallographer's outfit. Good work may be done with an ordinary microscope, if it be of fair quality, but one specially made for and therefore adapted to metallographic work is much better. The makers of microscopes are now competing with each other in the production of instruments suitable for metallographic work. Those of Messrs. Beck, Watson, Ross, and Swift, in this country, and of Messrs. Reichart, Leitz, Zeiss, and other firms on the Continent leave little to be desired, and are made at various prices. Fig. 210 illustrates the Rosenhain microscope, which can be used either vertically or horizontally. The latest form of the Le Chatelier microscope made by Reichert with a reflex camera attached is perhaps the most convenient for photo-micrographic work.

In all ordinary microscopes the object to be examined is transparent, and the light is reflected up from below ; for metallographic work this cannot be done, and the stage is best made solid. The samples to be examined may be of considerable size, so that a much larger motion of the stage or tube is necessary than in ordinary biological microscopes. Messrs. Swift make a stand so constructed that the stage can be dispensed with if necessary, the microscope standing on the article to be examined, so that large pieces can be examined without the removal of specimens.

For a reason which will be seen directly, the coarse adjustments should be attached to the stage, and not to the tube, and the stage should be provided with transverse motions in two directions, and should be capable of being accurately levelled. The light must obviously be thrown upon the surface to be examined, and reflected upwards into the objective. With low powers, $\frac{2}{3}$ in. and upwards, there is no difficulty—the light can be thrown upon the sample by

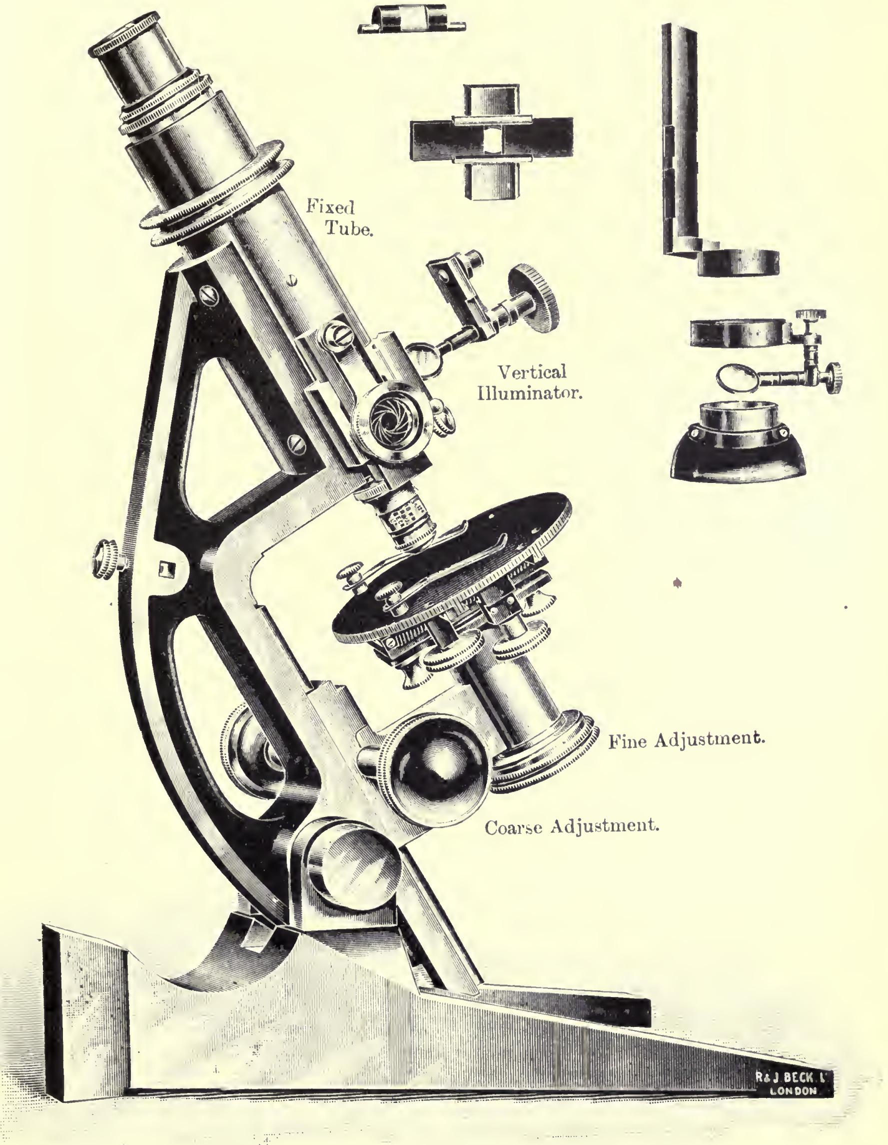

Fig. 210.—Rosenhain Metallurgical Microscope.

means of a bull's eye condenser. This is usually called natural or oblique illumination. With high powers, this method of illumination is impracticable, as the sample is so near the objective that the light cannot reach it, and some other method of illumination must be devised, and vertical illumination by means of a reflector within the tube of the mircoscope is therefore used. This method of illumination can be used for low powers as well as for high, but it is often undesirable for the former.

The simplest form of vertical illumination is that of Messrs. Beck. At the lower end of the microscope tube, just above the objective or at some other convenient place, is fixed a short tube which contains a small disc of very thin unsilvered glass, so arranged that it can be rotated into any required position, and opposite this a circular hole is made in the tube. A horizontal beam of light is sent into the tube through the opening, and if the mirror be placed at an angle of 45 deg. the light will be partly reflected downwards and partly transmitted, the latter part being lost.

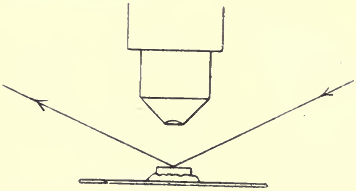

FIG. 211.—Smooth Surface, appears Dark by Oblique Illumination.

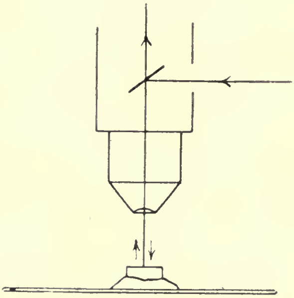

FIG. 212.—Smooth Surface, appears Bright by Vertical Illumination.

The light which passes downwards passes through the objective, illuminates the object. and is reflected back again ; the upward beam striking the glass is partly transmitted and partly reflected, the portion transmitted passes upwards and reaches the eyepiece.

It is quite obvious that by this arrangement there is a considerable loss of light by the various reflections and transmissions, but enough reaches the eyepiece for the purpose.

In place of this simple mirror, a prism may be used, and Messrs. Beck have recently introduced a new form of mirror. the one half of which is silvered to act as a reflector, whilst the other half is clear to transmit the image.

Appearance of the Object.—The appearance of the object varies very much with the character of the illumination, a surface which appears bright with an oblique illumination often appearing dull by vertical illumination, and vice versa, so that when a specimen is described as being bright or dull, the character of the illumination should always be specified. Suppose a perfectly smooth surface to be examined by oblique illumination, it will appear dull, or almost black, whilst on the other hand by vertical illumination it will appear brilliantly bright. The explanation of this is quite simple. A beam of light falling obliquely on a smooth surface is reflected according to the law of reflection, and none of the light enters the object glass which is vertically above it, and thus the surface appears dark. (Fig. 211.) On the other hand, when the light is sent down vertically on to the smooth surface, nearly the whole of it is reflected back, and thus the surface appears bright. (Fig. 212.)

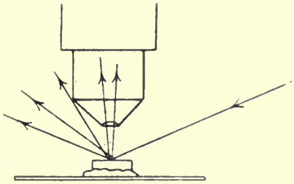
FIG. 213.—Uneven Surface, appears Bright by Oblique Illumination.

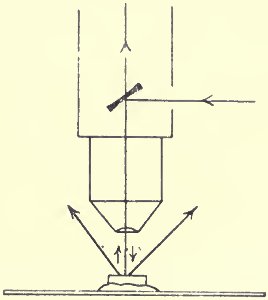
FIG. 214.—Uneven Surface, appears Dull by Vertical Illumination.

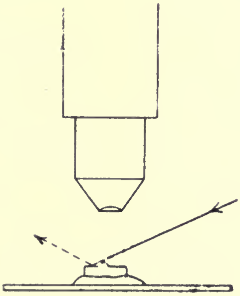
FIG 215.—Shadow Cast by Portion in Relief with Oblique Illumination.

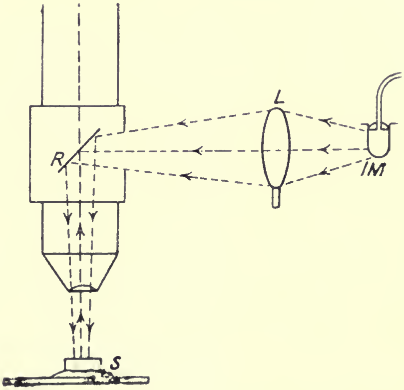

FIG. 216.—Method of Obtaining Vertical Illumination. S, Specimen for examination; R, Reflector inclined at 45 deg.; L, Condensing lens; IM, Incandescent mantle.

If the surface be rough the oblique ray will not be regularly reflected, but will be scattered, so that a fair portion will enter the objective lens, and the object will appear bright (Fig. 213); on the other hand, if the light is sent down vertically upon the uneven surface, only a small proportion will be directly returned, so that the surface will appear dull. (Fig. 214.)

When the sample is etched, some constituents stand up in relief, the surrounding portions having been dissolved away, and with oblique illumination a distinct shadow will be cast (Fig. 215), which will make the distinction between the two constituents much more pronounced than by vertical illumination, where there can be no shadow. Similarly a small hole or depression will be much more strongly marked by oblique than by vertical illumination, since in the former case it will be in shadow.

It very frequently happens, therefore, that a change from oblique to vertical illumination quite alters the appearance of the specimen—the surfaces which before were bright become dull, and those which were dull become bright, and holes or scratches become much less strongly marked.

In order to preserve the results of an examination, a photograph should, if possible, be taken. The magnification should be given thus: 30 X, meaning that the photograph is 30 times linear larger than the sample, and the illumination should always be marked O for oblique illumination, and V for vertical illumination.

Polish Attack.—The sample of steel may be subjected to what Osmond has called a polish attack. This consists in polishing on parchment moistened with a 5 per cent solution of nitrate of ammonia. After continued friction some parts of the steel surface are coloured brown, whilst other parts remain brilliantly white. This method is not much used now unless for a preliminary examination of a specimen.

Etching.—The specimen is etched slightly with a suitable agent such as tincture of iodine, very dilute nitric acid (1 per cent in alcohol), or a dilute solution of hydrochloric acid in alcohol. A saturated (*i.e.*, 5 per cent) solution of picric acid in alcohol is very useful in some cases, especially when phosphorus is present. The sample may be washed with water, lime water, and again with water or alcohol, and finally dried in a current of air.

The sample is sometimes further etched with 10 per cent or 20 per cent nitric acid, or other powerful etching agent, if the dilute solution is too slow in its action. Sauveur obtained good results by etching with strong nitric acid 1·42 sp. gr., and washing in running water. In almost all cases the sample should be examined after each stage of etching.

The object of this treatment is obvious. The constituents are differently acted on by reagents; some will be more readily dissolved than others, so that the surface, instead of being perfectly smooth, will have some of the constituents standing out in relief. Thus they will be more readily visible. The appearance of the various portions—*e.g.*, whether they appear bright or dull—will depend not only on their actual condition, but also on the way in which they are illuminated.

Heat tinting is now sometimes used to show up certain constituents, as for example phosphide inclusions.

Micro-Constituents of Iron and Steel.—A very large number of samples of iron and steel of all kinds have now been examined by various observers, and a certain number of definite constituents, of which the structure is well defined, have been made out. These, of course, are not all present in every sample, any more than all the elements are present in one compound, but every sample of iron and steel is made up of some of them. The constituents are here first briefly described, and then the principal varieties of iron and steel are discussed and illustrated by photomicrographs.

Ferrite.—This may be pure iron, or it may be iron containing silicon, manganese, nickel, copper, phosphorus, vanadium, chromium, molybdenum, or tungsten, and definite chemical compounds retained in solid solution in the greater mass of iron and other constituents. Pure iron, when slowly cooled from a temperature of 750 deg., consists of a mass of crystal grains, the boundaries between which can be seen, by polishing and etching,

Fig. 217.—Microstructure of pure Ferrite, in Swedish Charcoal Iron, showing Crystal Grains. Magnified 150 diameters.

as a network of lines. (Fig. 217.) These grains have no doubt been formed by the pressure of the crystallising masses, and are what Rosenbusch calls allotriomorphic crystals, or crystals which have not been able to develop freely, so as to take their proper crystalline form owing to mutual interference.

On etching for several seconds in a 10 per cent solution of nitric acid in water both negative and positive cubical crystal forms appear on the faces of the crystal grains, which are so orientated as to have their cleavage planes parallel to the surface of the polished metal. When crystal grains are of sufficient size to admit of their being fractured independently, the line of cleavage takes a direction parallel to one of the sides of a cube. Fig. 218 shows the structure obtained by etching a sample of iron containing 4 per cent of silicon, the tendency to develop these crystal forms being greatly increased by the presence of silicon.

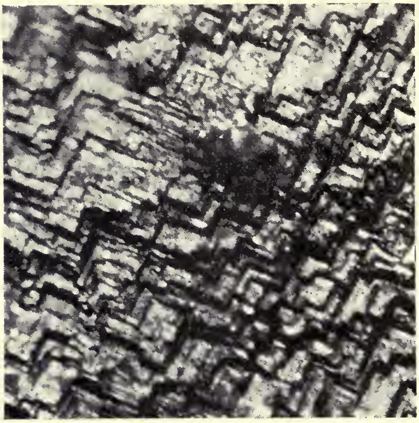

Fig. 218.—Iron with 4 per cent Silicon, showing Cubical Crystals (Stead). Magnified 130 diameters.

Ferrite is softer than the other constituents of iron, and is readily acted on by etching agents, so that the other constituents stand out in relief in the polished and etched sample. Ferrite occurring in steel is rarely pure, and as the foreign constituents modify its properties, when these are in sufficient quantity to make a pronounced change in the ferrite, the name of the element, in full or in an abbreviated form, should be prefixed to the term ferrite. Thus pure iron might be called ferro-ferrite; the ferrite in nickel steels, nickel-ferrite; in phosphoric steels, phospho-ferrite; and so on.

Ferrite may occur structurally free, when it is called pro-eutectoid or alpha-ferrite, or as a constituent of pearlite, when it is referred to as eutectoid-ferrite. In low carbon steels, when quenched, the ferrite, if structurally free, is likely to be present as gamma-ferrite.

Ferrite is the ground-mass of mild steels when slowly cooled or annealed, and is the chief constituent in wrought iron. It also occurs in grey cast iron as silicon-ferrite.

Carbon.—As already explained, graphite is always present in pig iron. When the pig iron is broken in the usual way the perfect cleavage of the graphite determines the fracture along the cleavage planes, and thus the graphite shows as flat or curved flakes. In the micro-sections, the flakes are cut through, so that they appear as thin curved lines. Figs. 219 and 220 show the arrangement of graphite in two samples of pig iron.

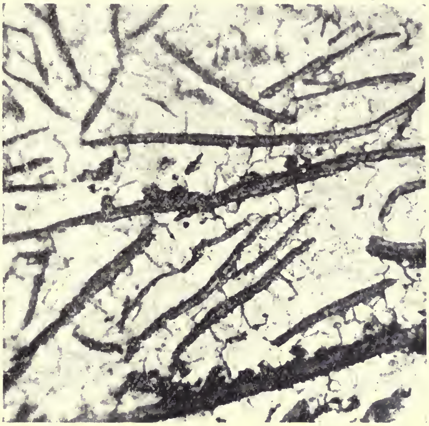

FIG. 219.—No. 1 Hematite Pig (Stead). Magnified 40 diameters. (The dark areas are graphite, the ground mass is silicon-ferrite.)

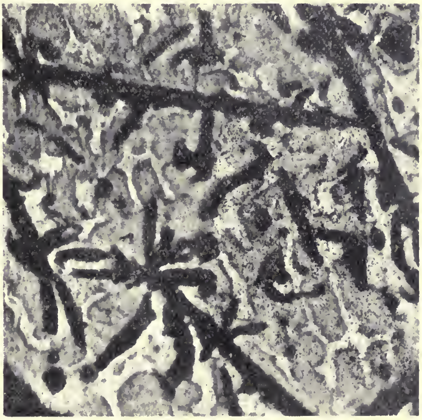

FIG. 220.—No. 3 Cleveland Pig Iron, containing 1·6 per cent (Stead). Magnified 40 diameters. (The black areas are graphite; the white are the phosphide eutectic; the half-tone areas are silicon-ferrite.)

Annealing Carbon.—When pure carbon steels containing more than 1 per cent of carbon are very slowly cooled from 1,000 deg. Cen., a portion of the carbide is decomposed, and an equivalent of carbon is set free in the form of annealing carbon, or, as it is sometimes called, annealing graphite. Prof. Ledebur obtained the separation by hammering a piece of steel until the heat produced

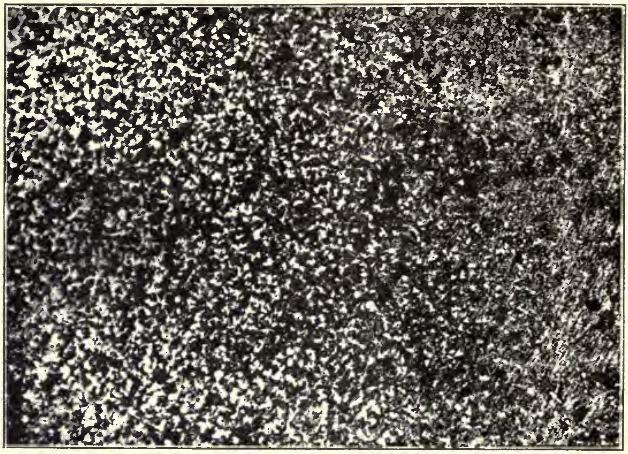

Fig. 221.—Reaumur Malleable Iron, showing small dark patches of amorphous carbon (black) embedded in Pearlite, and ground mass of Ferrite (white). Magnified 30 diameters.

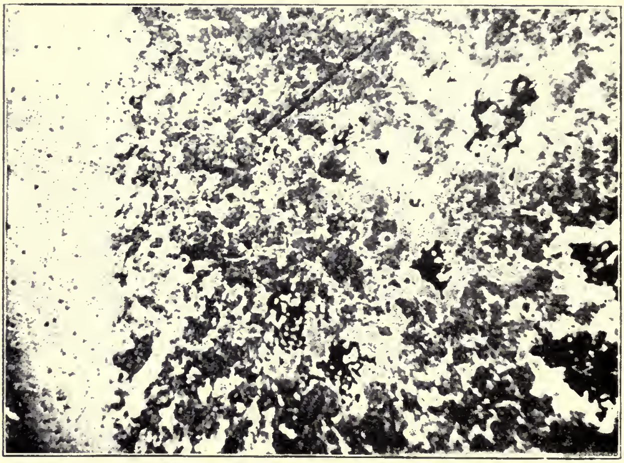

Fig. 222.—Blackheart Malleable Iron, showing large patches of amorphous carbon (black) in ferrite ground mass (white) and Pearlite (grey). Magnified 30 diameters.

by the percussion had raised it to redness, when he found that a large proportion of the carbon previously existing as carbide was changed into annealing carbon. Annealing carbon is found in steel with a black fracture.

On solution of such steel in nitric acid the carbon is left in an insoluble form, and when filtered and dried gives the characteristic graphite streak when rubbed on paper. By heating the steel to a temperature short of fusion, and cooling in air, the free carbon disappears, and re-combines with the iron to form carbide. It is most frequently found in malleable cast iron obtained by annealing white iron for several days at a temperature of over 1,000 deg. Cen. Figs. 221 and 222 show it in Reaumur and American Blackheart iron as amorphous black patches.

Cementite.—When iron contains even as small a quantity as ·02 per cent of carbon, minute, irregularly-shaped brown specks appear after the polish attack and after etching with dilute acid. These dark areas contain practically the whole of the carbon. On examination under a high power, they are found to consist of two separate constituents, one of which stands out in relief above the other. This always remains white, whilst the other constituent is coloured brown. The bright constituent is a definite carbide of iron, Fe_3 C, the carbide which was isolated by chemical means by Abel many years ago, and which is therefore often called Abel's carbide, but to which the name cementite, as suggested by Howe, is now usually given. This is the constituent of the steels which is least readily acted on by reagents, and, being the hardest constituent, stands out in relief after polishing or etching.

Cementite occurs in three forms—(1) structurally free, as primary cementite in slowly cooled white iron, and in high carbon steels; (2) as a eutectic with austenite in quenched or quickly cooled white iron; and (3) as eutectoid cementite when associated with ferrite as one of the elements of pearlite. The structurally free cementite does not occur in normal steels with less than ·9 per cent of carbon, but even mild steels, if annealed for a very long time, allow the cementite in the pearlite to "ball up" into structurally free grains. In pearlite it is present in thin curved plates or rounded grains. In high carbon steels the pro-eutectoid cementite forms cell walls round the grains of pearlite.

Pearlite.—This constituent appears after etching, in plates and grains, and shows to the eye under suitable illumination, a play of colours not unlike mother-of-pearl. Dr. Sorby, who discovered it, gave it the name of the pearly constituent—whence the name pearlite, now generally used, is derived. Under a low power it seems to be a homogeneous substance, which is darkened, on etching, to a shade of brown to blue, and even black, according to the duration of the attack; but under a high power it is seen to be made up of alternate layers or grains of the two constituents which have been already described, viz., ferrite and cementite. Owing to the difference in hardness the two constituents are unequally worn down in polishing, and thus a series of fine lines or grooves is produced, the scattering of the light from which gives the pearly appearance. (Fig. 223.)

Pearlite is the form in which the carbon is always present in slowly-cooled steels, and when the carbon reaches about ·9 (or ·8 in presence of other impurities) it constitutes the whole mass of the metal. If ·89 be taken as the saturation or "eutectoid" point, the pearlite will contain 13·4 per cent cementite and 86·6 per cent

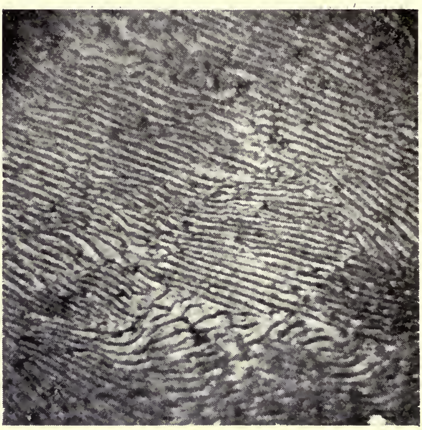

Fig. 223.—Laminated Pearlite in slowly-cooled Eutectoid (·9 per cent carbon) Steel. Magnified 500 diameters. (Stead.)

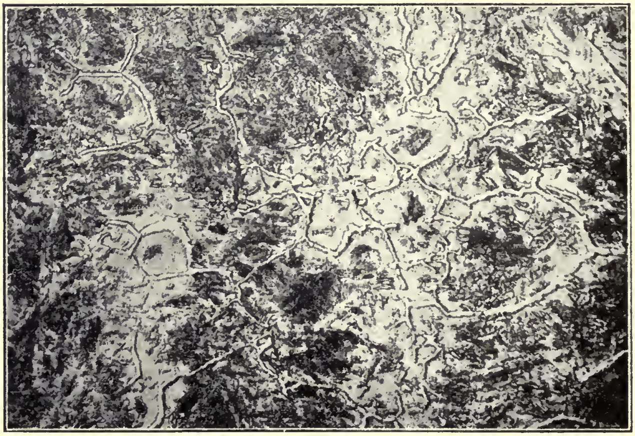

Fig. 224.—Cementite (white) forming network around Pearlite grains in 1·75 per cent Carbon Blister Steel. Magnified 15 diameters.

of ferrite. Pearlite is not a eutectic, as it is formed at a considerably lower temperature than that at which the steel has completely solidified; but as it has all the other characteristics of a eutectic, *e.g.*, definite chemical composition, constant temperature of formation, and a laminated structure under the microscope, it has been agreed to call it a eutectoid, as suggested by Professor Howe.

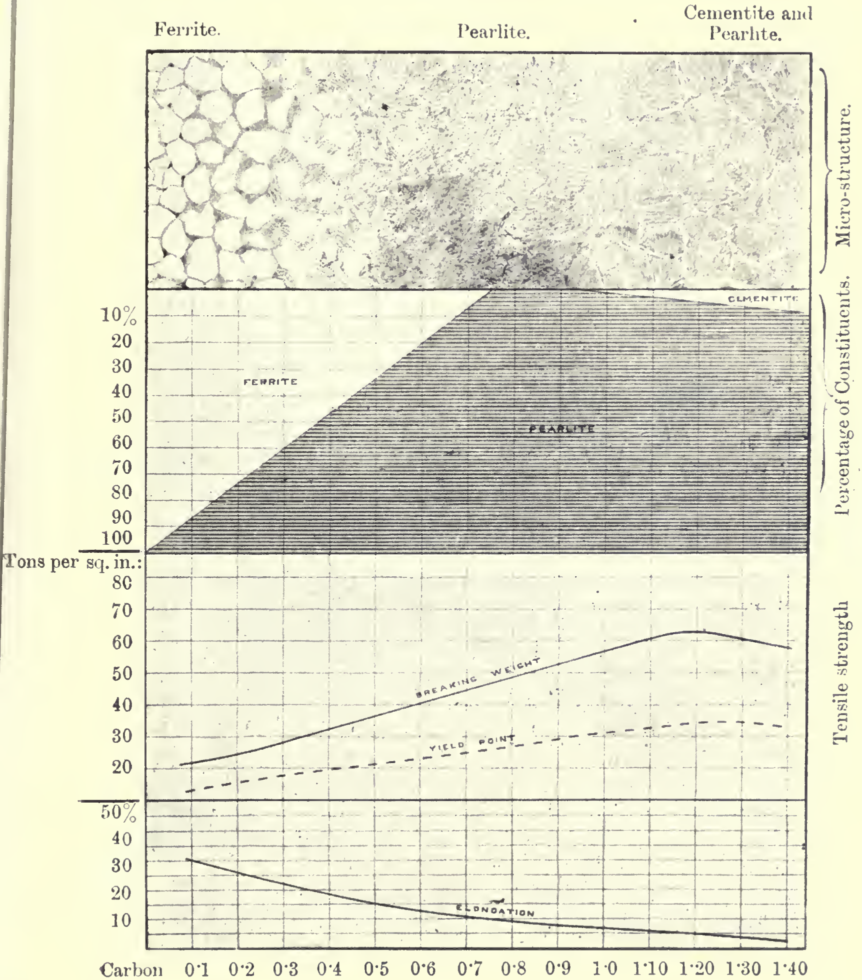

Fig. 225.—Diagram of Physical Properties of Steel (Stead).

High carbon steels containing between ·75 and 1 per cent of carbon are composed of pearlite; but the bands of ferrite decrease in thickness and in quantity with increase of the carbon. Below ·89 per cent the steels are called hypo-eutectoid, and show some structurally free ferrite surrounding the pearlite areas. When about 1 per cent is reached, the grains of pearlite are found to be more or less completely surrounded by free cementite, and with 1·2 per cent each grain is entirely surrounded by that substance. In tool steels containing 1·2 per cent or more carbon, when the forging into bars has been effected at temperatures during which the cementite was separating or has separated, from solid solution, instead of being present as envelopes to the grains, it is present in rod-like forms more or less broken up, which are parallel to the direction in which the steel was drawn out. When the carbon is further increased the cementite also increases, and yields thicker and thicker cell walls, bands of the same substance passing into and through the pearlite grains. This is best shown by blister steel, which, at the outer surface may be as rich in carbon as 1·75 per cent when the cementite envelopes are very thick as shown in Fig. 224.

The diagram Fig. 225 shows approximately the changes in the constituent structure of iron containing between ·05 and 1·4 per cent carbon, and ·4 per cent manganese after heating to 1,000 deg. Cen., and slowly cooling. It is only diagrammatic, but it gives a better idea of the structure than many photographs. Below the diagram of micro-constituents of the steel are diagrams showing the probable proportion of pearlite, ferrite, and cementite present, and the approximate tenacity, yield point and elongation of the steels in forged bars cooled in the air after hammering and rolling.

The composition or internal structure of the pearlite areas seems to vary in medium and high carbon steels with the different conditions of heating and cooling, being more openly laminated the slower the cooling and showing less free ferrite than would be expected from the carbon content.

Martensite.—When steel of almost any carbon content is quenched rapidly in water or iced brine, the passage over the critical points is so rapid that the usual changes which result in the separation of pearlite, with either ferrite or cementite, cannot take place, and the structure on etching shows a well-marked accicular or needle-shaped formation, in which the grains are seen to be arranged crossing in such a way as to suggest a triangular shape. Osmond has named this constituent Martensite, after Professor Martens, of Charlottenburg. But it is really not a single constituent of definite composition since it is found in all steels which have been positively quenched—with carbon content anywhere between 0·15 and 2·2 per cent. It may be regarded as a transition product in the decomposition of Austenite, and it varies in hardness according to its carbon content, being in fact a solid solution of iron carbide in one of the allotropic modifications of iron, probably beta. (Fig. 226.) On annealing a steel showing this martensitic structure, the needle shapes gradually disappear, and if the heating is sufficiently prolonged or carried at once to a temperature just above the Ar_1 point, the structure becomes pearlitic. On dissolving the hardened steel in dilute acid, a dense black residue is left which is quite different from the plates of Abel's iron carbide left on dissolving the unhardened steel. High power magnifications show the characteristic martensite structure to be made up of two differently etching portions in almost all cases except that of the ·89 per cent or eutectoid steel, when the structure is very minute and practically homogeneous. To this saturated Martensite, Professor Howe has given the name of Hardenite, which term is often now used synonymously with Martensite, which should always be named by its carbon content to indicate its variable nature and physical properties.

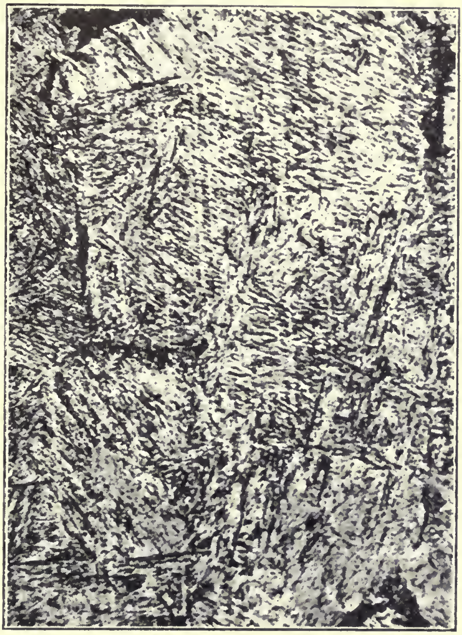

Fig. 226.—Martensite structure of ·26 per cent Carbon Steel, quenched in water from 950 deg. Cen. after prolonged annealing. This shows some dark areas of Troostite and a small proportion of free Ferrite (white). Magnified 300 diameters.

Hardenite.—The term Hardenite is used by Professor Arnold for the structure of "saturated steel" when quenched from just above the critical point. On etching the polished specimen, there is no structure discernible, and it appears to be an amorphous solid solution. On quenching this "eutectoid" steel from higher temperatures, however, intersecting needles are developed on etching. Arnold regards hyper-eutectoid steels when quenched as solid solutions of iron carbide and Hardenite, and the hardened hypo-eutectoid steels as solutions of Hardenite and Ferrite.

Dr. Stead points out that the characteristic needle structure is not always indicative of pure Martensite, as Troostite may also be present. Thus a ·9 per cent carbon steel, if quenched somewhat slowly from 900 deg. Cen., shows Martensite needles at the surface and Troostite needles beneath. The Troostite needles darken rapidly on etching, whilst the Martensite does not colour so rapidly. Slight etching of pure Martensite does not reveal the needle structure, but by stronger etching a selective action takes place and the needles appear; if the polished surface becomes completely brown, and is then slightly polished, the Martensite needles appear white on a dark ground, but if the needles are of Troostite, the repolishing will make them appear dark on a white ground of Martensite. (Fig. 227.)

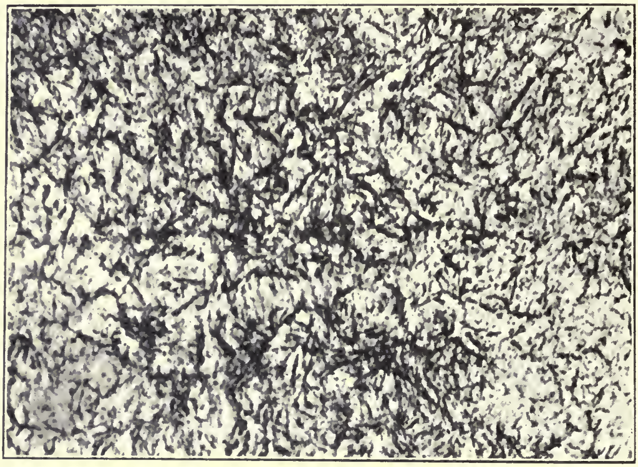

Fig. 227.—Hardenite or Saturated Martensite, ·89 per cent Carbon Steel, quenched in water from 800 deg. Cen. This shows a large number of dark etching needles of Troostite in a white ground mass of Martensite. Magnified 300 diameters.

Austenite.—At a temperature of about 1,200 deg. Cen. in steel containing 1·5 per cent of carbon, the carbide completely dissolves, and on chilling in ice-cold water little or none of it is found in the free state. The Martensitic needle-structure is well marked in the specimen after polish attack, or after a slight etching with ordinary reagents, when it appears as dark interlacing lines on a white ground. The white part is a new constituent discovered by Osmond, who has named it Austenite after Sir W. Roberts-Austen. It is not quite so hard as Hardenite, being scratched by a needle point which does not affect Hardenite, though neither can be cut or machined by the hardest tool steel. Sometimes the etching agents darken the Austenite areas and leave the Hardenite white, as is shown in Fig. 228. Austenite is a solid solution of iron carbide in gamma-iron and is non-magnetic, both at the temperature at which it is stable and when retained in cold steel by the mechanical effect of the compression during the severe quenching required to prevent its transition. It is remarkable that it is readily transformed into Hardenite with an increase in volume, by simple immersion in liquid air for a few minutes. The conditions for its occurence are rapid quenching from a temperature not less than 1,000 deg. Cen. in a liquid not above zero Cen. and the carbon content of the steel must not be below 1·1 per cent, and even then the whole structure is not entirely composed of Austenite, some of it always decomposing into Hardenite. It is rather a source of weakness than anything else, and hardly ever occurs in commercial steels, since even if it were formed accidently in quenching, the subsequent tempering would entirely decompose it into the stronger transition products.

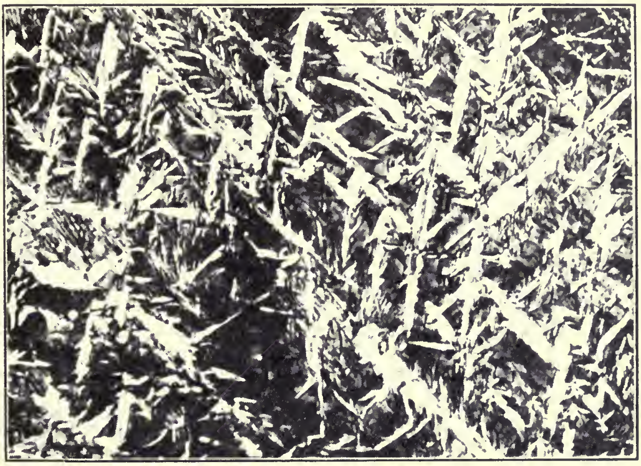

Fig. 228.—Austenite (dark) associated with Hardenite (white needles) in 1·6 per cent Carbon Steel, quenched from 1,100 deg. Cen. in iced brine. Magnified 300 diameters.

Transition Constituents.

Troostite.—When steels containing over 1 per cent of carbon are negatively quenched in oil, warm water, or in large pieces in cold water, or in any other way so that the cooling over the critical points is not very rapid, the polished section, on slight etching, indicates the presence of two, and when the carbon is very high of three distinct coloured constituents. The first, coloured brown, is amorphous, and is the softest constituent, and has been called "Troostite" by Osmond. The second, which is only slightly darkened on etching, is hardenite; and the third, which remains white, is cementite. On quenching and tempering high carbon steels Troostite is almost always present, and is detected by its readiness to assume a yellow or brown colour by the polish attack or on etching. Troostite is also present in steels of medium carbon content, when they are heated to 850 deg. and cooled to about 690 deg. Cen., and then quenched at that temperature in iced water, or are quenched from 700 deg. in warm water or oil (Fig. 229). The composition of Troostite must vary widely in high and medium carbon steels. It is one of the transition products of Austenite decomposing into pearlite and ferrite, which reaction has not been allowed time for completion on account of the rate of cooling.

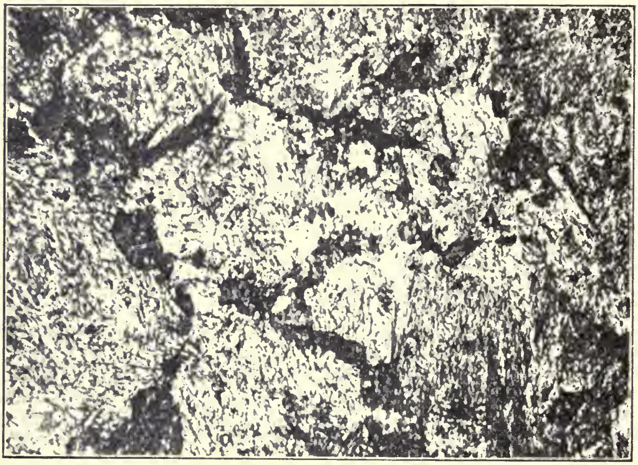

Fig. 229.—Troostite (dark) embedded in a ground mass of Martensite; produced by oil quenching ·65 per cent Carbon Steel from 750 deg. Cen. Magnified 300 diameters.

Sorbite.—This constituent was first described by Osmond, and he has since referred to it as unsegregated pearlite. It is difficult to distinguish from troostite, as its colour reactions are similar. Sorbite is more rapidly coloured than troostite, and whilst troostite is associated with martensite, sorbite is usually associated with pearlite, but it is almost certain that under some conditions of cooling, Troostite may be associated with Pearlite. Sorbite is an important constituent in steel, increasing its strength very considerably. Fig. 230 shows sorbite associated with Pearlite in a mild steel quenched in oil.

For years high-class wiremakers, by secret means which were carefully guarded, have produced wire rod having the excellent quality of enabling it to be drawn down to a much greater degree of fineness than was possible in the untreated material, and of giving remarkable toughness and strength to the finished wire.

The difference in the behaviour of the wire rods, before and after treatment, to the action of etching fluids is very pronounced. When they are cut, polished, and etched side by side in a bath of dilute nitric acid, the surface of the untreated wire assumes a grey colour, whereas the treated material becomes brown. On examining them under the microscope, pearlite is evident in both, but in the first or normal steel the cementite is less perfectly separated than in the second, and what is almost pure ferrite in the normal steel is replaced by sorbite in the treated material.

Fig. 230.—Sorbite (black) associated with Pearlite (grey) and Ferrite (white) in a ·26 per cent Carbon Steel, quenched in oil from 800 deg. Cen. Magnified 300 diamteers.

There can be no doubt whatever that it is the sorbite in the "patented steel" which is responsible for the improvement in the mechanical properties. It is now well known that the "patenting processes" consist of heating the steel to a high temperature and then subjecting it to a mild form of chilling, usually referred to as negative quenching, as, for example, in a bath of oil, not sufficient to produce the martensitic structure, but rapid enough to prevent the complete, or almost complete, separation of free ferrite and cementite in the pearlite. The good properties given to oil-quenched steel is largely due to the presence of Sorbite.

The following is an instance in which the value of Sorbite is shown, as the treated steel contained much unsegregated pearlite or sorbite ; indeed, it was difficult to detect the cementite in the pearlite areas. The medium carbon steel was quenched from 800 deg. Cen., reheated to 650 deg. Cen., and then cooled in air.

0·35 per cent Carbon Steel.	Normal.	Treated.
Breaking weight	42·2 tons	51·5 tons
Elongation in 2 in.	23 per cent	23 per cent
Contraction of area	36·1 ,,	38 ,,

Osmondite.—Professor Heyn has recently so named a new constituent in hardened steels which have been tempered at 400 deg. Cen., and which seems to be of definite constitution, although it is not clearly distinguishable under the microscope. It is described as a solid solution of iron carbide in alpha-iron, so that it is even less stable than the other transition products of Austenite into pearlite. Its presence is recognised by the steel, which although tempered, still retains the carbide in solid solution, being more rapidly dissolved in dilute sulphuric acid and more deeply coloured on etching with hydrochloric acid in alcoholic solution, than any of the other constituents. It may be looked upon as intermediary between troostite and sorbite in the series of changes which occur in letting down the hardness of quenched steel by tempering.

Constitution of Iron and Steel.

When a liquid solidifies from fusion it may behave in two ways. It may solidify as a whole, as when pure water freezes to ice, or it may solidify in two stages—first, a portion may solidify, leaving a larger or smaller quantity of a residual "mother liquor," which afterwards solidifies. In the former case the structure may be crystalline, but all the crystals will be of the same character ; in the latter there will be two or more forms of crystals, so that the resulting solid will not be homogeneous.

In the case of iron or steel when in the liquid condition, all the substances are held in solution in the excess of iron, but in what form they exist it is impossible to say. It may be that in many cases compounds are in solution which crystallise out on cooling, or it may be that the compounds which separate are formed during solidification, or in some cases during the subsequent cooling.

Steel.—When a mass of steel has solidified, the changes that may take place are by no means ended. That changes may and do take place during cooling has long been known, and the nature of the changes to some extent understood, but until the invention of the Le Chatélier pyrometer,* by which the temperature of a cooling mass of metal could be determined and recorded, it was not possible to determine the temperatures at which the changes took place.

If a mass of perfectly homogeneous material, such as a pure metal which undergoes no allotropic modification, be allowed to cool, the cooling will go on with perfect regularity, and if a curve be plotted with temperatures for the ordinates and time of cooling for the abscissae, the curve will be perfectly continuous ; or if the couple of a Le Chatélier pyrometer be embedded in the metal and a mirror galvanometer be used, the spot of light will move steadily towards the zero mark as the temperature falls.

When the same experiment is made with a mass of high-carbon steel containing about 1 per cent of carbon, starting at, say, 1,000 deg. Cen., the cooling goes on regularly till a temperature of about 700 deg. Cen. is reached, when it is suddenly arrested, and either becomes much slower or stops altogether for a time, or even the temperature may rise. Then uniform cooling is resumed, and goes on steadily till the temperature of the air is reached. This retardation of cooling, or recalescence, as it is called—for in some cases dealing with large masses of metal the amount of heat evolved may be so large as to produce a visible glow—can only be due to one of two causes : Either (1) the rate of radiation or heat loss must be arrested, so that the cooling takes place more slowly ; or (2) some chemical or physical change must take place within the mass of metal by which heat is evolved, thus compensating for the continued cooling due to radiation. The former alternative is very improbable, and the latter therefore is most likely the correct explanation of the phenomena. If the steel be quenched from a temperature above this point the metal will be hard, and the structure will be largely martensitic ; if it be cooled slowly over this point the steel will be comparatively soft, and the structure will be mainly pearlitic. The point is often spoken of as the critical point.

Further investigation has shown that the phenomena are much more complex than this, and that with steels containing less carbon there may be two or even three points of retardation of cooling, and by plotting a curve of these recalescences a diagram is got which is very useful in understanding the constitution of the iron-carbon alloys. It is shown in Fig. 231, which is a modification of Roozeboom's diagram, as it has been necessary to correct some of his theories in the light of more recent investigations.

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*The Le Chatélier pyrometer consists of a fused junction of two metals—one of thin platinum wire, and the other a similar wire of platinum alloyed with 10 per cent of iridium. When this junction is heated or cooled, a very small electric current is set up, which can be detected and measured by a suitable apparatus, called a galvanometer or millivoltmeter.

M. Chernoff introduced a notation which has come into general use for indicating these changes. He designates the temperatures at which there is an inequality (retardation of cooling, or arrest of heating) by the letter A. The retardations which take place during cooling he indicates by Ar, and the reverse changes, the arrests on heating by Ac. For every point Ar there must be a corresponding Ac, the changes being reversible, but it does not follow that the two points will be identical: indeed, the point Ac is usually about 30 deg. higher than the corresponding point Ar, thus showing that the changes in constitution take some time to accomplish, and this explains why it is possible to prevent them almost completely.

Howe and Osmond have shown that by hastening the cooling the critical point Ar is lowered, until, when the cooling is sufficiently rapid, there is no retardation, and Ar therefore disappears.

The critical points are indicated by the letters Ar_1 Ar_2 Ar_3 and Ac_1 Ac_2 Ac_3, Ar_1 and Ac_1 being the lowest and Ar_3 and Ac_3 the highest temperatures. With very mild steel (·09 per cent carbon) three points of retardation are noticeable. When the carbon exceeds ·3 the first critical point Ar_3 disappears, and when the carbon is about ·8 per cent the second critical point Ar_2 disappears, leaving only Ar_1. Before these two arrests disappear the temperature indicated by the highest point seems to fall till it coincides with the one next below, so that the critical points are not fixed temperatures under all conditions.

The stable modifications of the chief constituents in iron and steel are best represented in the diagram got by plotting the freezing-points and also the recalescence or critical points, using the percentages of carbon for abscissæ. From this it is obvious that there are in the slowly cooled alloys of iron and carbon, eight regions with fairly definite boundaries, and these are shown in the modified Roozeboom diagram given in Fig. 231. Recent research with the aid of the electric furnace shows the maximum solubility of iron for carbon in the form of one or other of the carbides, to be about 9·6 per cent, at a temperature of 2,220 deg. Cen., which solubility falls off with either an increase or a decrease of temperature. Thus below 1,837 deg. the maximum amount of carbon capable of being held in solution is approximately 6·7 per cent. In region I. the whole mass is liquid, and in the regions II. and III there exists a mixture of primary crystals and concentrating mother-liquor, whilst in all the regions below these, the metal is completely solid. With about 4·3 per cent of carbon the true eutectic of Austenite and graphite solidifies as whole, molten iron in region III., with more than this percentage of carbon, first of all throws out primary graphite during the crystallisation interval, thus impoverishing the mother-liquor in carbon until it attains the eutectic composition when it solidifies as an entity at 1,130 deg. Similarly in region II., it is primary Austenite which freezes out, thus enriching the liquid portion in carbon until the same eutectic composition is reached, when the Austenite-graphite eutectic freezes. (See Fig. 250.)

In region IV. Austenite or gamma-iron is the stable constituent, but when cooled below this, it is resolved into other constituents. Thus with less than ·3 per cent of carbon a transitory modification of beta-iron is stable above 750 deg. Cen. and in region V., and below

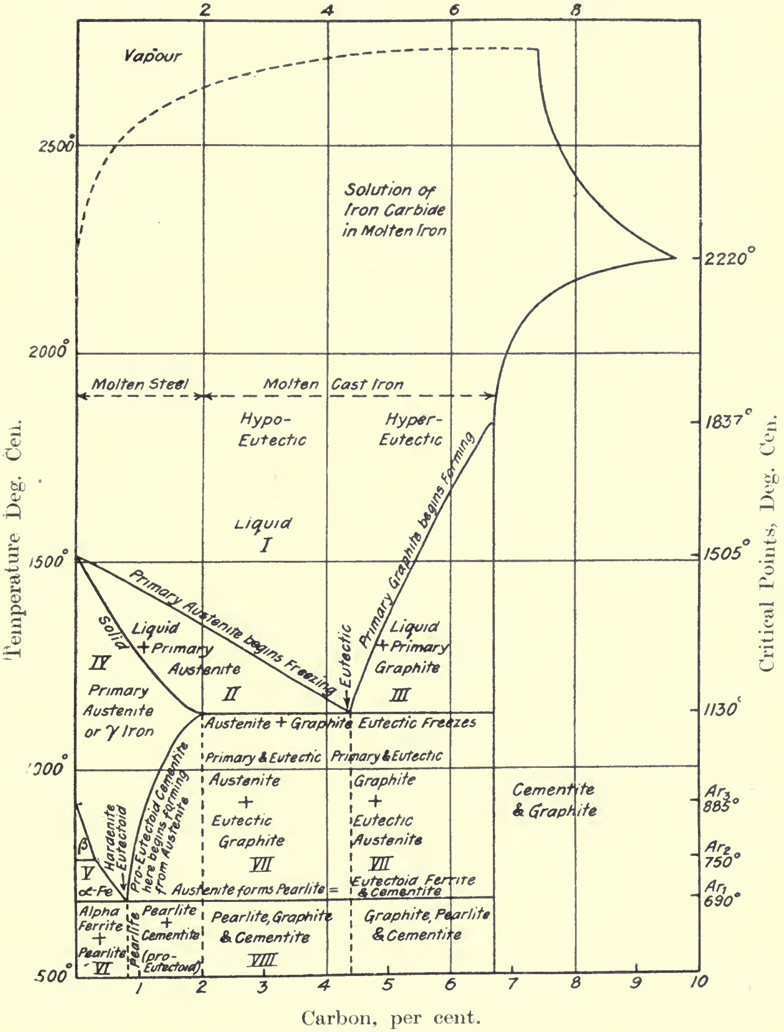


Fig. 231.—Stable Iron-Carbon Diagram.

it in VI., alpha-ferrite or magnetic iron is the stable form along with pearlite. At Ar_1 the decomposition of Austenite into pearlite, which is made up of eutectoid ferrite and cementite, is completed, this reaction or change not being instantaneous, and hence the numerous intermediate transition products occur, but cannot be shown on the equilibrium diagram. Above the eutectoid point it is no longer pro-eutectoid or “ excess ” ferrite which forms, but pro-ectectoid cementite. In the region VII. Austenite and graphite exist, but during slow cooling the Austenite decomposes, and after the final change the constituents found present in region VIII., at ordinary temperatures, are pearlite, cementite, and residual graphite.

In the case of the meta-stable iron-carbon diagram given by Roberts-Austen, the condition of affairs resulting from rapid cooling from above 1,130 deg. Cen. is shown, the chief difference being that in place of the Austenite-graphite eutectic there exists the unstable Austenite-cementite eutectic. (See Fig. 249.) Thus in region III., it is primary cementite which separates from the solution, and in region VII. pro-eutectoid cementite forms progressively. Region VIII. then shows only pearlite and cementite, but with this distinction that below the eutectic proportion the cementite is both eutectic and pro-eutectic, whilst above 4·3 per cent of carbon, there is primary cementite in addition. The unstable condition is largely removed by reheating the iron to a temperature well within the range of region VII., when a large quantity of the carbon separates as temper or amorphous carbon.

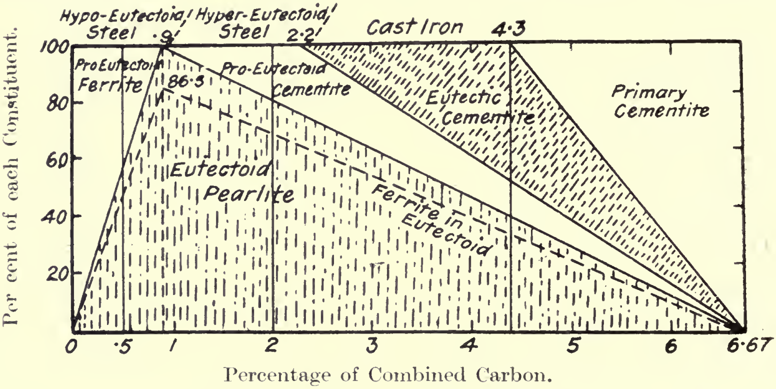


FIG. 232.—Constituents of slowly-cooled Steel and White Cast Iron.

The percentage of the constituents in slowly cooled steels and white cast iron is shown graphically in Fig. 232, from which it will be seen that the ordinates from the points giving the combined carbon content, cut the graphs in intercepts which express the relative amounts of the constituents which may be visible under the microscope. Thus from the formula $Fe_3 C$ it is obvious that pure cementite would contain 6·67 per cent of carbon, and that for each one per cent of carbon present the amount of cementite is 15 per cent. Since the structure is all pearlite at the eutectoid point with about ·9 per cent of carbon, it must contain 13·5 per cent of cementite and 86·5 per cent of ferrite, *i.e.*, a ratio of approximately

1 to 6; and hence the amount of pearlite in any medium or low carbon steel will be the percentage of carbon multiplied by 111. Thus, in a 0·5 per cent carbon steel, the total pearlite will be 55·5 per cent, made up of 7·5 per cent of eutectoid cementite with 48 per cent of eutectoid ferrite, the balance, *i.e.*, 44·5 per cent, being pro-eutectoid ferrite, sometimes described as excess or structurally free. Similarly a 2 per cent carbon steel will contain 30 per cent of total cementite, but the 70 per cent of eutectoid ferrite will hold about 11 per cent of eutectoid cementite, so that there will only be 19 per cent of pro-eutectoid cementite structurally free.

In white cast iron, with 4·3 per cent carbon content, the whole mass at 1,130 deg. Cen, consists of a eutectic of Austenite and cementite, the cementite containing 6·67 per cent of carbon, and the Austenite 2·2 per cent. Thus the amount of eutectic cementite which persists unaltered in the cold-stable state, is represented by (4·3 — 2·2) ÷ (6·67 — 2·2) or 47 per cent, and the remaining 53 per cent of eutectic Austenite on cooling gives rise to pro-eutectoid cementite 53 (2·2 — ·9) ÷ (6·67 — ·9) or 11 per cent, leaving the balance of 42 per cent of hardenite, which will become pearlite below 670 deg. and contain 5·7 per cent of eutectoid cementite with 36·3 per cent of eutectoid ferrite.

These percentages are of course by weight, so that the apparent area occupied by the various constituents on the surface of a micro-section, may be found to vary to a slight extent from the approximations arrived at by calculation or the use of the diagram.

Grey Iron.—In the case of ordinary hæmatite iron in the liquid condition carbon is readily absorbed, and if a large quantity of coke has been used in its production, large quantities of graphite separate whilst the metal is cooling and is still liquid, showing that at a high temperature molten iron can hold a larger quantity of carbon in solution than it can at lower temperatures. A considerable portion of the graphite does not separate till the iron is at least partially solid. That which separates while it is liquid floats to the surface and escapes, whilst that which separates later remains fairly equally distributed through the mass of silicon-ferrite. As this silicon-ferrite has a very much higher melting point than the iron containing carbon, the graphite must be rejected at the moment of solidification.

The condition of the carbon in the fluid metal is open to doubt. It has been argued that, as it is graphite which falls out of solution, it is that form of carbon which is dissolved in the iron. On the other hand, when minute particles of fluid grey iron are projected with force into ice-cold water, it is not graphite which is found in the chilled iron, but carbide of iron, or cementite.

This evidence can be interpreted differently. Either the carbon existing in the fluid iron as graphite instantaneously combines with the iron to form carbide, or it may originally exist as carbide, and, in consequence of instantaneous cooling, the decomposition into iron and graphite is impossible, and it therefore remains as carbide. The latter hypothesis appears to be the more reasonable, and is supported by the chemical examination of grey irons high in silicon after rapid and slow cooling. It is well known that the higher the silicon the less the amount of carbide of iron there is present in the cold iron, and that 4 per cent of silicon practically causes the whole of the carbon to separate as graphite during solidification. When such iron is dissolved in strong hydrochloric acid, the silicon is oxidised and gelatinises, whereas it does not do so in the same iron which is chilled from the liquid state, for it remains in a dense, compact form, and retains the shape of the original particles. The fact that silicon gelatinises in the one and not the other must be regarded as evidence of a difference in the condition of the silicon.

When iron with 4 per cent of silicon, but free from carbon, is poured into ice-water, and is afterwards dissolved in acid, the silica gelatinises just as it does in the same normally-cooled material and in the slowly-cooled grey pig iron; chilling, therefore, this carbonless silicon iron does not affect the silicon condition. We are therefore forced to conclude that it is the difference in the carbon condition in the normal and chilled grey iron to which we must look for the cause of the difference in the silicon condition.

In dissolving ferro-silicons containing between 4 and 8 per cent silicon in acid, the silica gelatinises. The metals containing more silicon than 8 per cent do not do so, and the silica remains dense and retains the shape of the pieces of iron treated. Although it cannot be absolutely proved, are we not justified in regarding it as a reasonable hypothesis that in the chilled grey iron the silicon-iron compound contains 8 or more per cent of silicon, and that for this reason it does not gelatinise. If we accept this explanation, we must admit that when the iron is fluid the silicon and iron are differently associated than they are in the slowly-cooled metal, and that in solidifying a part of the silicon in the high-silicide portion of the fluid iron leaves it and combines with the iron originally combined with the carbon, causing a separation of graphite. The important discovery of P. Lebeau that silicon will pass into and diffuse in iron just as carbon does, tends to strengthen the hypothesis.

If the 3·5 per cent carbon existed as Fe_3 C in the fluid iron, there would be 52·5 per cent of the carbide and 47·5 per cent of iron associated with the 4 per cent of silicon. This latter portion, if separated, would contain 8·4 per cent silicon, or a compound which, as has been shown, does not gelatinise in acid.

It is conceivable that the exponents of the graphite solution hypothesis might argue that in the act of rapid chilling the carbon instantaneously combines with the iron, driving the silicon into the residuum, but as this involves a double instantaneous reaction it seems hardly probable.

The more simple hypothesis that chilling retains the relations of the carbon, iron, and silicon existing in the fluid iron is justified by the evidence afforded by what occurs when medium carbon steel is chilled in water, for it is now admitted that chilling retains the carbide in solid solution, the state in which it existed at a high temperature.

Phosphorus.—Phosphorus exists in the solid iron in the form of a fusible phosphide eutectic, shown in Fig. 233, which necessarily is last to solidify (at about 980 deg. Cen.), and as this is found bedded in the centre of the silicon-ferrite crystals, it seems that solidification commences at the borders of the graphite plates and grows from them, forcing inward the fusible phosphorous compound (Fe_3P).

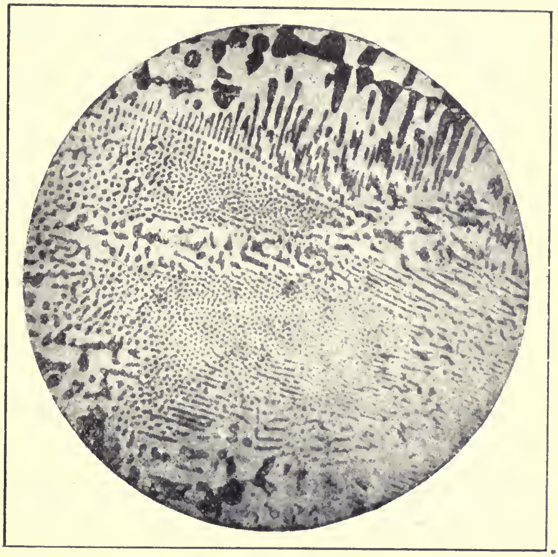


FIG. 233.—Ingot containing 10·2 per cent Phosphorous and 89·8 per cent Iron (Stead). It is the eutectic of iron phosphide and iron. It has only one critical point, at about 980 deg. Cen. Magnified 300 diameters.

Fig, 220, which is a sample of No. 3 Cleveland iron containing 1·6 per cent of phosphorus, shows the position of the carbon plates and the phosphorus compound. Fig. 219 is a No. 1 hæmatite pig containing almost no combined carbon. It is interesting as showing the separate crystal grains of the silicon ferrite and absence of the phosphide eutectic. When such a pig is broken, the fracture follows the cleavage of the graphite flakes. The graphite frequently assumes the form of curved plates, the edges of which are seen in the cut sections.

As the percentage of silicon is increased the carbon decreases, and with 20 per cent of silicon there is an entire absence of carbon, and the iron breaks with a silvery white fracture. In high silicon irons the metal between the graphite plates is easily fractured, the lines of weakness being the cleavage planes of the crystal grains. Such irons therefore give the peculiar fracture known as "glazed" or "glazey iron." The larger the percentage of phosphorus the less silicon is required to make the iron "glazey." For instance, Cleveland iron is glazed with 4 per cent of silicon in the presence of 1·5 per cent of phosphorus, whereas hæmatite iron must have at least about 7 per cent of silicon to give an equivalent appearance. The reason seems to be: (1) 1·5 per cent phosphorus combines with about 8·5 per cent of iron, which cannot combine with carbon, and the graphite is therefore less than in hæmatite metal; and (2) the phosphorus compound is itself brittle, and the fracture has a more easy track through it.

When the silicon in pig iron is low, the fracture is close in texture, as in forge grey irons, or is white or white with specks of grey, as in white and mottled irons.

In forge grey irons only part of the carbon is present as graphite, and this is in thinner flakes than it is in Nos. 2 and 3 qualities. In good No. 4 the mass of the metal consists of pearlite, and the phosphorus compound is still found in the same relative position as in the grey varieties, but usually in greater numbers of smaller masses, and is more evenly distributed. In hard forge iron there is less graphite, and free cementite appears.

White Iron.—White iron shows no grey spots, and consists of cementite, pearlite, and, if phosphorus be present, of the phosphide eutectic. There are two distinct classes of white iron. The purest classes of Swedish iron represent the first class, in which the fractured surface is not regular, and is free from large cleavage planes of cementite; the second in which the fracture passes between the massive plates of cementite, and yields bright, flat cleavages. This iron has been called sparry iron when manganese is not in quantity, and spiegeleisen when between 5 and 30 per cent of manganese is present.

Fig. 234 shows the structure of Swedish white iron containing about 4·0 per cent carbon and 0·2 per cent silicon and traces of manganese. The dark areas are pearlite, the white are cementite. The pearlite areas are arranged in symmetrical order corresponding to the axes of an octahedron, and resemble the crystallites which first fall out of solution in many alloys. The spaces between these crystallites have the well-known character and structure of the honeycombed type of eutectics, and consist of cell walls of cementite and cell substance of pearlite. It is without doubt the true eutectic of white irons, containing little or no phosphorus. The symmetrical geometric disposition of the pearlite areas points to the fact that it first began to crystallise from the liquid, a little in advance of the eutectic with which it was associated, and that as soon as the eutectic point was reached the residue solidified into hardenite and free cementite, the former splitting up into pearlite with lamellar cementite and ferrite on cooling through the Ar_1 critical range.

Fig. 235 shows the structure of spiegeleisen in which the broad bands represent the sections of plates of cementite, consisting of $(Fe\,Mn)_3\,C$. On fracturing the section, the cleavage passed through the centre of these plates. The metal on each side has the structure of the honeycombed eutectic. It is evident that it is the massive plates of cementite which first crystallised out of the liquid iron, the eutectic solidifying at a later period. The contraction cavities

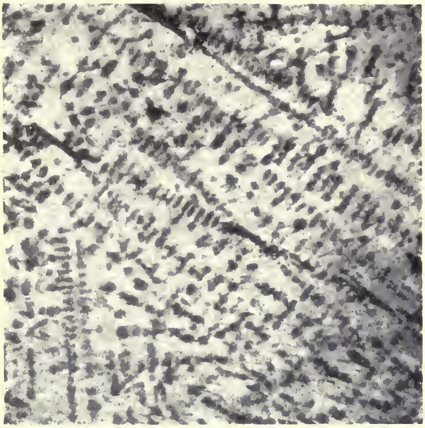


Fig. 234.—Swedish White Iron. Magnified 20 diameters. (The dark parts are pearlite; the white parts cementite eutectic.) (Stead).

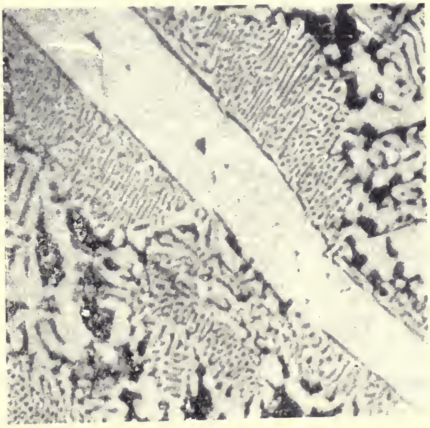


Fig. 235.—Spiegeleisen. About 5·5 per cent Carbon. Magnified 60 diameters (The broad band is a crystallite of the carbide of iron and manganese; the intergranular mass is carbide eutectic.) (Stead.)

in spiegeleisen and sparry iron often contain plates of cementite attached to the body of the pigs; these having crystallised in advance, the eutectic contracts before solidification into the surrounding iron, leaving the plates in the free state.

In the first class, represented by white Swedish iron, liquid pearlite is in excess, and solidifies in advance of the eutectic ; in the second it is the cementite which exceeds the eutectic proportion and first falls out of solution.

In presence of much phosphorus, as in ordinary Cleveland white iron (Fig. 236), the fracture often shows small cleavage plates of cementite ; but if silicon and sulphur are low and manganese present to the extent of 1·5 to 2 per cent, the fracture then resembles that of spiegeleisen with large cleavage faces.

The difference in structure of the non-phosphoric and highly-phosphoric iron is very marked.

Phosphide of iron and cementite in pig irons remain white, and stand out in relief after polishing and etching. The former for a long time was believed to be cementite, but recent research has shown that on heating the polished sections in a bath of molten tin to a temperature of about 300 deg. Cen. oxidation tints appear on the surface, and when the cementite has assumed a red-brown colour the phosphide of iron has a pale yellow tint. On continued heating the phosphide at one period becomes salmon in colour and then heliotrope-purple. No other constituent at any stage assumes the salmon tint. It is therefore distinctive of phosphide of iron.

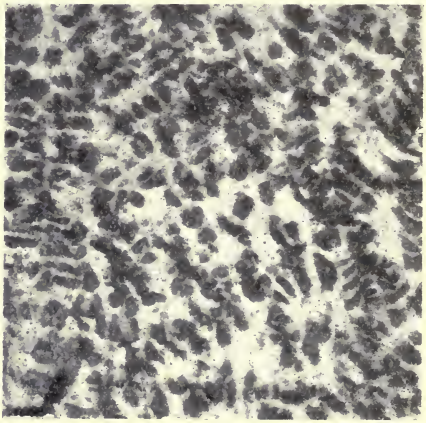


FIG. 236.—Cleveland White Iron. Magnified 20 diameters. (Stead.) (The dark areas are pearlite ; the white are cementite and phosphide eutectic.)

Sulphur.—When iron free from manganese is melted with a little sulphur, at the point of solidification the sulphide of iron, Fe S is thrown off to the borders of the crystals, and is easily detected on polished surfaces in the form of more or less continuous pale brown lines, which are sections of the cell wall envelopes of

Fe S. Fig. 237 is a good example of a sample with 1 per cent sulphur. It was Arnold who first discovered this behaviour of sulphides.

Such metal at red heat is simply a mass of iron grains stuck together by a substance free from ductility, so that when struck it easily breaks, and is, therefore, excessively red and cold short.

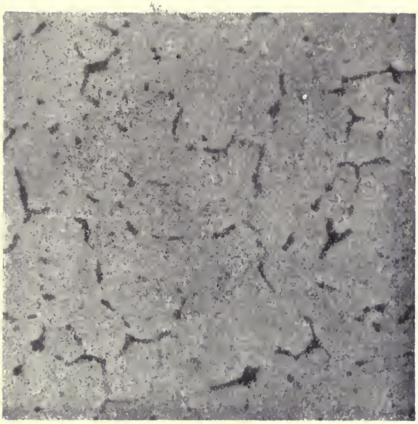
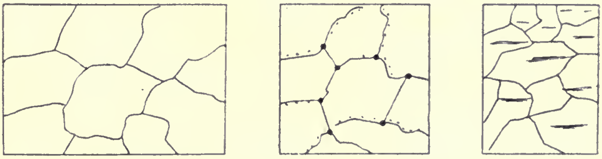


Fig. 237.—Steel containing 1 per cent Sulphur. (The dark areas are sulphide of iron; the white areas ferrite.) Magnified 160 diameters. (Stead.)

No steels are ever made with so much sulphur as 1 per cent. The photomicrograph, therefore, is only given here as illustrating in an exaggerated form the way sulphides dispose themselves in iron.

Manganese is added in the finishing of all commercial steels, the effect of which addition is to decompose any sulphide of iron which may be dissolved in the fluid steel, according to the reaction—

$$FeS + Mn = Fe + MnS.$$



As Cast. On Cooling. After Rolling.

Fig. 238.—Diagram of effect of Sulphur on Steel.

Judging from a large amount of metallurgical experience, it would appear that sulphide of manganese is less soluble in iron and steel than sulphide of iron, and that during the solidification of the steel the sulphide of manganese separates at an earlier period than sulphide of iron. At the point of solidification, however, the sulphide of manganese also forms envelopes around the crystalline grains of the steel, but when the masses of steel are comparatively large they soon break up and form into globules, which distribute themselves at more or less equable distances apart, thus allowing the metallic portions of the contiguous crystal grains to perfectly cohere. The diagram Fig. 238 illustrates what occurs when steels containing sulphur solidify immediately after casting, and how the sulphide separates on cooling, after annealing and after rolling.

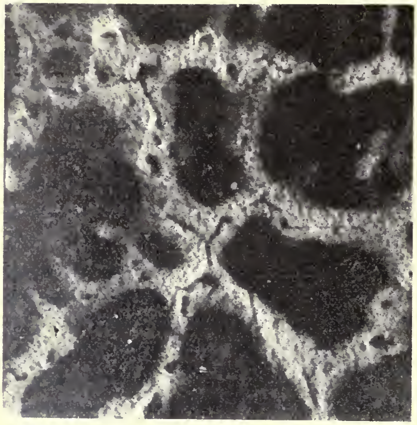


FIG. 239.—Brittle Steel Casting, showing intergranular deposits of Sulphide of Manganese in the Ferrite. (The dark parts are pearlite.) Magnified 60 diameters. (Stead.)

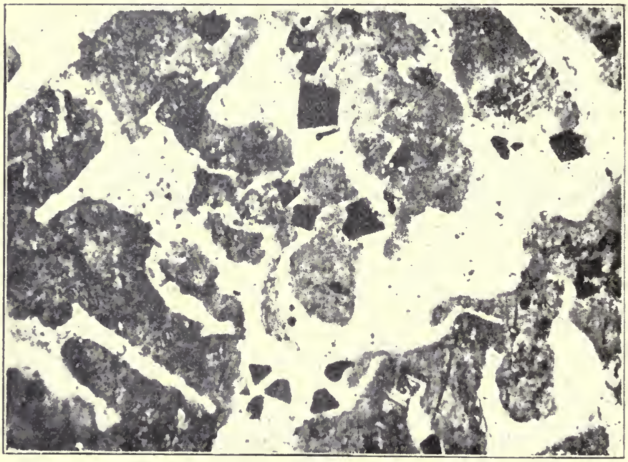


FIG. 240.—White Iron, containing ·7 per cent of sulphur, showing black cubes of MnS, in ground mass of Cementite (white) and Pearlite (dark). Magnified 120 diameters.

Steel castings frequently contain crystal grains partially enveloped with sulphide of manganese. Such castings are remarkable for their brittleness. On bending the polished specimens, and then examining under the microscope, it is seen at once that the fracture commences at the sulphide envelopes, and, once having started, traverses the whole mass. Fig. 239 is an example of a brittle casting.

The same material was made good by annealing at 900 deg. Cen. The sulphide envelope was, after such treatment, discontinuous and consisted of globules.

When sulphur occurs in iron which is white, the manganese is usually sufficient to combine with it, forming small cubical crystals of MnS, which show up well on etching, scattered through the cementite ground-mass as seen in Fig. 240.

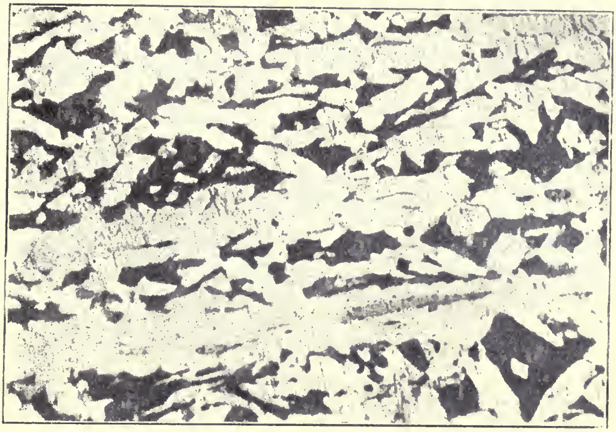


Fig. 241.—Slag inclusion in Mild (·3 per cent) Steel, showing grey in Ferrite "ghost," or carbonless area, and black patches of Pearlite. Magnified 120 diameters.

Levy has shown by microscopical evidence* that sulphur, when not above ·8 per cent in cast iron, separates as sulphide of iron in absence of manganese. This separation takes place in juxtaposition with small cementite crystals, at about 1,130 deg. Cen., along with the austenite-cementite eutectic, thus forming a triple eutectic, which prevents the coalescence of the cementite, as a preliminary step in its decomposition into ferrite and free carbon. The persistence of the sulphide links throws the cementite into an emulsified form, thus necessitating several hours' heating at a high temperature before coalesence can occur, and this is said to explain why sulphur has the power of retaining the carbide in the form of cementite, and so keep the iron white during the short period of solidification and cooling of cast iron in ordinary practice.

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* Journal Iron and Steel Inst., vol. ii., 1908.

Slag.—When this occurs in steel it is chiefly a mixture of managnese sulphide and silicate which has been entrapped during the solidification of the metal, and is not a serious defect if it occurs only in small scattered shots. If these are at all segregated however, they may lead to serious trouble, amounting to fracture if they exist near the surface. They are readily visible on the polished section, and are seen to lie in the ferrite portions when the steel is etched, as shown in Fig. 241. The most common occurrence of slag is in malleable or wrought iron, which owes its fibrous structure to the elongation of the slag patches during the rolling. The structure of the longitudinal section is shown in Fig. 242, which clearly reveals the ferrite structure of the ground-mass.

FIG. 242.—Slag in Wrought Iron, showing black in Ferrite ground mass. Magnified 60 diameters.

CHAPTER XLIV.

HEAT TREATMENT OF IRON AND STEEL.

The thermal treatment of iron and steel has for long been recognised as constituting one of the most important branches of metallurgy, and much work has been done on the subject within recent years, only a brief outline of which can be given in the space of one chapter. The term is sometimes erroneously applied to the whole working of these materials from the ore to the finished product, but it is more generally restricted to the heat treatment given to the metal in order to bring it into the required condition for the varying purposes to which it may be put.

The physical properties of the metal are very profoundly altered by varying the heat treatment, in which annealing and quenching are the chief operations, and it was soon understood that the chemical composition had a large part in governing what was the correct mode of treatment. So long as the results obtained were judged only by mechanical tests or the appearance of the fracture produced, considerable uncertainty existed and unreliable results were common, but with the application of the pyrometer and the microscope has come a remarkable improvement in the control of the heat treatment, so that much better results are now possible with all classes of material.

Cast Iron.—The thermal treatment of cast iron is for the most part confined to the two opposite objects of chilling, to produce on the surface of a soft grey iron a hard or white skin, and annealing of hard white iron castings to produce soft malleable material. The annealing of grey cast iron is only resorted to in the event of the casting being too hard to machine easily, in which case some of the combined carbon is " let down " to the " temper " or amorphous condition, and thus softens the metal, or, in the event of too rapid cooling, internal strains may have been set up, and a mild annealing is used to relieve these. However, if the temperature of the casting be maintained in the region of 800 deg. Cen. for about half an hour, a very considerable reduction in the strength of the metal results, due to the breaking down of the pearlite structure and the formation of more uncombined carbon. Grey cast iron which is subjected to repeated heatings has been shown to increase both in volume and weight, and after developing extreme brittleness it may eventually become almost completely disintegrated. This is due to most of the graphite being oxidised out, and the iron with silicon dissolved in it, becoming oxidised to iron oxide and silica respectively. Such a brittle or " burnt " structure is shown in the micrograph (Fig. 243), which shows the change brought about in a fire bar re-heated only about 200 times; it may be compared with the structure of the untreated or normal bar shown in Fig. 244. Carpenter has shown that to prevent this growth it is necessary to control the composition within narrow limits, introducing manganese to about 1·5 per cent, and keeping the carbon and silicon down to 2·5 and 0·5 per cent respectively, which means that the iron is almost white.

The effect of chilling a 2·5 per cent silicon iron which, with normal cooling, would develop a large proportion of graphite, is to retain most of the carbon in the combined condition, so that the structure shows a ground mass of cementite in which is embedded a considerable amount of pearlite which is most likely to be sorbitic in character, and the rapid cooling may leave some of the characteristic austenite-cementite eutectic, as shown in Fig. 245. This is the edge of a chilled grey iron casting, and only a short distance from this area the graphite has separated out in flakes in the pearlite, which is still interspersed with cementite, as shown in Fig. 246.

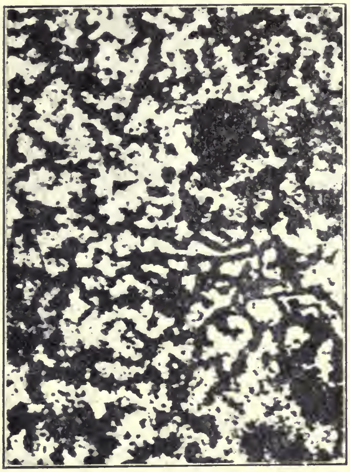


FIG. 243.—"Burnt" Cast Iron. White—Ferrite, Black—Iron Oxide and Silica as a Silicate. V. 90 X.

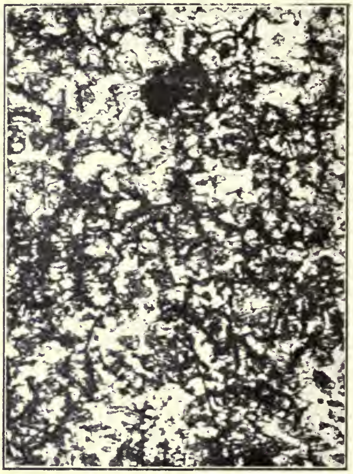


FIG. 244. — Normal Cast Iron. White—Silicon-Ferrite. Black—Graphite Flakes, Grey—Pearlite. V. 90 X.

White Iron.—The annealing of white cast iron is now very extensively practised in the production of what in this country are termed malleable castings, but elsewhere it is often known as malleable iron or even as semi-steel. The operation is usually conducted in Europe by packing the white iron castings in an oxidising material, such as iron ore, and maintaining them at a temperature of about 950 deg. Cen. for 120 to 150 hours, which produces ductile material as introduced by Reaumur. There is a small amount of the carbon removed by oxidation particularly at the surface of the metal, but the change is brought about by the decomposition of the carbide (cementite) into almost pure iron (ferrite) and carbon which is precipitated, not in flake form as happens from molten metal, but in a very fine, amorphous condition, when it is called " annealing " carbon, corresponding to the " temper " carbon of Ledebur. This form of carbon does not induce fracture of the metal when hammered as would flakes of graphite, and the brittleness has been removed by the alteration of the free cementite, only a small amount of combined carbon being left in the condition of pearlite. This structure is shown in Fig. 221, in which the white ground-mass is ferrite, the half-tone areas pearlite, and the black portions represent the amorphous carbon. A part of the pearlite area is shown more highly magnified in Fig. 247, which indicates very slow cooling of the metal to produce such distinct lamination of the pearlite. In the American method of making " Blackheart " malleable castings, the articles are packed in a material which is not oxidising, and are heated to about 750 deg. Cen. for a period of about 80 hours. In this way much less carbon is eliminated, and the patches of amorphous carbon are larger and more numerous. This is clearly shown in Fig. 222, which also illustrates the complete decarburisation of the surface layer.

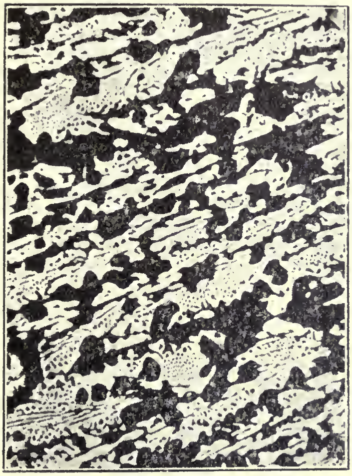


FIG. 245.—Chilled Grey Iron (Edge). White—Cementite, Black—Sorbite, Eutectic — Austenite — Cementite. V. 90 X.

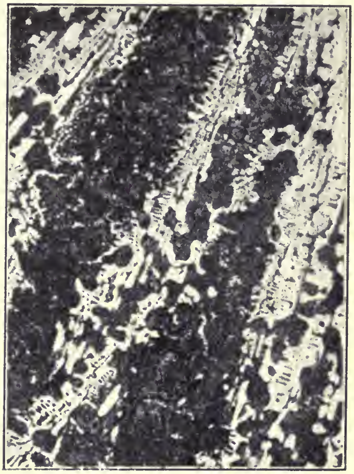


FIG. 246.—Chilled Grey Iron (Centre). White—Cementite, Black—Pearlite containing Graphite Flakes. V. 90 X.

Low silicon white iron, even when cooled moderately slowly as in ordinary casting, permits the pearlite areas to become fairly well laminated, but if the metal is now heated to about 950 deg. Cen., and quenched in cold water the structure is very different, as shown in Fig. 248. The ground mass of cementite is practically unaltered, but the areas formerly occupied by the pearlite now consist of Austenite (white) in a matrix of Troostite (black).

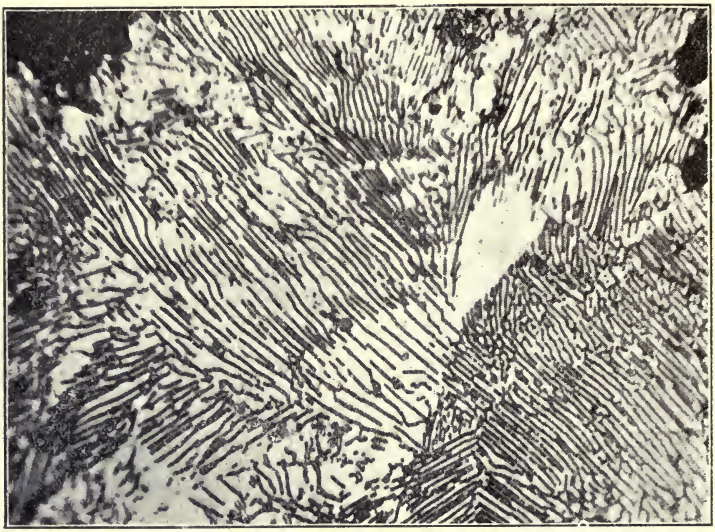


FIG. 247.—Pearlite area in Reaumur Malleable Iron. Magnified 900 diameters.

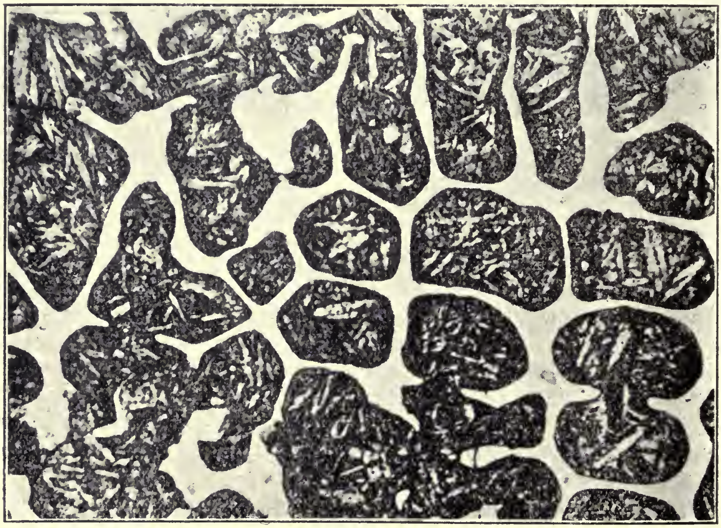


FIG. 248.—Quenched White Iron, Carbon 3·2 per cent. White ground mass —Cementite, Black Areas—Troostite containing white needles of Austenite. Magnified 240 diameters.

If iron of the eutectic composition, *i.e.*, containing 4·3 per cent of carbon be quenched immediately on solidifying at 1,135 deg. Cen., a characteristic structure is formed consisting of Austenite-cementite eutectic, for which Wüst has suggested the name Ledeburite. This is illustrated in Fig. 249, showing two sections of the metal taken at right angles to one another. However, if the quenching be even

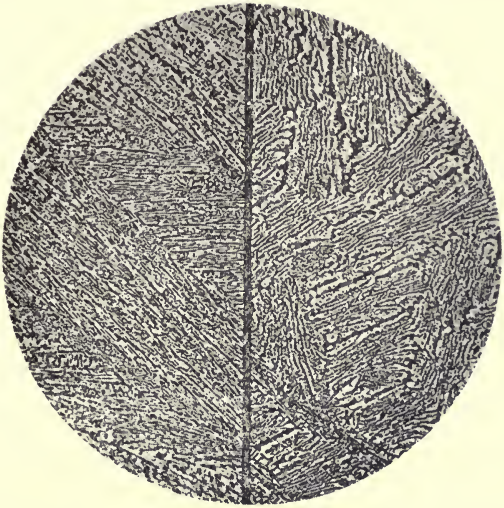


FIG. 249.—Ledeburite, Eutectic Structure of Austenite and Cementite in 4·3 per cent Carbon-iron quenched at 1 130 deg. Cen. (Wüst.) Magnified 90 diameters.

FIG. 250.—Eutectic Structure of Austenite and Graphite in 4·3 per cent Carbon iron slowly cooled from fusion and quenched at 1,000 deg. Cen. (Campbell.) Magnified 30 diameters.

slightly delayed, or silicon up to 1 per cent is present, graphite begins to make its appearance, and by sufficiently slow cooling over the eutectic range, Campbell has been able to develop a structure of a true Austenite-graphite eutectic, shown in Fig. 250, as proving that graphite can be formed from the molten state and not necessarily from the decomposition of cementite. However, as Howe points out, cementite is most usually the form first assumed by the carbon of solid iron, and from the decomposition of this cementite there results a large part and often the whole of the graphite which eventually forms. The change from cementite to graphite is exothermic, and hence in the direction of greater stability, taking place even in spite of the opposition to the change set up by the bulkiness of the resultant graphite. Microscopic evidence shows that cementite often changes directly into graphite without passing through solution in Austenite, whereas there is no such evidence of a direct change from graphite into cementite.

STEEL.

The heat treatment of steel is of much greater importance than that of cast iron, since most steel has, after casting, to be reheated and cooled several times and in different ways before the metal is turned out in a finished condition. Mechanical treatment is often an accompaniment of the thermal treatment, and the effect of these, either separately or together, can now be most intimately studied by the aid of the microscope.

Annealing is the term most generally applied to any kind of reheating of the metal, and may be for such widely diverse purposes as bringing the whole mass of steel to a desired uniform temperature prior to rolling or forging, and sometimes even welding. It may simply be for the purpose of removing the internal stresses set up by the work put upon it, more particularly when the temperature has fallen below red heat, and it is a necessity after such operations as wire drawing, &c. Previous to hardening the steel by quenching, the metal must be treated by annealing at a suitable temperature, in order that the chilling may confer the requisite degree of hardness upon it, and if the brittleness produced by hardening is too great, then a mild form of annealing is used to temper the material by letting down the unstable structure to one which is less hard. Naturally such diverse purposes require different degrees of annealing, and the carbon content of the steel is also a most important factor in determining the temperature at which the annealing must be effected. The mass of the metal, as well as the time taken in the process, must further be considered, and the atmosphere of the furnace used must be so regulated as not to alter the composition of the outer layer of the steel, as it is apt to do if it is not kept reducing or at any rate nearly neutral.

The general effect of annealing is to soften the steel and give it a greater ductility, and although the tensile strength may be lowered, the elastic limit is often slightly raised. Drastic annealing, either at too high a temperature, or prolonged for too long a time, produces a very considerable weakening of the metal, and for most purposes the temperature of the highest recalescence point should not be much exceeded. A steel which has been raised to a temperature of 900 deg. Cen., for a few minutes and then allowed to cool naturally in air, is frequently referred to as Normalised. The term "overheated" is applied to steel which has been annealed at too high a temperature, often considerably above the point Ac_3, and allowed to cool without having any work put on it to reduce the very large grain-size produced by the over-heating. The ill effects of this can, in most cases, be removed from the steel, provided the annealing at the high temperature has not been unduly prolonged, by simply reheating to the correct annealing temperature for a few minutes, this point depending upon the carbon content and being only a little above the top critical temperature. This restoring process is sometimes referred to as heat refining for grain, but a more certain result can be got by the expedient of mechanically treating the metal by rolling or forging, during the period it is cooling down to a little below the lowest recalescence point. Work below that point greatly increases the brittleness of the metal, while finishing at any appreciably higher temperature lowers the strength. Overheated steel is characterised by a very coarse crystalline structure, which makes the metal liable to fail under stresses which would be withstood by the steel if properly heat-treated. The microstructure shows a typical triangular appearance in mild steels, and in medium carbon steels the ferrite branches seem to penetrate the pearlite areas in a lattice formation which is admittedly brittle. Stead's brittleness is a peculiarity exhibited by dead mild steel, containing less than 0·15 per cent of carbon, which has been subjected to a prolonged annealing at a temperature between 600 deg. and 700 deg. Cen. Stead showed that the coarse crystallisation in this case could commence at as low a temperature as 500 deg., and might still be vigorous at 750 deg., but, like over-heating, this fault can be completely removed by a short annealing at about 900 deg. Cen. The damage seems to arise from the low temperature annealing being able to bring the orientation of the ferrite crystals in considerable areas into the same direction, so that the cleavage planes are made parallel, and thus a shock is liable to produce fracture. The heating to over the Ac_3 point restores the strength and ductility by allowing the crystals to again assume their normally hetrogeneous orientation.

Burnt Steel.—This term is commonly applied to all overheated steel, but it is only correctly used for steel which has been heated to near its fusion point. The temperatures at which incipient fusion commences in various carbon steels has been most recently determined by Gutowsky, who showed that the boundary line of Regions II. and IV. of the Roozeboom diagram (Fig. 231) must be considerably lowered from the determined recalescence points. Thus the burning of medium and high carbon steels commences at a temperature almost 100 deg. Cen. lower than was formerly believed possible, and the structure he got on quenching showed the small Austenite-cementite areas of eutectic solidified from fusion. Figs. 251 and 252 show the changes of structure caused by quenching high carbon steel at slightly different temperatures. Stansfield considers that steel burned to this stage may also be restored like simple overheating, but such is not the case

Fig. 251.—Austenite and Hardenite Structure of completely Solid Steel (C. = 1·76 per cent) quenched in water at 1,120 deg. Cen. (Gutowsky.) Magnified 200 diameters.

Fig. 252.—Austenite-Cementite Structure in the "Fusion Spots" of partially molten Steel (C. = 1·76 per cent) quenched in water at 1,170 deg. Cen. (Gutowsky.) Magnified 200 diameters.

when the burning has been continued long enough to permit the liquid portions to segregate to the surface and escape, leaving a cavity the surface of which is readily oxidised. Gas may even be generated inside the metal at the junction of the much enlarged crystals, and an actual separation may ensue. Fig. 253 shows a mild steel which has been burned, and not only is the pearlite in a powerfully over-heated condition, but there is a distinct film of iron oxide traversing the ferrite envelopes, and this inclusion renders the metal exceedingly liable to fracture. No heat treatment short of remelting can remedy this fault. Ingots and castings do not become burnt in passing from the molten to the solid condition on account of the fact that they are protected by the evolution of reducing gases dissolved in them, but on reheating the rolled steel there is not only the very coarse crystallisation induced, but also air may penetrate the mass along the crystal faces which have only a loose cohesion at the high temperatures which must be attained to produce burning. Even a sudden cooling from the high temperature does not prevent this defect.

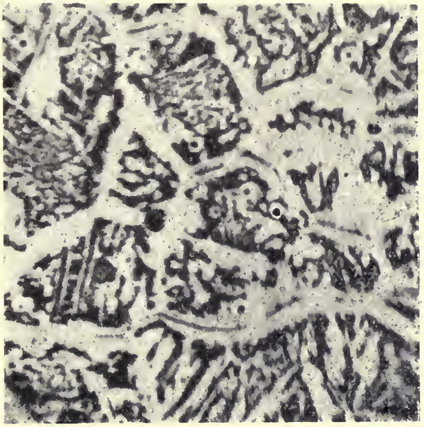


FIG. 253.—Burnt Mild Steel (Carbon = 0·3 per cent) showing Intergranular Formation of Oxide of Iron in the Central Ferrite Envelopes. (Stead.) Magnified 80 diameters.

Quenching.—This operation is performed by suddenly cooling the metal from a bright red heat, and the degree of hardness produced depends first, upon the carbon content, increasing as this rises; secondly, to a less extent, upon the temperature from which the steel has been quenched; and thirdly, and most decidedly, upon the rate of cooling over the critical points. The hardening of very mild steels is hardly perceptible, except by a microscopical examination, and is usually most pronounced with steels containing over one per cent of carbon, *i.e.*, tool steels. If the quenching is done from a point below the pearlite transformation (690 deg.) no hardening at all will result, and, on the other hand, if the quenching temperature be much above the Ac_3 point, the steel is likely to be excessively brittle. The best temperature from which to quench any steel is just above the lower boundary line of the area of Region III. (Fig. 231), which gives the maximum hardness combined with the smallest grain size. The rapidity of cooling is most important, and varying hardness may be produced by quenching in different media. Thus positive quenching in cold water, iced brine, mercury, &c., is so severe as sometimes to produce rupture of the material, and even when "water-cracks" are not produced, a subsequent annealing is required before the tool is suitable for most industrial purposes. This tempering, as it is called, is often judged by the colour of the oxide film got by the oxidation of the skin of metal on reheating, but a pyrometric method of controlling the temperature is preferable. Less drastic quenching in oil is at times referred to as tempering, but although it produces similar results to the double process, it is incorrect so to apply the term and "negative" quenching is a better description.

The structure of quenched steel is very fine and almost structureless, but under the microscope is seen to consist more or less completely of Martensite.

With the carbon content at or about the eutectoid proportion (·89 per cent) the whole structure consists of Martensite if the quenching has been from a temperature of 800 deg. Cen. or thereabout. When properly made in actual practice, this constituent is quite homgeneous and uniform in composition, so that slight etching does not reveal the characteristic needle structure, but with deeper etching dark and light portions are resolved at high magnifications due to a form of selective etching, similar to that produced even in a pure metal such as ferrite. In mild steels, however, it is seldom possible, in practice, to attain this homogeneous structure of the solid solution on quenching, and a certain amount of structurally free ferrite is found associated with the Martensite, part of which may also have decomposed into the darker etching Troostite around the borders of the Martensite. If the section were small enough and the low carbon steel quenched quite instantaneously, then theoretically homogenous, pure Martensite would be obtained without any free ferrite, but under normal working conditions the tendency of the solid solution of the iron carbide in iron to fall back again out of solution into concentrated areas is too great for the rate of cooling over the critical points. In the same way, if a normal medium carbon steel be heated quickly to just over the top critical point and then quenched, the Martensite or Hardenite is found to occupy almost exactly the areas previously taken up by the Pearlite, and so it is necessary to anneal for some time at a temperature slightly above the quenching temperature in order to get a more perfectly homogeneous Martensite structure.

One theory to account for the much-increased hardness conferred on the steel by quenching is that it is entirely due to the carbon which exists as the definite compound $Fe_{24}C$ called Hardenite in the quenched steel, and that this decomposes on annealing, or on slow cooling, into the duplex laminated structure of ferrite and the normal carbide Fe_3C, or Cementite. However, the more general opinion is held to be proved by the experiments pointing to the existence of iron in three distinct allotropic modifications, the stability of which depends chiefly on the existing temperature, and only in a secondary degree upon the elements present which alter the point at which the transformation from one modification into another occurs. Dr. Rosenhain gives the causes which contribute to the hardness of quenched steels as :—(*a*) The inherent hardness of carburised gamma iron, present in the quenched steels in the form of Austenite and partly also in Martensite ; (*b*) the hardness of a solid solution existing under constraint, *i.e.*, by the forcible suppression of a decomposition reaction ; (*c*) the hardness due to severe internal stresses caused by rapid cooling and by volume changes due to the allotropic transformations of the iron ; and (*d*) the individual hardness of beta iron. Most probably reasons (*a*) and (*d*) are the two chief causes to which the hardness must be ascribed.

Tempering—This is necessary to reduce the excessive hardness produced by quenching, and so render the tool suitable for ordinary work. The amount of this softening depends solely upon the temperature attained, although in practice the time element is often used as a guide in conjunction with the colours displayed by a polished surface of the metal. A temperature of 100 deg. Cen. is sufficient to temper the brittleness to a small extent, but the usual range of tempering temperatures lies between 220 and 330 deg. Cen., and is best regulated by using a bath of oil or molten lead in which the tool is heated. The rate of cooling from the tempering temperature is immaterial, although it is customary to cool off rapidly. The structure of mildly tempered steel usually retains some of the Martensite, interstratified with Sorbite, and sometimes with higher tempering, a small amount of free ferrite. If the temperature is raised to about 650 to 700 deg. Cen. the effect of the quenching is completely obliterated, and a very fine-grain structure of Sorbite and ferrite results. This degree of tempering is seldom resorted to, and is more often referred to as annealing.

The beneficial effect of quenching most steels from high temperatures followed by tempering, are most remarkable and effect important improvements in the mechanical properties of carbon steels, such as increased tenacity, toughness, and reduced liability to fracture by shock.

If the original material is of a coarse texture with widely-separated areas of structurally-free ferrite and pearlite, Le Chatélier advises a second heating and quenching in order to effect a perfect diffusion of the carbide, followed by a reheating to under 700 deg. Cen.

When steels of medium carbon content are allowed to cool slowly, the pearlite and structurally free ferrite arrange themselves into more or less large and independent areas. On heating such steel to certain definite temperatures depending on the carbon. and other constituents present in the steel, the carbide becomes more or less equally distributed throughout its mass; when suddenly chilled. the carbide remains diffused, and the steel is hard and brittle. By proper reheating to a point a little below the critical point Ac_1, the carbide and ferrite tend to disentangle themselves, and re-form into pearlite; and if the heating is sufficiently long continued at Ac_1, they actually do so, but are very perfectly distributed, and the material is much more regular and homogeneous than it was before the treatment. If the reheating is not prolonged, and not higher than is sufficient to admit of partial re-formation of the pearlite, the granular cementite which does separate is invariably associated with sorbite, and the steels are immensely improved in enduring properties.

One very remarkable instance of the value of heat treatment is given by Le Chatélier in his paper on "Brittleness Tests by Shock on Notched Bars," read before the International Association for Testing Materials at the Buda-Pesth Congress in 1901, in which he quotes the experience of M. Barba, who thoroughly tested an extra soft steel by subjecting notched bars to the falling weight test in the natural condition and after-heat treatment. The results are given in the following table:—

Treatment.	Height of Fall to Produce Fracture.	
Natural or annealed below 900 deg.	0·40	metre.
Annealed at 900 deg. or above	2·00	,,
Quenched above 900 deg. and annealed below 700 deg.	6·00	,,
Quenched without annealing at 800 deg.	1·40	,,
,, ,, ,, ,, 850 ,,	2·20	,,
,, ,, ,, ,, 950 ,,	4·47	,,
,, ,, ,, ,, 1,150 ,,	5·00	,,

High-carbon or Tool Steels.—Carbon, ·2 to ·95 per cent.—The usual definition of steel includes those carbon-iron alloys containing less than 2·2 per cent of carbon, but in actual practice the limit of 2 per cent is seldom exceeded, and most tool steels lie above the "eutectoid" point. When slowly cooled or in the normal condition these steels all contain some free Cementite, which partially envelops the grains of Pearlite in the lower range, and with higher content of carbon, forms a continuous meshwork which becomes less filliform as the carbon increases, until it may exist as separate plates or grains. Annealing causes the smaller grains of pearlite to coalesce and more or less completely break up the Cementite envelopes, the remains of which are left scattered through the areas of Pearlite. This is shown in Figs. 254 and 255. On quenching these tool steels from a temperature not above 750 deg. Cen., the

Cementite envelopes persist practically unaltered, but the Pearlite is replaced by Hardenite, which shows the characteristic Martensitic structure under high magnification. By heating the steel to just above the Ar_3 temperature before quenching, no free cementite can be detected on polishing and etching the specimen, the whole

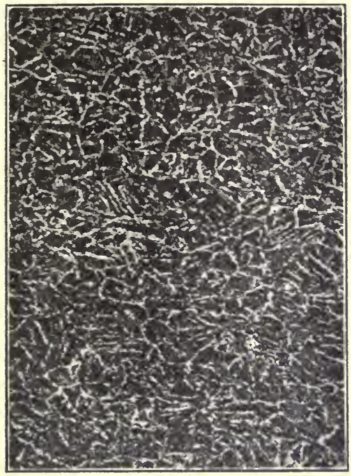


FIG. 254.—Normal Structure of 1·3 per cent Carbon Steel (Cementite and Pearlite). V. 90 X.

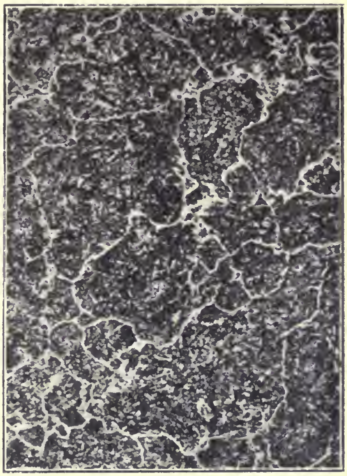


FIG. 255.—Annealed Structure of 1·3 per cent Carbon Steel (Cementite and Pearlite). V. 90 X.

FIG. 256.—Martensitic Structure of 1·3 per cent Carbon Steel, quenched from 1,000 deg. Cen. (Austenite and Hardenite). V. 600 X

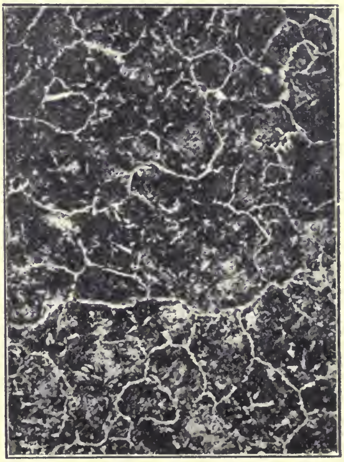


FIG. 257.—Normal Structure of ·65 per cent Carbon Steel (Ferrite and Pearlite). V. 30 X.

structure appearing as Hardenite, in which, under suitable conditions the crystallites of Austenite may be noticed. (Fig. 256.) The steel, after quenching from such high temperatures, is decidedly brittle and coarse grained, in which state it is useless as a tool. Suitable tempering is often able to restore the requisite fine-grain, the degree of annealing required depending upon the carbon content and the vigorousness of the quenching.

Medium-carbon Steel.—Carbon, ·9 to ·3 per cent.—These are sometimes referred to as Pearlite steels in which the utmost strength consistent with ductility is obtained, and without the intense hardness conferred by the presence of free Cementite.

Their structure is very similar, after ordinary etching, to those of the high carbon steels, only the white meshwork surrounding the Pearlite grains is of Ferrite instead of Cementite, and as the carbon content increases this meshwork diminishes, and is practically unnoticeable with more than ·75 per cent of carbon. Fig. 257 shows a micrograph of a ·65 per cent carbon steel, which is very similar to the structure illustrating the 1·3 per cent carbon steel slightly annealed. The difference is more marked on viewing the actual specimen, and in addition to the great difference in the hardness and ease of cutting, the two specimens can be distinguished by suitable etching. Thus a solution of sodium picrate applied to the medium carbon steel would produce almost the same structure on etching, whereas the high carbon steel would have the cementite meshwork blackened, the Pearlite remaining less deeply etched. In this range of steels, the top recalescence has disappeared, and Ar_2 is continuously lowered as the carbon content increases until, with ·9 of carbon, all three critical points are coincident at 690 deg. Cen. As the Ferrite becomes less and less, the spaces into which the carbide can diffuse on heating become more and more reduced, and complete diffusion is effected at lower and lower temperatures. The best temperature for heat-refining is thus progressively lowered, and also the temperature at which quenching may be done to yield a completely Martensitic structure is also reduced. As the diffusion of the carbide gradually affects the gamma change in the ferrite, it is complete before the temperature of 870 deg. Cen. is reached, so that there is no arrest at Ac_3, but correspondingly the intensity of the thermal disturbance at Ac_1 is increased. The normal or rolled steels do not often show well laminated Pearlite in the structure, but a very moderate annealing, at 800 deg. Cen. for a few minutes, produces very distinct pearly lustre visible even to the naked eye on etching. Figs. 258 to 261 show the structure of a ·46 per cent carbon steel under varying conditions of heat treatment.

Mild Steel.—Carbon, ·3 to ·12 per cent.—These steels, when slowly cooled show a structure which consists of a white ground mass of Ferrite, with patches of pearlite distributed as irregular specks. If cooling be very slow, the size of the crystals is increased and the carbide is gathered into larger isolated patches. Such steels show the three points of retardation on cooling.

When such a steel is heated for some time to 700 deg. Cen, and then quenched in water, the Pearlite areas retain their form and size, but consist entirely of Hardenite. They stand out in bold relief when the steel is polished, and leave a dense black deposit on the surface on long etching with acid. In coarse-grained steel, when the heat

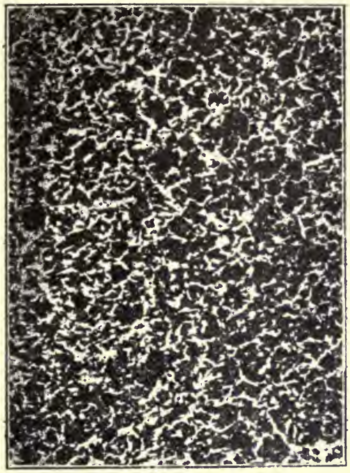


FIG. 258.—Normal Structure of ·46 per cent Carbon Steel (Ferrite and Pearlite). V. 90 X.

FIG. 259.—Annealed Structure of ·46 per cent Carbon Steel (Ferrite and Pearlite). V. 90 X.

FIG. 260.—Overheated Structure of ·46 per cent Carbon Steel (Ferrite and Pearlite lattice). V. 90 X.

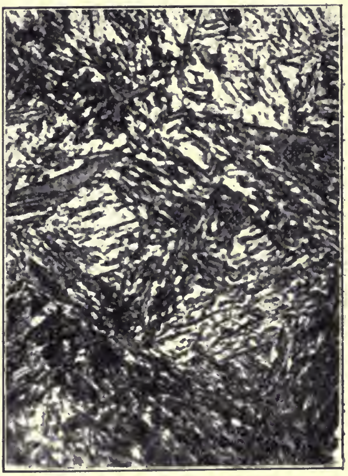


FIG. 261.—Martensitic Structure of ·46 per cent Carbon Steel quenched from 750 deg. Cen. (Hardenite and Beta-Ferrite.) V. 600 X.

is raised and kept at about 750 deg. Cen., for a short time the carbide of the pearlite slightly diffuses outwards in all directions into the surrounding ferrite, but only to a limited distance. On cooling through 690 deg. to 600 deg. in 10 minutes and polishing, the metal, instead of having what were originally large unit areas of pearlite, contains several very minute areas in groups separated by Ferrite. The carbide of the original Pearlite areas apparently expands when heated, and on comparatively rapid cooling it has not time to contract to its original position, and therefore breaks up into several groups.

If the steel at 750 deg. is quenched, the etched surfaces contain black areas of Hardenite corresponding to the space into which the carbide diffused, and to that in which the groups of Pearlite referred to above are located.

If the steel originally was built up of very large crystalline grains with the Pearlite areas distributed at great distances apart, the parts of the Ferrite into which the carbon diffuses at 750 deg. is broken up into a large number of minute grains, at the junction of which the re-formed Pearlite is situated. The Ferrite outside these areas is apparently not in any way affected.

On heating to 800 deg. Cen. there is a greater diffusion of carbide, and in the air-cooled material the spaces of re-formed pearlite occupy a greater area, but still do not spread over the whole of the iron—some portions of the original large Ferrite grains still remain not broken up. On heating to 900 deg. Cen., although the carbon is not diffused throughout the whole mass, the Ferrite is all broken up into smaller grains. This change is effected, on the portion of Ferrite into which the carbon had not diffused, by heat alone at the temperature of Ac_3 in the same way as carbonless iron is changed at the same point.

On heating mild steel there is a small arrest at Ac_1, due to the change in the Pearlite areas, a second arrest at about 750 deg. (*i.e.*, Ac_2) in the Ferrite unaffected by the diffusing carbide, and a third at Ac_3 when the balance of the free Ferrite changes its allotropic state ; but in addition to changes at these well-marked zones, and judging from the fact that as the carbide steadily diffuses and extends its excursions, the structure is broken up into small grains, it is justifiable to believe that the Ferrite, co-incidentally as it is invaded, changes gradually to the gamma state between the temperature of 750 deg. Cen. and 870 deg. Cen.

On heating to 1,300 deg. and quenching from that temperature, about half of the polished section darkens on etching with acid, the other portion remaining white. The carbide, originally occupying a space of under 10 per cent of the whole mass, diffuses into about 40 per cent of the surrounding Ferrite. The portion which becomes dark on etching corresponds with Hardenite, and has a coarse, well-developed structure. If, instead of quenching, the steel be allowed to cool slowly in air, the Pearlite is found in more or less continuous bands traversing the very large crystal grains which are thus broken up into what appear to be plates or grooves. If the cooling is protracted, the Pearlite contracts or diffuses into widely separate areas, generally at the junction of contiguous grains, and the Ferrite returns to its normal polygonal form of oriented grains.

Fig 262.—Diagram of changes which occur on heating, quenching, or slowly cooling a Mild Steel containing about 0·1 per cent Carbon. (Stead.)

Fig. 262 illustrates diagrammatically the changes which occur on variously heat-treating a sample of mild steel, and the microstructure is detailed as follows.

(1) A typically laminated Pearlite area is shown surrounded by crystal grains of Ferrite, which constitute the ground-mass of the sample.

(2) The sample, after prolonged heating at 700 deg. Cen. and quenching in water. The Pearlite has changed and has been replaced by Hardenite.

(3) The same steel heated to about 800 deg. Cen. and then quenched in water. The eutectoid cementite had disappeared and partially dissolved in the surrounding Ferrite forming Hardenite. The crystalline structure of the Ferrite is broken up by the diffusion of the carbide in solution.

(4) The same steel, after cooling from 800 deg. Cen. through Ar_2 in 10 minutes. The black areas represent Pearlite, but in this case it has not had time to separate into lamenæ of Cementite and Ferrite, but has remained in the Sorbitic condition.

(5) The same steel heated to above 1,000 deg. Cen. and quenched in water. The dark area is Martensitic in structure, and is composed in the centre of Hardenite, the small grains of which contain most carbon, whilst the carbide in solution at the boundaries is more diffused. The free Ferrite is all broken up into a smaller number of grains, but they are not so small as in the area dominated by the carbide in solution.

(6) The same steel after heating to above 1,200 deg. Cen. and cooling in a few minutes through Ar_1. The structure consists of Sorbitic-Pearlite and structurally free Ferrite in very fine grains.

Figs. 263, 264, and 265 show micrographs of a normal, annealed, and over-heated steel containing ·25 per cent of carbon.

Dead-mild Steel.—Carbon less than ·12 per cent.—This is the purest form of iron commercially produced, and it consists almost entirely of Ferrite, which is sometimes called iron-ferrite, as impurities are almost completely absent. As the amount of carbon diminishes, the top recalescence point rises until in absolutely carbonless iron it is just under 900 deg. Cen. Pure iron thus shows three very distinct arrests between 600 and 900 deg. on heating or cooling, and yet on quenching from above Ar_3 no appreciable increase in hardness is produced. On long continued heating to temperatures below 800 deg. Cen. the size of the crystal grains gradually increases until in certain cases they have been known to grow to a diameter of 1 to 3 cm. from grains which originally had a diameter ·01 mm. It is the larger of the originally minute crystal grains which dominate and attract the smaller, causing them to change their relative crystallographic axial position to that of their own. It appears certain that when contiguous crystals of different orientation with relation to each other change their positions, so that all are orientated alike, the junctions disappear, and all unite to form a larger crystal grain. When coarsely granular iron is heated to 900 deg. Cen. it becomes finely granular, the breaking up of the structure being probably coincident with the change of the iron from one allotropic modification to another (β to γ) at Ac_3, so that the crystalline organisation of Beta iron is destroyed, and a new organisation of a fine crystal grain is substituted. The practical value of this will be understood when it is known that grossly crystalline iron is often very brittle, and that by simply heating it to 900 deg. Cen. the brittleness is entirely removed. The new and fine-grained organisa-

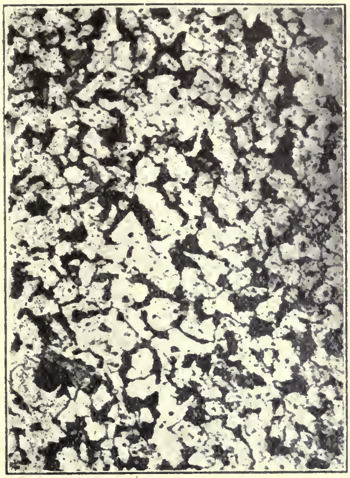


Fig. 263.—Normal Structure of ·25 per cent Carbon Steel (Ferrite and Pearlite). V. 180 X.

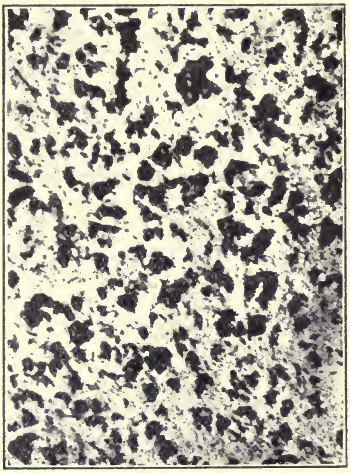


Fig. 264.—Annealed Structure of ·25 per cent Carbon Steel (Ferrite and Pearlite). V. 180 X.

Fig. 265.—Overheated Structure of ·25 per cent Carbon Steel (Ferrite and Pearlite Lattice). V. 60 X.

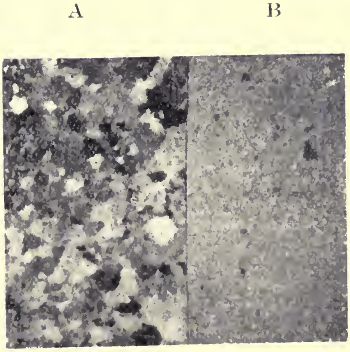


Fig. 266.—Pure Swedish Iron (Ferrite). (A) Large Crystal Grain; (B) Grain refined by heating to 900 deg. Cen. (Stead.) Magnified 10 diameters.

tion formed when the iron changes to the Gamma state is not sensibly altered by normal cooling in the air, and is therefore retained, even although in cooling the iron changes first to Beta and then to Alpha iron. (Fig. 266.)

When Ferrite is heated slowly to 740 deg. Cen. an absorption of heat takes place, and the metal ceases to be attracted by the magnet. This critical point is Ac_2, and, according to Osmond, marks the change of the iron from the Alpha to the Beta form. At between 850 deg. and 900 deg. Cen. (about 870 deg. Cen.) a greater absorption of heat takes place; the critical point is Ac_3, and, according to Osmond, marks the change from Beta to Gamma form. The reverse changes which take place on cooling at Ar_3 and Ar_2 are attended with evolution of heat, and therefore retardation of cooling.

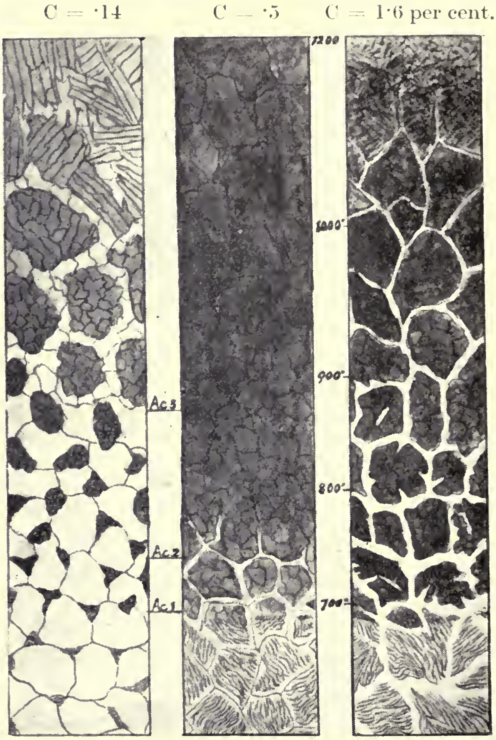

C = ·14 C = ·5 C = 1·6 per cent.

FIG. 267.—Diagram of the Changes which occur on Heating and Quenching Steels with various Percentages of Carbon. (Stead.)

Theory of Steel.—Steel consists essentially of iron and carbon, and it varies much in properties, not only according to the proportions in which these constituents and also impurities are present, but also, as has been already explained, according to the treatment it has received, and it becomes important to consider what are the causes of these changes. The most important change to be considered is that which takes place when the metal is suddenly cooled or quenched, and thus becomes hardened. If this were the only change, and there were only the one critical point, the explanation might not be difficult; but, as has been already explained, there are three critical points to be taken into account, and the microscope has shown great changes in structure corresponding to these. Fig. 267 represents diagrammatically the changes observed in the structure of low, medium, and high carbon steels, as they are heated to varying temperatures and then quenched.

The Carbon Theory is that the changes evolving or absorbing the heat at the critical points are due to the changes in the way in which the carbon is combined. Sudden cooling, of course, fixes it in the condition in which it was above the point of quenching, and this prevents the change, producing the heat evolution and fixing the character of the metal.

Sauveur had sections prepared of a sample of very mild steel showing the three points of retardation. He found that when the steel was quenched above Ar_3 it contained only ferrite and Martensite, and by measurement he estimated 77 per cent of ferrite and 23 per cent of Martensite. Quenched between Ar_2 and Ar_3, the structure was the same, but the ferrite was 73 per cent and the Martensite 27 per cent, the Martensite being much harder than in the first case, and obviously containing a smaller percentage of carbon. Quenched between Ar_2 and Ar_1, the quantity of Martensite had been reduced to about 11 per cent, and was therefore still richer in carbon; and quenched below Ar_1, the composition was about 10 per cent pearlite and 90 per cent structurally free ferrite.

Changes in the condition of the carbon do not seem to be capable of explaining the evolution of heat, especially as critical points are observed in carbon-free iron; and quenching, although it has not the same striking hardening effect in the case of very mild steels that it has in steels higher in carbon, yet does produce changes in tensile strength and other properties too great to be accounted for by the change in the condition of the minute quantity of carbon present. In one case quoted by Howe, the tensile strength of a steel with only ·06 per cent of carbon was tripled by sudden cooling to a low temperature. A change in the condition of the carbon does not seem capable of explaining the loss of magnetic power in iron at high temperature.

The Allotropic Theory—The explanation of the phenomena of recalescence, according to this theory, is that there are three modifications of iron, known respectively as α (Alpha), β (Beta), and γ (Gamma) iron, each of which is stable only within a certain range of temperature. It can almost be said that this theory is now proved, as a large amount of information has been obtained which supports it, and which makes it, at least, a good working hypothesis. The recent research work of Dr. Rosenhain on the crystalline structure of iron at high temperatures, most clearly proves the existence of the three distinct modifications which he has shown to possess widely different mechanical properties. He also found that β-iron, although existing at a higher temperature, is harder and stronger than α-iron; and, moreover, that the change from α- to β-iron involves a volume change.

The three varieties of iron seem to differ in crystalline form. γ iron crystallises in the cubic system in combinations of the cube and octahedron, and macles are very numerous. These are the crystals which are formed when steel solidifies from fusion and often show twinning. β and α irons crystallise also in the cubic system, in forms distinct from γ iron, but isomorphous one with another. Dr. Rosenhain has shown how the crystalline structure varies, by observing the different types of slip-bands produced on straining the ferrite at various high temperatures.

α Iron. This is the iron which is stable at ordinary temperatures, and which therefore exists in all irons that have been slowly cooled. It forms below 750 deg.

β Iron. This form has only a transient existence under ordinary circumstances, its range of stability being between 750 deg. Cen. and 900 deg. Cen. It is non-magnetic, and increases in hardness at the commencement of the change. If this form of iron could be preserved right down to ordinary temperatures its hardness might be even greater, as indicated by the upper dotted line in Rosenhain's diagrammatic curve connecting hardness with temperature. (Fig. 268.)

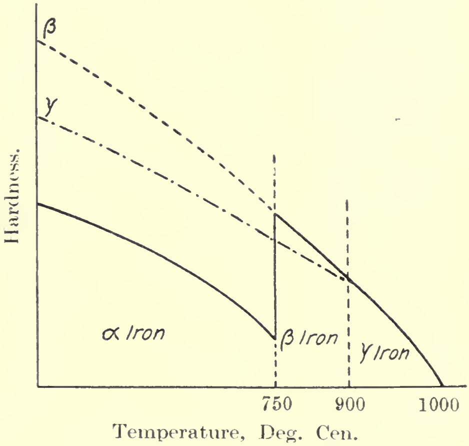


FIG. 268.—Hardness—Temperature Curve of Pure Iron. (Rosenhain.)

γ Iron. This is the form of iron stable above 900 deg. Cen., and it is also non-magnetic, but is much softer than the β modification, both at high temperatures, and if partly preserved in this condition at normal temperature.

It follows therefore that as a mass of liquid iron solidifies from fusion it will solidify into the γ condition. This it will retain till it has cooled to 900 deg., when it will pass into the β form, and this at about 750 deg. will pass into the a form. And the passage from the one form to another will be a point of retardation seen in the cooling curve of pure iron. (Fig. 269.)

In mild steel there are three points of retardation—or heat evolution—Ar_3 marking the passage from γ to β iron Ar_2, the change from β to a iron, and Ar_1 the passage of the carbon from the hardening to the carbide condition, and also of Gamma to Alpha iron in the areas corresponding to the Pearlite, so that the last traces of Martensite are decomposed with formation of Pearlite.

Assuming the existence of these various forms of iron, it becomes an important question to decide whether the hardening of the steel is due to change in the condition of the iron or of the carbon, because it is quite obvious that both changes might take place and yet the hardening be due to only one of them. According to the carbon theory, as already explained, it is due to the change in the condition of the carbon ; according to the allotropic theory, it is due to change in the condition of the iron, the a being soft and the β and γ irons hard, though, of course, at high temperatures they will be soft in mass, owing to the free play of the molecules. Sudden cooling prevents the passage of β in a iron, and therefore keeps the metal hard. As the two changes might not take place at exactly the same temperature, it might be possible to harden steel in such a way that the metal should be soft and the carbon in the hardening condition,

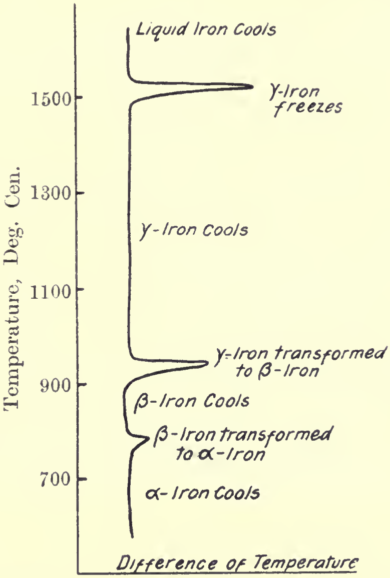


FIG. 269.—Derived Differential Cooling Curve of Pure Iron. (Rosenhain.)

or the metal hard and the carbon in the carbide condition. This, however, does not seem to have been done. As the percentage of carbon in steel increases the two points come nearer together, till they coincide and the changes are simultaneous.

The Solution Theory.—This was suggested as a compromise between the two above-mentioned theories, and is the one now very commonly accepted, as it accepts the salient features of both, and accounts for the varying hardness of quenched steel by the fact that there are varying concentrations of a solid solution of iron carbide in one or other of the three allotropic forms of iron, and this serves to explain most of the moot questions not consistently solved by either theory alone. If the hardening of the iron on chilling were due to the iron being in the hard condition, how is it that it is not possible to harden pure iron? The answer to this is that when the iron is pure the change from γ to β and β to α iron takes place so rapidly that no chilling can retain it in the harder form. Carbon in solution as carbide has a great tendency to retard the change, and thus to keep the iron in the hard form. The presence of foreign elements may also indirectly have a very great influence on the changes produced by cooling. Manganese has a still more striking effect than carbon in tending to keep the iron in the hard state. When there is over 7 per cent of manganese present, the iron does not pass into the α condition even on slow cooling to ordinary temperatures. There is no critical point observable, and the iron is non-magnetic until it has been brought considerably below normal

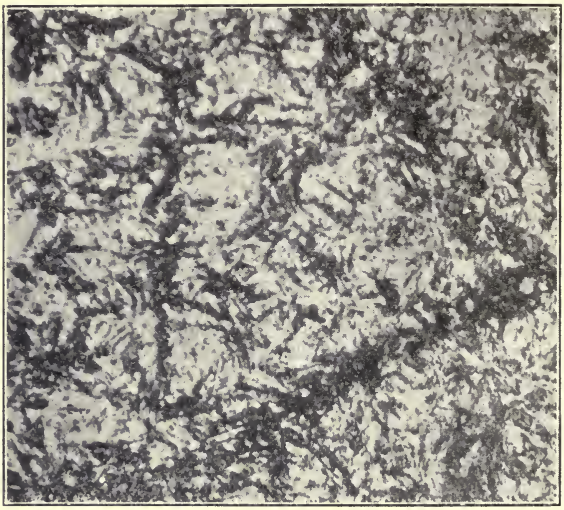


FIG. 270.—Martensitic Structure of 6·2 per cent Manganese Steel after Annealing and slow Cooling. Magnified 300 diameters.

temperature. Even an annealed steel containing 6·2 per cent of manganese and 0·6 of carbon, still shows the typical Martensitic structure, illustrated in Fig. 270, in which the darker etching constituent is evidently Troostite. The same steel, however, after immersion for a few minutes in liquid air, at about – 196 deg. Cen., became comparatively soft to the file, was very much more strongly magnetic, and the micro-structure appeared as shown in Fig. 271. The Martensite has been completely decomposed, and only a small amount of the Troostite (dark) is left embedded in Sorbite, and some areas of Manganese-Ferrite are shown white.

Nickel has also a similar effect, so that with between 10 and 25 per cent present the metal shows no magnetic properties until it

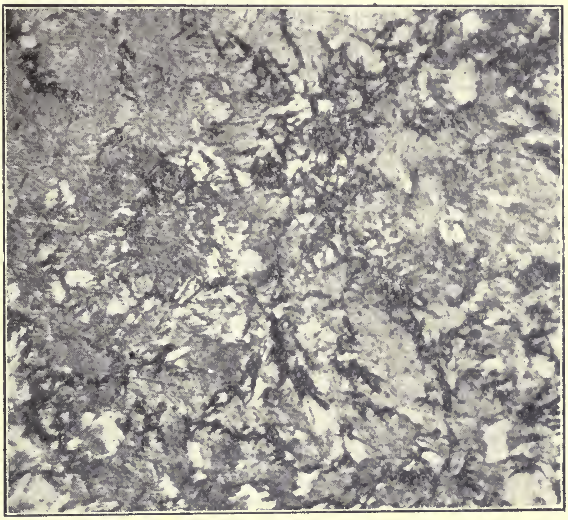


FIG. 271.—Sorbitic Structure of 6·2 per cent Manganese Steel after transformation in Liquid Air at – 196 deg. Cen. Magnified 300 diameters.

has been cooled down to 40 deg. Cen., after which, on regaining normal temperatures, it is quite strongly magnetic, and only loses this property on reheating to about 600 deg. Cen. This phenomenon of non-reversible transformation is defined as the capability of existing at ordinary temperatures in two different physical states, characterised by the appearance or disappearance of magnetism, and also by possessing a higher tensile strength, and very much lower elongation when magnetic than when non-magnetic. The structure of the non-magnetic variety shows a homogeneous solid solution of nickel Gamma-iron, and the same Austenitic structure is got by etching ordinary carbon steel, which has been heated to over 1,000 deg. Cen. in vacuo, with vapour of hydrochloric acid. This etching of the steel when hot produces on the polished surface a pattern representing the structure of the metal at the temperature of the etching, and when the steel has cooled (undergoing transformations in structure) the micro-structure still shows that which was imprinted on the surface at the moment of etching. Baykoff has in this way produced a series of photo-micrographs of varying carbon steels all etched while at a temperature of over 1,100 deg. Cen., and he showed that at this temperature they all consist of polyhedral aggregates of Austenite irrespective of the carbon content, just as the solid solution theory indicates.

The following table is useful in comparing the various theories advanced to explain the constitution of steel at various temperatures:

Temperature.	Carbon Theory.	Solution Theory.	Microstructure.
At Ar_3	Solution of Sub-carbide in iron. $Fe_{24}C$.	Solid solution of iron carbide diffused in Gamma-iron.	Austenite (softer than Martensite.)
Change at Ar_3 ...	Maximum density of solution.	Passage of iron from Gamma to Beta condition.	Austenite decomposing to form Martensite.
Between Ar_3 and Ar_2.	Solid solution of Hardenite in Iron	Solid solution of iron carbide diffused in Beta iron.	Martensite and Troostite.
Change at Ar_2 ...	Segregation of Sub-carbide.	Passage of Beta iron to Alpha condition.	Transition of Troostite into Sorbite.
Between Ar_2 and Ar_1	Further aggregation of Hardenite.	Solid solution of iron carbide diffused in Alpha iron.	Osmondite, a transition product between Troostite and Sorbite.
Change at Ar_1 ...	Passage of concentrated Hardenite into Pearlite.	Dissolution of iron carbide Fe_3C from Alpha iron.	Sorbite and traces of "eutectoid" Cementite.
Below Ar_1	Pearlite with either Ferrite or Cementite.	Separation of the Carbide as Cementite in Pearlite.	Laminated Pearlite with free Ferrite or Cementite.
Cause of Hardening on quenching.	Retention of the Sub-carbide undecomposed as Hardenite.	Retention of the hard, allotropic forms of iron, this action being helped by the presence of iron carbide in solution.	Martensite and hard Gamma or Beta-Ferrite.

Effect of Work.—When iron or steel is subjected to work it becomes sensibly hardened, and in many ways the effect of work is similar to that of sudden cooling. Professor Howe endeavours to explain this by assuming that the grain-size is reduced to very small dimensions by each pass through the rolls, or by each blow of the hammer, but on emerging they grow rapidly again at high temperatures but less quickly at low temperatures, so that the final size depends upon the finishing temperature and the amount of pressure during the last pass. It is more likely that at high temperatures the steel is sufficiently mobile to be distorted more readily by the sliding of the crystals past one another rather than by crushing, but that at lower temperatures less sliding is possible owing to the decreased mobility, and so more crushing of the crystals takes place. It has been suggested that work may throw the iron into one of its harder allotropic modifications, and Dr. Beilby has deduced from his classical discovery of the plastic flow of metals that mechanically induced flow produces the transient existence of a layer of molecules between the crystals in a state of mobility closely analogous to that of a liquid, and the solidification of this is so rapid that the resultant solid is in the vitreous or amorphous condition. Thus the lower the temperature at which the rolling or hammering is done, the greater is the amount of liquefaction produced within the metal at all surfaces of slip or shear between the crystals, but this amorphous structure which hardens and stiffens the metal can be removed by annealing at a sufficiently high temperature to allow the free movement of the molecules to effect re-crystallisation and consequent softening of the metal.

APPENDIX.

EFFECT OF SILICON ON THE CONDITION OF THE CARBON IN CAST IRON. (Wüst and Petersen, Metallurgie, 1906.)

Silicon per cent.	Carbon.		Graphite in percentage of total carbon.	Proportion of carbon ejected by each part of silicon.
	Total.	Graphite.		
0·13	4·29	1·47	34	·473
0·25	4·16	1·66	40	·609
0·41	4·11	2·56	62	·549
1·14	3·96	2·69	68	·347
1·41	3·88	2·91	75	·354
2·07	3·79	3·25	85·8	·311
2·65	3·52	3·25	92·6	·300
3·25	3·41	3·33	97·6	·292
3·69	3·32	3·18	95·8	·281
3·96	3·24	3·18	98	·268
4·86	3·08	2·73	95	·251
5·06	2·86	2·59	90·5	·175

The irons were made from Swedish cast iron and ferro-silicon in the electric furnace.

EFFECT OF SILICON ON SHRINKAGE OF CAST IRON. (Keep, 1909.)

Average percentage of Silicon.	Shrinkage on various sections of test bar.					
	½ in. sq.	1 in. sq.	1 in. × 2 in.	2 in. sq.	3 in. sq.	4 in. sq.
1·00	·183	·158	·146	·130	·113	·102
1·50	·171	·145	·133	·117	·098	·087
2·00	·159	·133	·121	·104	·085	·074
2·50	·147	·121	·108	·092	·073	·060
3·00	·135	·108	·095	·077	·059	·045
3·50	·123	·095	·082	·065	·046	·032

The iron used in this test, called a "Mechanical Analysis" by Mr. Keep, was a brand of "Iroquois" Iron containing ·88 per cent of silicon, and enriched by remelting with various quantities of ferro-silicon. The shrinkages are given in inches per foot of length. The shrinkage decreases both as the silicon increases in percentage and as the size of the casting increases.

EFFECT OF SILICON ON GROWTH OF CAST IRON.

Analysis.			Growth on Heating.		Residual Carbon.	Loss of Carbon.	Gain in Weight.	
Si.	Mn.	Total Carbon.	1st Set	2nd Set.			Mean.	Approximate.
1·07	·25	3·98	15·40	16·80	2·45	1·53	0·85	2·38
1·79	·23	3·98	23·46	24·60	2·40	1·58	2·07	3·65
2·96	·25	3·79	32·85	36·40	2·60	1·19	3·85	5·04
4·20	·27	3·76	43·90	41·60	2·77	0·99	5·99	6·98
4·83	·30	3·79	59·50	55·30	3·25	0·54	6·66	7·20
6·14	·30	3·38	63·00	61·00	3·34	0·04	8·97	8·97

The irons contained ·01 per cent sulphur and ·013 per cent phosphorus. (Rugan and Carpenter, 1909.) All the figures are given in percentages, so that graphs may be constructed showing the effect of silicon on growth and gain in weight. The growths given are the result of 25 reheatings, and it was noted that the metal increased in volume very little after the fifteenth heating.

EFFECT OF MANGANESE ON GROWTH OF CAST IRON.

Analysis.			Growth on Heating,					Carbon content after 150 heats.			
Mn.	Si.	Total Carb'n	25th.	50th.	100th.	125th.	150th.	Total.	Combined.	Amorphous.	Per cent conv'rt'd
·51	·485	2·4	+1·6	3·8	4·9	5·35	7·49	2·146	0·693	1·453	67·71
·735	·471	2·4	+1·05	2·9	4·15	5·80	6·06	2·090	0·956	1·134	54·26
·935	·406	2·25	− ·1	+1·0	1·61	2·43	3·09	2·203	1·192	1·011	45·89
1·64	·587	2·66	− ·27	− ·36	− ·35	− ·21	− ·13	2·618	2·367	0·251	9·60

The irons were white, and contained ·01 per cent sulphur and ·01 per cent phosphorus. (Carpenter, 1911.) All the figures are given in percentages, so that graphs may be drawn to show the effect of manganese on the volume changes after the different number of reheatings. The fourth iron showed a shrinkage instead of a growth; and the tensile strength was increased by the heat treatment Phosphorus and sulphur both tend to diminish the growth on reheating.

EFFECT OF PHOSPHORUS ON THE SHRINKAGE OF CAST IRON.

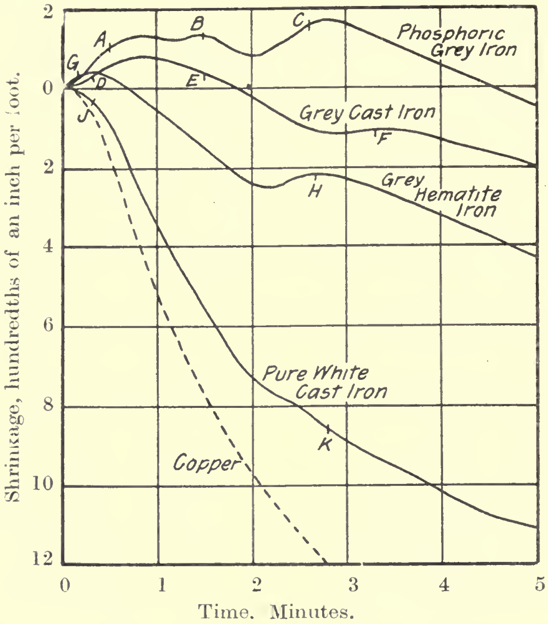


FIG. 272.—Contraction Curves of Cast Irons. (Turner.)

Extensometer tests show white iron to have one retardation during contraction and two recalescences.

Non-phosphoric grey iron shows two arrests in the rate of contraction, practically coincident with the two retardations in the cooling curve.

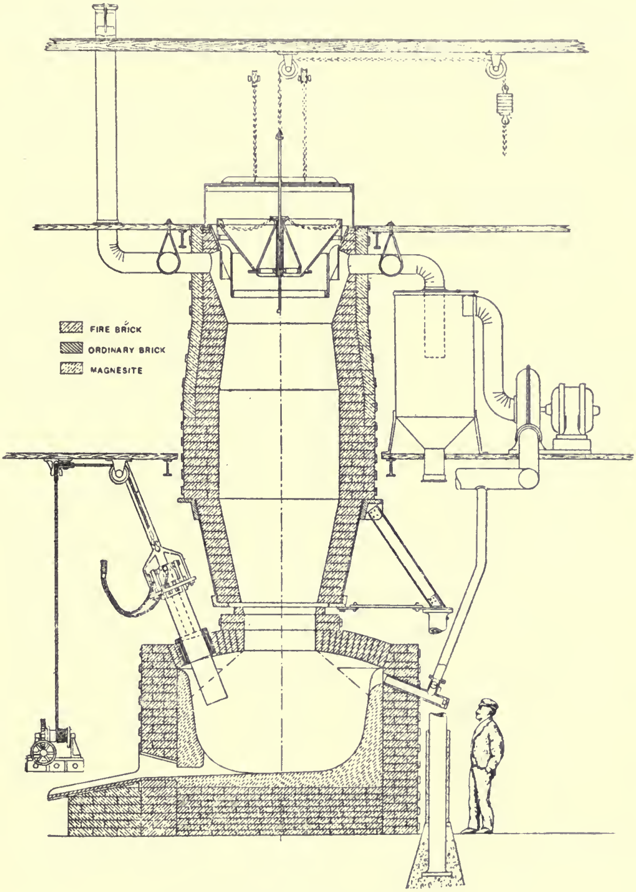
Phosphoric grey irons give three actual expansions during cooling, and three corresponding arrests in the cooling curves.

These graphs show what class of metal expands on solidification, and explain why under certain conditions a solid piece of cast iron may float on the surface of the same material when molten.

Analysis.		White Iron.	No. 3 Grey Haematite.	No. 1 Northampton.	Grey Foundry Cast Iron.
Carbon, combined .		2·73	0·86	0·15	0·79
Carbon, graphitic . .		nil	2·53	2·60	2·73
Silicon		0·01	3·47	3·98	1·41
Sulphur		trace	0·03	0·03	0·07
Phosphorus		0·01	0·04	1·25	0·96
Manganese		trace	0·55	0·50	0·43
Retardations in cooling curves.	1	J 1045°	G 1135°	A 1060°	D 1095°
	2	absent	absent	B 900°	E 905°
	3	K 665°	H 695°	C 730°	F 695°

ELECTRIC SMELTING IN SWEDEN.

At Domnarfvet, in Sweden, the production of pig iron in electric furnaces has been started by Dr. Haanel.* The furnace used consists of two parts, a lower melting chamber, 7 ft. high, into which the electrodes pass, and a shaft, 18 ft. high, which contains the descending material. The shaft is carried on a series of iron columns, so as to relieve the roof of the melting chamber of weight. The melting chamber is so arranged that as the charge slips down a space is left between it and the roof at the points where the electrodes enter.



Electric Iron Smelting Furnace.

There are three electrodes, each built up of two carbons, so as to give an electrode 63 inches long, and with a cross section 22 in. by 11 in. They enter the chamber by means of a water-cooled stuffing box, and can be raised or lowered as required.

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* "Iron Age," September 16, 1909.

The top of the furnace is closed by a bell and cone, the waste gas is drawn off, passed through a dust catcher, and then is returned to the furnace by three tuyeres. A standpipe is provided by which excess of gas can escape into the air. As no air is blown in the gas is carbon-monoxide and carbon di-oxide, produced by the reduction of the ore.

The ore used was magnetite, containing 62·96 per cent of iron, and the reducing agent a coke with 85 per cent of carbon, and lime was used as a flux.

The current was supplied at 40 to 50 volts, and the power employed was 400 to 450 kw. The charge consisted of ore 220 lbs., lime 4·4 lbs., coke 41·4 lbs, a consumption of coke equal to 605 lbs. per ton of iron. As the runs were experimental the output was small, but amounted to 2·44 tons of iron per electric horse power year. The electrodes were consumed at the rate of about 5 kg. per metric ton (2,204 lbs.) of iron produced.

UTILISATION OF FLUE DUST.

The difficulties of the treatment of the dust in the blast furnace are very great, and many attempts have been made to overcome these. One of the most successful is that known as the Schumacher process, by which briquettes sufficiently strong for blast furnace use are readily produced. The flue dust is mixed with about three times its weight of fine ore, these being fed into a mixing machine where the requisite amount of a 30 per cent solution of calcium chloride is added and thoroughly mixed in, and thence the mixture is passed to hydraulic pressing machines, by which it is compressed into blocks about the size of ordinary fire bricks. The bricks as they leave the press are hot owing to the chemical changes which take place, and which result in cementing the material into a hard but porous mass suitable for blast furnace use. The cost of the calcium chloride is small, as only about 2 per cent of the salt is required, and the coke dust in the flue dust is utilised in the production of heat in the furnace.

THE HOESCH STEEL PROCESS*.

The principal difference between this and the ordinary basic open hearth process is that the slag is separated from the metal early in the heat. About two hours after the furnace has been charged with liquid metal, about 90 per cent of the phosphorus of the pig iron will have passed into the slag, which will contain over 20 per cent of phosphorus pentoxide ($P_2 O_5$), and will amount to about 15 per cent of the weight of the metal; and the metal will retain about 1·5 per cent of carbon. The whole charge is poured into a ladle; the slag is allowed to run over into slag boxes, and the metal is returned to the furnace for finishing. While the metal is out of the furnace lime and ore are charged upon the bottom, and when the metal is

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* B. W. Head, J.I.S.I., Vol. xix. (1912).

returned to the furnace these act on it very rapidly. As the recharged metal contains very little phosphorus the second slag will be comparatively free from phosphoric acid, and there will be little danger of phosphorus going back, and the whole of the phosphorus is removed whilst the metal still retains ·4 or ·5 per cent of carbon, so that little recarburisation is necessary.

USEFUL THERMO-CHEMICAL DATA. HEATS OF FORMATION.

Of	Mol. Wt.	Calories per gram-molecule.	C.U. per lb.	C.U. per lb. of	
(Al_2, O_3)	102	392,600	3,850	7,270	Aluminium.
(Al_2, Si_2, O_7)	222	767,500	3,457	14,210	,,
(Ba, O)	153	133,400	872	974	Barium.
(C, O)	28	29,160	1,040	2,430	Carbon.
(C, O_2)	44	97,200	2,210	8,100	,,
(CO, O)	44	68,040	1,546	2,430	Carbon monoxide.
(Ca, O)	56	131,500	2,348	3,287	Calcium.
(Ca, S)	72	94,300	1,310	2,355	,,
(Ca, C, O_3)	100	273,850	2,739	6,846	,,
(CaO, CO_2)	100	45,150	452	806	Lime.
(Ca, Si, O_3)	116	329,350	2,840	8,230	Calcium.
(CaO, SiO_2)	116	17,850	154	326	Lime.
(Ca_2, Si, O_4)	172	471,300	2,740	5,890	Calcium.
$(2CaO, SiO_2)$	172	28,300	165	354	Lime.
(Ca_3, Al_2, O_6)	270	789,050	3,680	6,575	Calcium.
$(3CaO, Al_2O_3)$	270	1,950	72	162	Lime.
(Ca_3, P_2, O_8)	310	919,200	2,965	7,660	Calcium.
$(4CaO, P_2O_5)$	366	180,000	492	1,125	Lime.
(Fe, O)	72	65,700	913	1,173	Iron.
(Fe_2, O_3)	160	195,600	1,223	1,746	,,
(Fe_3, O_4)	232	270,800	1,168	1,612	,,
(Fe, C, O_3)	116	187,800	1,618	3,353	,,
(Fe_3, C)	180	Negligible	—	—	,,
(Fe, Si)	84	,,	—	—	,,
(Fe, S_2)	88	24,000	273	429	,,
(Fe_3, P)	199	43,300	218	258	,,
(Fe, Si, O_3)	132	254,600	1,930	4,545	,,
(FeO, SiO_2)	132	10,600	80	190	Ferrous oxide.
(Mg, O)	40	143,400	3,585	5,975	Magnesium.
(Mg, C, O_3)	88	269,900	3,067	11,245	,,
(Mn, O)	71	90,900	1,280	1,652	Manganese.
(Mn_3, O_4)	229	328,000	1,432	1,988	,,
(Mn, C, O_3)	115	210,300	1,845	3,823	,,
(Mn, C_2)	79	116,000	1,470	2,110	,,
(Mn_3, P_2)	227	72,300	320	438	,,
(Mn, S)	87	54,800	630	996	,,
(Mn_7, Si_2)	441	52,500	120	136	,,
(Mn, Si, O_3)	131	276,300	2,110	5,023	,,
(MnO, SiO_2)	131	51,400	392	724	Manganous oxide.
(Ni, O)	74·5	61,500	825	1,050	Nickel.
(Ni, S)	90·5	19,500	215	333	,,
(P_2, O_5)	142	365,300	2,520	5,890	Phosphorus.
(Si, O_2)	60	180,000	3,000	6,428	Silicon.
(S, O_2)	64	69,260	1,090	2,180	Sulphur.
(S, O_3)	80	91,900	1,150	2,872	,,

USEFUL FACTORS IN BLAST FURNACE CALCULATIONS.

Unit Weight of	Requires	To form	In the proportion.	Factor.	Reciprocal.
SiO_2	Al_2O_3	$2Al_2O_3, 3SiO_2$	204 ÷ 180	1·133	0·882
,,	,,	$Al_2O_3, 3SiO_2$	102 ÷ 180	0·567	1·764
,,	BaO	$2BaO, SiO_2$	306 8 ÷ 60	5·113	0·196
,,	,,	BaO, SiO_2	153·4 ÷ 60	2·557	0·392
,,	CaO	$2CaO, SiO_2$	112 ÷ 60	1·866	0·536
,,	,,	CaO, SiO_2	56 ÷ 60	0·933	1·072
,,	FeO	$2FeO, SiO_2$	144 ÷ 60	2·400	0·417
,,	,,	FeO, SiO_2	72 ÷ 60	1·200	0 833
,,	MgO	$2MgO, SiO_2$	80 ÷ 60	1·333	0·750
,,	,,	MgO, SiO_2	40 ÷ 60	0·666	1·500
,,	MnO	$2MnO, SiO_2$	142 ÷ 60	2·367	0·423
,,	,,	MnO, SiO_2	71 ÷ 60	1·183	0·845
CaO	Al_2O_3	$3CaO, Al_2O_3$	168 ÷ 102	1·310	0·764
,,	S	CaS	32 ÷ 56	0·571	1·750

USEFUL FACTORS IN SLAG CALCULATIONS.

Unit Weight of	Contains Oxygen in the proportion.	Factor.	Lime equivalent (proportion)	Factor.	Reciprocal.
Al_2O_3	48 ÷ 102	0·471	56 ÷ 34	1·647	0·607
BaO	16 ÷ 153	0·132	56 ÷ 153	0·366	2·732
CaO	16 ÷ 56	0·286	56 ÷ 56	1·000	1·000
FeO	16 ÷ 72	0·222	56 ÷ 72	0·778	1·286
MgO	16 ÷ 40	0·400	56 ÷ 40	1·400	0·714
MnO	16 ÷ 71	0·225	56 ÷ 71	0·7886	1·269
SiO_2	32 ÷ 60	0·533	56 ÷ 60	0·933	1·072

USEFUL THERMAL AND PHYSICAL CONSTANTS OF GASES.

C.P. of Carbon to		Density.			S.H.	C.P. of Gas.	Factors for Combustion of			
							Unit Weight.		Unit Volume.	
Gas.	C.U.	D.	F.	L.	C.U.	C.U.	O.	A.	O.	A.
CO_2	8,080	22	·1234	1·9712	·2169	..	..	..	..	..
CO	2,400	14	·0784	1·2544	·2450	2,400	0·572	2·49	0·5	2·38
CH_4	1,543	8	·0447	0·7168	·5929	12,000	4·00	17·4	2·0	9·52
C_2H_4	663	14	·0784	1·2544	·4040	10,400	3·43	14·9	3·0	14·28
C_2H_2	−1,842	13	·0734	1·1648	..	11,500	2·86	12·4	2·5	11·9
H	..	1	·0056	0·0896	3·409	29,300	8·0	34·8	0·5	2·38
O	..	16	·0893	1·4336	·2175	Air contains		By weight	By volume	
Steam	(H_2O)	9	·0502	0·8064	·4805	Nitrogen		77 per cent	79 per cent.	
N	..	14	·0784	1·2544	·2438	Oxygen		23 per cent.	21 per cent.	
Air	(N+O)	14·438	·0809	1·2936	·2375			100	100	

C. P. = Calorific Power of a fuel or gas, and is the number of heat units evolved by the complete combustion of one pound of it.

C. U. = Centigrade Thermal Units. This unit of heat is the amount of heat required to raise the temperature of one pound of water one degree Centigrade. (C. U. $\times \frac{9}{5}$ = British Thermal Unit.)

D. = Density of a gas is half its molecular weight. Hydrogen being taken as 1, (F) is the weight of one cubic foot in lbs. and (L) the weight of one litre in grammes.

S. H. = Specific Heat; *i.e.*, the number of heat units required to raise the temperature of one pound of the gas one degree Centigrade.

Factors: These give the Weight and Volume of O (Oxygen) and A (Air) required for the complete combustion of unit weight and unit volume of the gas being burned.

The volume of a gas is taken at N. T. P., *i.e.*, normal temperature and pressure, which is 0 degrees Centigrade and 760 m.m. of mercury (say, 30 in.).

The volume of any gas increases by $\frac{1}{273}$ (= ·003663) of itself for each one degree Centigrade its temperature rises above normal; this is called the Coefficient of Expansion of gases, and is $\frac{1}{459}$ (·002179) in the Fahrenheit scale.

Table Showing the Average Values obtained over a number of Years for the Breaking Strain in Tons per Square Inch of Section, Corresponding to the Percentage of Carbon in Mild Open-Hearth Steel.

Carbon per cent.	Tensile Strength.	Carbon per cent.	Tensile Strength.
·12	25	·29	37½
·13	26	·30	37½
·14	27	·31	37½
·15	28	·32	38
·16	29	·33	38
·17	30	·34	38½
·18	31	·35	38½
·19	32	·36	39
·20	33	·37	39
·21	33½	·38	39½
·22	34	·39	39½
·23	34½	·40	39½
·24	35½	·41	40
·25	36½	·42	40
·26	37	·43	40½
·27	37	·44	40½
·28	37	·45	41

From ·12 to ·20 per cent Carbon the relation holds good :—

Tensile Strength = 100 times carbon present plus 13.

From ·2 to ·3 per cent Silicon raises the Tensile Strength about 1 ton. ·1 per cent Silicon is equivalent to ·02 per cent Carbon in raising the Tensile Strength of the steel.

Phosphorus below ·03 per cent lowers Tensile Strength about 1½ tons.

USEFUL FACTORS IN ORE CALCULATIONS.

Unit weight of	Contains	In the proportion	Factor.	And yields	In the proportion	Factor.
$FeCO_3$	Fe	56 ÷ 116	·4828	Fe_2O_3	160 ÷ 232	0·6897
FeO	Fe	56 ÷ 72	·7778	Fe_2O_3	160 ÷ 144	1·1111
FeS_2	Fe	56 ÷ 120	·4667	Fe_2O_3	160 ÷ 240	0·6667
Fe_2O_3	Fe	112 ÷ 160	·7000	FeO	144 ÷ 160	0·9000
Fe_3O_4	Fe	168 ÷ 232	·7241	FeO	216 ÷ 232	0·9310
$MnCO_3$	Mn	55 ÷ 115	·4786	Mn_3O_4	229 ÷ 345	0·6638
MnO	Mn	55 ÷ 71	·7747	Mn_3O_4	229 ÷ 213	1·0751
Mn_3O_4	Mn	165 ÷ 229	·7206	MnO	213 ÷ 229	0·9300
$MgCO_3$	Mg	24 ÷ 84	·2857	MgO	40 ÷ 84	0·4762
$CaCO_3$	Ca	40 ÷ 100	·4000	CaO	56 ÷ 100	0·5600
CaS	Ca	40 ÷ 72	·5556	CaO	56 ÷ 72	0·7778
P_2O_5	P	62 ÷ 142	·4366	reciprocal		2·2903
SiO_2	Si	28 ÷ 60	·4667	,,		2·1429

The factors have been carried to the fourth decimal place, but in calculations only the third significant figure need be taken as an approximation.

INDEX.

The Common Metals (Non-ferrous).

The Metallurgy of Copper, Tin, Zinc, Lead, Antimony, Aluminium and Nickel.

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