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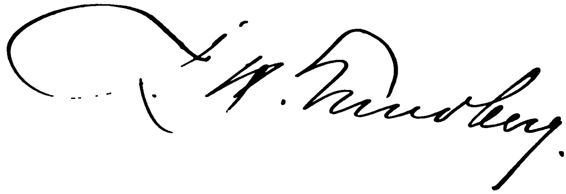

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RAILWAY ECONOMY

USE OF COUNTER-PRESSURE STEAM IN THE LOCOMOTIVE ENGINE AS A BRAKE

BY

M. L. LE CHATELIER

INGÉNIEUR EN CHEF DES MINES

TRANSLATED FROM THE AUTHOR'S MANUSCRIPT BY

LEWIS D. B. GORDON, F.R.S.E.

HONORARY MEMBER OF THE INSTITUTION OF ENGINEERS IN SCOTLAND.

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INTRODUCTION.

For some years past attempts have been made to overcome the inconveniences of "reversing steam," so as to enable the driver to utilize, without difficulty or danger of any kind, the *work* done during the inverted action of the locomotive engine, for regulating and checking the speed of trains in descending long steep gradients.

In France, M. Beugniot; in Austria, M. Zeh, have experimented with closed exhaust nozzle, the one so as to cause a vacuum behind the pistons, the other to establish a pressure behind the piston, and thus avoid drawing in the heated gases of combustion from the smoke-box.

In the beginning of 1865, Mr. De Bergue experimented with a system of brake by compressed air, ingeniously arranged so as to prevent the introduction of the fixed gases into the boiler. This system gave satisfactory results for short runs of two or three minutes; but, like the others, it did not answer when the action was prolonged.

In July 1865, M. Le Chatelier directed experiments to be made on this important subject on altogether a new principle. His ideas have been put in practice with a success so complete, that in France and Spain his system is now applied to above two thousand engines. In Germany it has also been recently introduced.

In a *Mémoire sur la Marche à Contre-Vapeur des Machines Locomotives,*[1] published by M. Le Chatelier in April of this year, a *Notice Historique* of the commencement and early progress of this system is given.

[1] **Paris, 1869. Chez Dunod, Éditeur. Quai des Augustins, 49.**

From the documents appended to that *Notice*, it is quite evident that the engineers of the *Chemin de Fer du Nord de l'Espagne*, being under M. Le Chatelier's orders as engineer-in-chief, received his instructions, but conducted the experiments with an imperfect conception of those instructions, and with little skill, and thus more than a year was lost in obtaining results which might have been obtained in a fortnight. It was not, indeed, till early in 1869, when M. Le Chatelier himself, relieved of more important duties, took upon himself the practical examination of the question, that the experiments were completed on various railways in France. These experiments have now determined the true solution of the questions which he had proposed on 19th September 1865, and a comprehensive basis has been laid down for all applications of his system for the future.

In the *Mémoire* M. Le Chatelier describes the trials made by the engineers to whom he sent his instructions, and points out the mistakes into which those engineers fell. He also rectifies certain erroneous views of the theory of the subject which have been put forth; and he adds a historical notice, in which his just claims as an inventor are vindicated.

The only object of the present publication is to explain the principles, the mode of application, and the results obtained from M. Le Chatelier's experiments, To the system its author has given the name of *Marche à Contre-Vapeur,*—working with counter-pressure steam,—to distinguish it from the usual expression of *renversement de Vapeur*, reversing steam. The explanation and description of the details relative to the first trials made in Spain, and subsequently by the engineers of the great railway companies of France, and the historical notice, have been omitted.

It will be found that this system of working counter-pressure steam has the following advantages:—

1°. It puts the control of the speed of the train into the hands of the driver of the locomotive himself, giving him a means of instantaneously using all the load on the driving wheels as a brake, without danger to himself or stoker, and with little physical effort.

2°. It gives a higher degree of security against collisions and over-running stations than has hitherto existed, and greatly facilitates all shunting operations.

3°. It economizes rails, by dispensing in a great measure with the use of the brakes of the tender and brake vans.

4°. It economizes wheel-tires and grease.

5°. It allows of the number of brakesmen being permanently reduced.

Again, it has to scientific engineers the interest of being an illustration of the dynamic theory of heat; the *work* of retardation being converted into heat which is in great part sent to the boiler, instead of being wasted in abrading rails and tires, heating pistons, stuffing boxes and wheels, and thereby wasting grease and oil.

To obtain these results, the apparatus required is of extreme simplicity, can be applied to any construction of locomotive at small cost, and without any other alteration of the engine than that of fixing the apparatus upon it.

M. Le Chatelier having asked me to translate his valuable *Mémoire*, I persuaded him to recast it, with the view of adapting it more especially to English readers; and I have translated his manuscript to the best of my ability, happy in the privilege of being permitted to associate my name with that of one of my oldest friends in the publication of an invention so creditable to the well-earned fame of its author, and so important to railway economy.

My only regret is, that the uncertain and feeble state of my health should have caused a delay of nearly three months in offering the following pages to the public.

LEWIS D. B. GORDON.

Château de Bossey, Céligny,
Genève, *July* 24, 1869.

MEMORANDUM OF MULTIPLIERS FOR CONVERTING BRITISH AND FRENCH MEASURES.

Mètres into feet, ...	3·2809	Feet into mètres, ...	0·3048
Millimètres into inches, ...	0·03937	Inches into millimètres, ...	25·4
Square millimètres into square inches, . .	0·00155	Square inches into square millimètres, . .	645·14
Kilomètres into miles, ...	0·6214	Miles into kilomètres, ...	1·6093
Kilogrammes into lbs., ...	2·2046	Lbs. into kilogrammes, ...	0·4536
Litres into gallons, ...	0·2202	Gallons into litres, ...	4·541
Atmospheres into kilogrammes on the square mètre,	10333	Atmosphere into lbs. on the square inch, .	14·7
Centigrade degrees into Fahrenheit's degrees, .	1·8	Fahrenheit's degrees into Centigrade degrees,	0·5556

(The Zero of the Centrigade Scale corresponds to 32° Fahrenheit.)

For complete Tables of Multipliers see Rankine, *Useful Rules and Tables*, etc. London, 1866.

ON THE APPLICATION OF COUNTER-PRESSURE-STEAM IN LOCOMOTIVE ENGINES AS A BRAKE.

THE difficult and often dangerous operation of reversing steam in the locomotive engine is well known to all who have had to do with the working of trains on railways; and hitherto, the engine-drivers never have had recourse to it save in cases of imminent danger. To reverse the steam while a train is running the driver has suddenly, by reversing the handle of his engine, to bring the valve gear into unison with the motion of the pistons and axles. The steam in counter-pressure is a force of resistance which rapidly overcomes the *vis viva* of the train, if it be running on a level, and equilibrates the accelerating force of gravity, if the train be descending an incline.

This reversing of the steam has, however, the great inconvenience of heating the cylinders and the whole metallic mass in connexion with them; of destroying the packings; decomposing the grease, and causing the rubbing surfaces to bite. To remedy this inconvenience, which very soon renders the operation impossible, it is only necessary to introduce a small jet of water from the boiler, by an orifice of from one-tenth to one-sixth of a square inch area delivering from 8 lbs. to 40 lbs. of water per minute, and lead it to the bottom of the exhaust pipe near the cylinders. This water has a temperature corresponding to the pressure of steam in the boiler, and bursts into ebullition the moment that it is exposed to a lower pressure—that of the atmosphere,—and the exhaust pipe is at once filled with a kind of froth or watery steam which is drawn into the cylinders by the retrogression of the pistons. The water held in suspension is converted into steam by contact with the metallic mass of cylinders, pistons, covers, etc. It cools them, and prevents the effects of heating which the counter-pressure tends to produce. Besides, if the injection be sufficient, the quantity of steam thus formed is also sufficient not only to insure the filling of the cylinders, but to provide for a discharge by the exhaust nozzle, so that any introduction of the gases of the smoke box into the cylinders and into the boiler is prevented, and the effective working of the Giffard injectors is secured.

A part of the water of injection may be replaced by steam taken directly from the boiler and led by a branch pipe into the pipe which carries the water; but this substitution must be made with caution. When the admission of counter-pressure steam is required during the greater part of the stroke of the piston, in order to produce instantaneously a great force of resistance for the purpose of stopping a train, or of moderating the speed of a heavy train on a steep gradient, the use of steam for the injection must be very carefully managed. The steam mixes with the water, and if it be in excess, it carries the water along with it to the chimney, diverting it from the object for which it is intended, namely, to cool and lubricate the cylinders. This substitution, which is not absolutely necessary, may however be useful in certain circumstances, and to satisfy certain particular conditions.

All the mechanism necessary for applying the system of working counter-pressure steam consists in a tube of *an inch* to an *inch and a quarter* diameter, and a cock or valve. Where it is deemed useful to apply steam as well as water, a second cock or valve is added, and a short branch pipe.

The theory, if we may apply so ambitious a term to a system so elementary, consists in the transformation of the effective *vis viva* of the train which it is desired to stop, or of the mechanical effect due to gravity in the descent of inclines, and which may be represented by a certain number of foot-pounds into an equivalent number of units of heat or *calories.* One part of the heat produced is carried off by the steam which escapes by the funnel and is lost; the other part provides for the maintenance of the temperature of the cylinders and of the boiler, and constitutes, in fact, a saving.

I propose, in the following pages, to develop the general ideas on this subject; to point out all the particularities which the use of counter-pressure steam presents; and to make known the applications which have been made of, and the services which may be expected from, this new system of utilizing the locomotive engine as a brake power.

CHAPTER I.

ON REVERSING THE STEAM.

In order to make perfectly clear the manner in which the reversing of the steam acts, compared with the action of steam in the usual forward motion of the engine, I have represented in two double diagrams (Figs. 1 and 2, Pl. I.) the variations which the pressure of the steam undergoes during a complete oscillation of the piston, and on its two sides. In Fig. 1 the distribution is in accordance with the direction of motion, and in Fig. 2 it is in opposition to this direction. That is to say, Fig. 1 represents the steam pressing on the piston and acting as an accelerating force, and Fig. 2 represents the steam forced back by the piston producing the counter-pressure, and thereby acting as a retarding force.

These figures are made from the original diagrams taken by M. Forquenot of the Orleans railway, who applies daily, with great success, Watt's indicator to the study of all the phenomena of distribution, and of the use of steam generally in the locomotive engine. It is by means of the experiments, the details of which M. Forquenot has had the kindness to place in my hands, that I have been able to elucidate with some degree of completeness the questions involved in the application of counter-pressure steam.

The form of the diagrams, Figs. 1 and 2, Pl. I. (the latter of which was taken during experiments with injection of water *and* steam), has been somewhat altered in order to make the variations of pressure more obvious. The diagrams of Pl. II. have, on the other hand, been reproduced exactly as the instrument gave them.

To simplify the grouping together of the diagrams and their discussion, I have supposed that the piston is reduced to a *line*

Pp or $P'p'$, and I have drawn the diagrams themselves within the frame representing the volume engendered by the stroke.

§ 1. *Usual Forward Motion, or Direct Admission.*

When the piston commences its stroke, for the forward motion for example, starting from the position *A B*, the slide valve moves in the same direction (that is to say, towards the front of the engine), and its outer or induction edge having uncovered the port *A*, the communication with the boiler is opened. The steam presses on the piston, which carries forward the connecting rod and the crank in the direction indicated by the arrow drawn in a full line. After the moment when, by the action of the link and the excentrics, the slide valve retrogrades and shuts the port *A*, the steam expands and continues to press the piston, but with a decreasing pressure. A little before the end of the stroke the eduction edge of the slide valve uncovers the port *A*, and the escape of the steam begins and continues up to the dead-point, at which the piston has the position *C D*.

The piston now moves back from the position *C D* towards *A B*, the greater part of the steam which filled the cylinder continuing to escape to the atmosphere; but before the end of the stroke, the motion of the slide valve shuts the communication of the port *A* with the exhaust pipe. The steam now shut into the cylinder is compressed or cushioned, and the clearance or prejudicial space is therefore filled beforehand with steam, at a pressure more or less approaching that in the boiler.

The crank and the wheel have at the same time made a complete revolution. But while this revolution has been made, the steam entering by the port *C* has exerted a symmetrical force on the opposite side of the piston. On the return of the piston from *C D* towards *A B*, it has been pushed by the steam, and has pushed the connecting rod and crank in the direction of the arrow shown by dots, thus assuring the continuity of the rotation. The expansion has followed the admission, and has been followed by the release or anticipated exhaust due to the lead; the continuation of the exhaust, and then the cushioning, take place during the return of the piston to its primitive position *C D*.

The resistance to the passage of the steam through the ports at the instant of exhaust, does not admit of the pressure falling to that of the atmosphere when the speed is anything considerable.

In Fig. 1, Pl. I., which shows the two diagrams superposed, the pressure exerted on each side of the piston is represented by a full line, or by a dotted line, according as the piston is moving forward or backward. To find the resultant pressure exerted at any moment on the piston, it is only necessary to take that part of the ordinates Pp or $P'p'$, which is intercepted by the two full lines of the diagrams, or between the two dotted lines, as ab or $a'b'$, according as the piston is moving forwards or backwards.

In this graphical analysis of the action of steam in the usual working of the engine, there is nothing but what is well known. It is given in order that the action of the engine moving with counter-pressure steam may more readily be appreciated.

It shows incidentally that the resultant pressure on the piston is not always a *motive force.* This pressure becomes a resistant force at the points K and K' more or less near to the dead point. This resistance is favourable for taking up the *vis viva* of the piston and its appendages, and for preparing for its stoppage and return at the dead point. This effect may be increased by combining the elements of distribution so as to increase the cushioning, and at the same time the advance of the exhaust. The *stud* or slide of the pistons T and T, excepting for two short portions of its stroke before arriving at the dead point, presses on the upper bar of the guide; it is this bar which retains the piston in its true rectilinear position.

§ 2. *Counter-Pressure Steam, or Inverted Admission.*

When the steam is reversed, the reversing handle having been fixed at one of the notches of the sector for the *backward* gear, *the regulator being open,* the direction of motion of the piston is unchanged, but the different phases of the distribution are inverted. At the moment the piston moves from the position $A\ B$, all the ports are closed, and the steam, or the mixture of steam and gas which fills the *clearance* or prejudicial space, expands to fill the volume swept by the piston. At the point at which the cushioning commences in the usual working, the eduction edge of the slide valve will uncover the port *A*, and the space behind the piston will be in communication with the exhaust pipe. A certain quantity of steam, or mixture of steam and gases, will issue from the cylinder; but as the port opens gradually, and as at that moment the piston is moving with great speed, this discharge will be small, and the volume swept by the piston will continue filled by the expansion of the gaseous mixture up to a certain point, varying with the position of the reversing handle, up to *b*, for example, in Fig. 5, Pl. II. Starting from this point, the volume swept by the piston continues to increase, and will be filled by the gases from the smoke-box, entering by the exhaust pipe and by the port *A*. When the piston reaches *C D* at the dead point, the communication with the exhaust pipe will still remain, and will so continue during the backward stroke of the piston, from *C D* towards *A B* to the point *C*, which corresponds to the *advance* of the exhaust in the usual working of the engine.

At this instant the mixture of steam and gas, confined behind the piston, is compressed by the motion of the piston towards *A B*, and this compression will increase rapidly up to the point *a*, which corresponds to the cut off or commencement of expansion in the usual working.

The port *A* being now uncovered by the induction edge of the slide valve, the steam from the boiler will rush in and fill up the cylinder, compress the mixture already there, and when an equilibrium of pressure with that in the boiler takes place, the new mixture, in which the gases from the smoke-box are present now only in a reduced proportion, will be driven back into the boiler. The resistance at the ports and in the steam-pipe give rise to an increased pressure in the cylinder, as is shown by the diagrams of Plate II.

It should be remarked that when the steam from the boiler commences to enter the cylinder at *e*, the port is only just opened, and that a large volume of steam is necessary to fill the cylinder; the equilibrium of pressure with the boiler takes place slowly, although the motion of the piston favours this equilibration by reducing the volume to be filled. This is a favourable circumstance, inasmuch as it prevents anything like a shock which would be prejudicial to the mechanism of the engine: but it has the inconvenience of reducing in a sensible degree the resistance due to the indirect admission or inversion of the steam.

The same effects are reproduced on the other side of the piston, and finally the result of the double stroke is represented on the two superposed diagrams of Fig. 2, Plate I. If it is desired to know the resultant effort, at a given point in the stroke, of the pressure of the steam simultaneously on the two sides of the piston, the portions *ab* or *a′b′* of the two ordinates *Pp* or *P′p′* intercepted by the two full lines give this resultant.

Here again there are two points, *k* and *k′*, where this resultant changes direction; but these points are much further from the ends of the cylinder, or nearer its centre, than in the case of direct admission, shown in Fig. 1 of the same Plate.

This circumstance is important. To it may be due the shocks, rattling of the grease-boxes on the guides,—rattling of the brasses of the connecting-rod heads on the studs, etc., which have been remarked in working with counter-pressure steam.

It is true, in working engines with counter-pressure, I have only once had occasion to remark these effects, which do not arise when the reversing handle is in the notch of least admission, but which become very sensible when the handle is at the 4th or 5th notch, and again disappear when the handle is drawn to the notch of maximum admission or full backward gear. They appear to depend on the change of position of the point *k* with the different degrees of admission; but as these effects do not occur when the engine is in good working order, and as the wear and tear increase rapidly if those parts of the mechanism having an alternative motion are permitted to have any play, it is most important that the condition of the engines should not be neglected. It is, in effect, an additional stimulus to the driver to keep his engine in perfect working order.

§ 3. *Calorific Effects.*

The inverted admission of the steam gives rise to a heating of the cylinders, pistons, piston rods, and slide valves, which tends rapidly to carbonize the packing of the stuffing boxes. This effect is due in part to the high temperature of the gases drawn in from the smoke-box. These gases, coming from the fire-box, traverse the tubes which are surrounded by water at 170° to 180° C., and their temperature is probably from 200° to 250°. But the principal calorific effect is due to the compression of the mixture of gases and steam confined behind the piston, to the sudden great compression which they undergo when the steam rushes in from the boiler to fill up the cylinder, and finally to the driving back of the new mixture into the boiler. The mechanical effect, or energy destroyed by the inverted admission, or by the resistance due to these various compressions in absorbing the *vis viva* of the train, or in overcoming the accelerating component of gravity produces a certain quantity of heat, a part of which is absorbed by the mass of metal, the temperature of which it raises rapidly, and part is returned to the boiler.

The rise of temperature in the boiler is limited by the escape of steam issuing by the safety-valves with the fixed gases coming from the cylinders, and that of the cylinders by the loss of heat due to external radiation.

In the case of Blowing-machines or Air-pumps, with slow motion and but slight compression of the air, equilibrium between the internal heating and the external cooling soon takes place, and the metal undergoes little elevation of temperature. But in the locomotive engine, as the compression is as much as nine to ten atmospheres, and as the number of strokes per minute is considerable, the heating increases far more rapidly, and is in fact proportioned to the internal work done, whereas the cooling is simply proportioned to the time and the temperature acquired. The limit at which the grease is decomposed, and at which the metallic surfaces begin to bite, is therefore soon attained. A locomotive engine cannot therefore run for any time with the steam reversed in the ordinary way without being rapidly rendered unfit for service.

Direct experiments made on the North of France line prove that by shutting the exhaust nozzle and drawing in external air, with the engine running at a speed of 20 miles per hour, the stuffing boxes were carbonized after a run of 1½ miles; and with an injection of steam alone, there was a similar result after a run of 2½ to 3 miles. The difference must be attributed to the presence of a small quantity of water in the steam drawn from the exhaust pipe, or admitted directly from the boiler, and to the difference of the specific heats of air and steam. Thus, the inverse admission of steam, as hitherto practised,—that is with the introduction of the hot gases from the smoke-box,—so seriously injures the engine as to render it unfit for service in less than five minutes.

§ 4. *Sudden return of the Handle to "Forward Gear."*

Reversing the steam as hitherto practised is accompanied with considerable danger to the driver. The reversing handle, held in its place by a vertical pall or stop, in the notch of the sector required for the distribution, has been observed to move suddenly back to its normal position, and in some arrangements of the link gear to strike the driver so severe a blow as seriously to injure him, or even to kill him. This cause of danger is particularly to be feared when the normal position of the reversing handle for full forward gear is at the back of the sector, inclined towards the tender.

This sudden return of the handle when the engine is moving forward, and the distribution set for running backward, has not been explained satisfactorily. The explanation which I am about to offer is not perhaps new, but it appears to me to account for all the varieties of effects hitherto observed. It will be sufficient to state the principle to enable engineers desiring to go more minutely into the question to form an exact idea of it.

The pressure of the steam on the slide valves gives rise to considerable friction in the reciprocating motion of those valves. This friction increases when the steam is reversed on account of the rise of temperature and consequent biting of the surfaces already mentioned. This friction has to be overcome by additional strain on the bars of the link-gear and excentric rods. The collars or rings press harder on the excentrics, and these thus become friction brakes, which cannot be carried round in the rotation of the axle, simply because the extremities of the rods are solidly attached to the link. They would carry the link itself into rotatory motion, which the friction of the excentrics tends to communicate to them, if they were not fixed to the lever for raising them, and these again to the bar going to the reversing handle.

When the engine is in full forward gear the reversing handle is at the owest notch of the sector, and the displacement of the link upwards is limited by an insurmountable obstacle. But if the driver reverses the steam by placing the reversing handle at the opposite extremity of the sector, he raises the link which remains suspended with no other means of fixing it than the stop on the lever placed in the notch of the sector; but the excentric rods tend to draw it down to its original position with a force increasing as the friction of the slide valves increases, and hence the friction on the excentric collars.

If the driver, in his haste to reverse the steam, has put the stop into the notch incompletely, if the vibration of the engine, or the strains on the link gradually work the stop out of the notch, it may well happen that the link will fall down to its lower position and cause the reversing handle to return suddenly and with violence to its normal position. It is during this movement that the driver may be struck, particularly if the arrangement of the mechanism be such that in the normal position the handle is at the back of the sector, as is generally the case.

From the same cause, the driver may find himself unable to reverse the steam when in motion, if he has not sufficient strength; or if he does not succeed at once in putting the stop into the notch, he may be pitched backwards, or thrown forwards, according to the normal position adopted for the revers ing handle.

An analogous effect may take place in those engines where the link is placed in its highest position for the full forward gear; that is to say, in making the lower part of the link act upon the stud of the slide-valve rod; but, in this case, it is the reversal of the steam which instantaneously produces the effect.

Those engines in which the link is suspended to a fixed point, and in which the system for raising it works a long connecting-rod, interposed between the stud and the slide-valve end, are not subject to these sudden returns of the reversing handle.

The use of the screw motion for the reversing gear is evidently a perfect preventive against this danger.

One of the principal causes of the success of the counter-pressure steam system in France has been the substitution of the screw motion for the ordinary lever as a reversing handle[1] by M. Marié, engineer-in-chief of the Locomotive department of the Paris, Lyons, and Mediterranean Railway. This valuable auxiliary has allowed of the new system of counter-pressure steam being generally applied and utilized in every branch of the service of this great system of railways. No other railway company has hitherto made so extensive an application of the system of counter-pressure; indeed the extent of the application on this system of lines exceeds that on all others put together.

[1] The screw motion, in the form in which it is applied by M. Marié, is due to Mr. Kitson of Leeds.—TRANSLATOR.

CHAPTER II.

APPLICATION OF COUNTER-PRESSURE STEAM.

§ 1. *Object and Advantages of the new System.*

THE application of a simple mode of obviating the difficulties consequent on the reversal of the steam, has supplied a want becoming daily more important. Railways with steep gradients are becoming more frequent; the trains run are becoming heavier, and the speed is being increased; and now, by taking a small stream of water from the boiler, and thus filling the exhaust pipe with a mixture of steam and water, all the difficulties of reversing the steam are found to disappear.

Already, throughout those sections of the French railway system on which the gradients exceed 1 in 85 to 1 in 66 (12 to 15 millimètres per mètre), the trains descend without the aid of brakes, and with a speed as regular as perfect safety demands, without any exceptional wear and tear on the engine, and with an insignificant increase in the expenditure of fuel.

The tires of the tender-wheels and of the brake-vans are no longer subjected to those causes of wear and distortion which the friction on the rails and on the brake-shoes gave rise to. The rails are relieved from the rapid destruction occasioned by the friction of the wheels—the breakages of rails arising from the alteration in form of the tires under the action of the brakes are avoided; and finally, an important economy of grease has been obtained, for the wheels, no longer heated by friction on the rails, cannot communicate heat to the nave and to the grease-boxes as they have hitherto done. On the incline at *Lannemezan,* on the *Chemin de Fer du Midi,* the inclination of which is 1 in 34 for a length of 6¾ miles, the company had ordered Bessemer steel rails for the descending line, but after a lengthened experiment it was evident that the rails did not wear more rapidly on the descending than on the ascending line, and the costly Bessemer steel rails were employed on other parts of the lines where there is a greater traffic.

The trains descending an incline are in the same condition, in reference to stopping them, as when they are moving on the level. The work done by the engine is always proportioned to the force of gravity; and, if it becomes necessary to stop the train, the brakes of the tender and of the brake-vans are there for the purpose. The resource of reversing the steam is no longer entirely at disposal; but as the admission of counter-pressure steam is not generally necessary save at a point intermediate between the extremes of full backward gear and mid-gear, it most frequently happens that the train can be stopped on the incline by using the retarding force of the counter-pressure with the reversing handle in the full backward gear. In several instances, the number of supplementary brakesmen for the descent of steep inclines has consequently been reduced, and where they are retained it is rather as a precaution against accidents in the ascent by the breaking of couplings than as necessary to safety in the descent.

Further, the system of counter-pressure steam is coming more and more into use for the regular stopping at stations. Often the signal for the guard in the brake-van at the tail of the train to put on the brakes in approaching a station, is the disappearance of steam at the funnel when the driver sets the link at mid-gear: the brake power is then supplemented with counter-pressure steam, and the train is stopped with the utmost precision. But it is not unusual to stop the train with the engine alone, the brake of the tender being reserved for cases of necessity. There are many drivers who understand and appreciate the instrument placed in their hands, who come up to the entrance to the station at great speed, and stop with the utmost precision in the shortest distance, whether with or without the aid of the brakes of the vans.

Experience, whether in the descent of inclines or in stopping at stations, proves that there is no inconvenience in employing the engine only to overcome the force of gravity, or to absorb the *vis-viva* of the train. It may be assumed that the use of counter-pressure steam, with the injection of water for the complete cooling of the cylinders, will become quite as general for the stoppage of trains at stations as for the descent of inclines; and that the loss of time for stoppages, which for omnibus trains is very important, will be sensibly diminished. The brakes will be used as a supplementary aid in case of a signal of alarm, or in case of an excess of weight in the train. This arrangement has as yet not been systematically adopted, however much observation would justify it, or however obvious as a matter of economy in the maintenance of fixed and rolling stock. It must not be inferred from the preceding observations that the brake-guards may be altogether dispensed with, but the number may be diminished. Thus relieved from secondary mechanical agency, the service would pass into the hands of the drivers, who would be altogether responsible, and who would use the whistle signal to the brakesman only in cases of alarm or danger, and therefore be more likely to have it obeyed than when constantly resorted to.

The question of brakes is very important. The substitution of a uniform motion with uniform speed for the variable motion under the action of brakes, is very properly considered as an essential element of safety.

For stopping trains at stations, the systematic application of counter-pressure steam, and its substitution for the ordinary brakes, except on extraordinary occasions, is still matter of discussion; but the experience which is being daily obtained of the use of the new instrument must, I think, lead to the general employment of counter-pressure steam, rendered perfect by the use of the screw for moving the reversing handle, and thus to a great simplification in the arrangement of the trains in stations, and to doing away with the necessity of breaking them up for re-arrangement. The driver keeps the regulator always open, and is thus enabled to move forward or backward, or altogether to stop the train, by simply adjusting the position of the slide valves.

§ 2. *Injection of Water.*

About the middle of 1865, when I first thought of organizing a system of experiments for removing the difficulties of reversing the steam, I began by trying whether it would be possible to work the engine for any considerable time by means of the compressed-air apparatus of Mr. de Bergue. I soon convinced myself that the heating of the cylinders went on so rapidly that this system was inapplicable for any length of run. It was then that I drew up a complete programme of experiments, the sum and substance of which was to establish a communication between the boiler and the lower end of the exhaust pipe, in order to supply there a jet of steam, or of water, and to force into the boiler the elastic fluids—steam or gases discharged from the cylinders by the return stroke of the piston. I pointed out three combinations to be experimented on in succession, according to the greater or less difficulty found in completely cooling the cylinders.

1°. Injection of steam mixed with air.
2°. Injection of steam in sufficient excess to prevent the entrance of air.
3°. Injection of water, instead of steam.

At first I supposed that the steam would carry along with it a sufficient quantity of water to absorb the heat produced, and that it would be condensed before reaching the cylinders. This idea was incorrect. During the working with steam reversed, the water ceases to be in a state of violent ebullition, and is only carried over in small quantities; and, besides, when the steam expands in issuing from the boiler, it dries, and the small quantity of water brought with it is almost entirely converted into steam.

The first experiment with a mixture of steam and gases drawn into the cylinders did not give favourable results. With the injection of an excess of steam—a system which I characterized as an *inverted steam-engine*—more satisfactory results were obtained, and it was found possible to work with a moderate admission of steam with light loads on moderate gradients, without burning the packings, and without injuring the rubbing surfaces. We have in France the example of a railway on which 200 engines have only a cock for the injection of steam, and the substitution of this for the gases drawn from the smoke-box has proved sufficient to render the counter-pressure steam applicable for stopping and shunting in stations, and for moderating the speed in the descent of goods trains on gradients of 1 in 260. Indeed, the injection of steam alone has been effectually applied to light trains on a short incline of 1 in 22.

But experience soon showed that the only general and complete solution of the question is found in the injection of water. To complete the absorption of the heat produced by the compression in the cylinders, to force back the steam into the boiler, and to render the reversal of the steam an absolutely innocuous operation, water is the only appliance.

The engineers in Spain, to whom I intrusted the experiments, never quite understood the effects which the injection of water should produce. The application of it was therefore made with timidity and with doubt.

They imagined that it must be reduced to the minimum quantity. As a consequence, the results obtained in this, the first application, were never complete, despite successive increments of the quantity of water added to the steam. It was in France that engineers first recognised the necessity of giving a great preponderance to water over steam, and thus succeeded in rendering the new system applicable under every circumstance of the locomotive service.

For many months the official reports sent from Spain (Chemin de Fer du Nord de l'Espagne) announced that the results obtained, from a mixture of steam and water, were quite satisfactory, but this was afterwards proved not to be the case. For two years and a half after my first programme was drawn up, this idea, that the solution of the problem consisted in injecting a mixture of steam and water into the exhaust pipe, prevailed. By successive trials—by rendering the steam and water cocks altogether independent of each other under the hand of the driver, the suitable proportion of water to steam in the various circumstances of admission, speed, distribution, and dimensions of cylinders, was arrived at. It is by correcting this erroneous notion, which attributes to steam a necessary part in the action, that in France alone the system has been applied to 1800 engines in work, or being fitted with the necessary apparatus. The practical result has been complete, because of the independence of the injecting cocks, which has allowed of the proportion of water being carried to the necessary limit in each case.

At the end of the year 1868, being free from my usual occupations, I determined on a consecutive study of the question, and on the verification of the results which had been obtained independently of my control. I soon perceived that my original notion—on which I had often by correspondence insisted—was correct in every respect; that the true solution consisted absolutely in the injection of water—that this solution satisfied every condition of the problem, and is probably the only one entirely applicable in cases of full admission and great speed. Steam, in fact, plays only a secondary part, prejudicial when above certain proportions, and, when used, to be applied with great caution, and only within certain limits.

The order which I shall follow in completing this explanation of the system will be found in harmony with its principles, but reversing the order of the modes of application which, until quite recently, have been adopted.

§ 3. *Effects of the Injection of Water.*

When we speak of injecting water issuing from the boiler into the cylinders of a locomotive engine, it must be borne in mind that it is not water in the state in which it would flow from a fountain; it is at a high temperature when it issues from the boiler, and rushes into space at atmospheric pressure. It enters at once into ebullition, and becomes steam at 100° C., in quantity corresponding to the heat employed.

The orifice of the injection cock has a section varying from 0 to 0·6 inch square (from 0 to 15 millimètres carrés), and the small pipe leading to the exhaust pipe is from 1 inch to 1¼ inch diameter; it takes a sinuous course along the side of the boiler, and is divided into two branches, so as to go to the ends of the exhaust pipes nearest the exhaust ports. The discharge of this cock is not limited by the form and dimensions of its orifice alone. The section, the length, and the bends in the small conducting pipe influence the discharge, which at a certain limit becomes constant, whatever be the opening of the cock, in consequence of the resistances in the conducting pipe. With a tube of 1¼ inches diameter, the limit appears to be (40 kilogrammes) about 90 lbs. of water (1½ cubic feet or 9 gallons) per minute, and with a tube of 1·57 inch (40 millimètres) diameter, the limit of discharge seems to be about 18 gallons per minute, or double the above. But in practice the greatest discharge required does not exceed 50 to 60 lbs., or less than 6 gallons per minute.

The vaporization of a portion of the hot water will vary according to the quantity discharged, and will be accomplished at a variable point of the injection pipe, or at all events on its arrival at the exhaust pipe. The exhaust pipe will therefore be filled with a froth or emulsion, such as that which issues from a water tube broken by excess of pressure, or such as issues from the waste pipe when a boiler is emptied under steam pressure. This mixture of water and steam moves with great velocity through the injection pipe, and the water-drops, being broken, or, as it were, pulverized, by striking against the sides of the exhaust pipe, it becomes truly elastic and compressible when drawn into the cylinders, and readily circulates like saturated steam in the steam pipe and in the ports.

It is easy to form a correct notion of the composition of this mixture of steam and water by calculation.

If we suppose the boiler to be at a pressure of 9 atmospheres absolute, from which 10 kilogrammes of water per minute are taken for injection, there will be formed a certain quantity of steam $= x$. The temperature of the water in contact with saturated steam at 9 atmospheres is 175°·77 Centigrade, and the quantity of heat which one kilogramme gives up when its temperature descends to 0° is equal to 178·017 calories,[1] accord-

[1] A *calorie* is the quantity of heat necessary to raise the temperature of one kilogramme of water from 0° to 1° Centigrade. The thermal unit employed in Britain is, *the quantity of heat which corresponds to an internal of one degree of Fahrenheit's scale in the temperature of one pound of pure liquid water at and near its temperature of greatest density* (39°·1 Fahrenheit). Therefore—

British thermal units in above French units = 3·9683
and French thermal units in British unit = 0·2599

The thermal unit is called "*Joule's equivalent*," and is sometimes, in British writings, denoted by the symbol J. It is established by the mechanical theory of heat, that heat is converted into work, and *vice versa*, in a proportion which, though not yet fixed absolutely by experiment, is considered sensibly equal 1 : 772 in British units, and 1 : 424 in French units. That is to say, the disappearance of a British unit of heat will produce work equivalent to 772 lbs. raised 1 foot high; or the disappearance of 1 calorie, the French unit, will raise 424 kilogrammes 1 metre high.—See Rankine, *A Manual of the Steam-Engine, etc.*, Part III. Chapter iii., *Principles of Thermodynamics.*

ing to M. Regnault's experiments. The quantity of heat given up by a kilogramme of water at 100° in descending to 0° is 100·5 calories. Besides, according to the tables of M. Zeuner,[1] the transformation of a kilogramme of water at 100°C. into steam at 100° requires for the displacement of an atmosphere 1646 times greater in volume, a quantity of work equivalent to 40·092 calories. And lastly, the excess of the internal heat of a kilogramme of steam at 100° Centigrade above the internal heat of a kilogramme of water at 0° is equal to 596·76 calories. We can therefore establish the following equation between the quantity of heat contained in the 10 kilogrammes of water in the boiler, and that which must exist in the water and steam at 100°, increased by what is due to the work done in the formation of steam—

$$10 \times 178{\cdot}017 = (10 - x)\ 100{\cdot}5 + x(596{\cdot}76 + 40{\cdot}092)$$

from which we find $x = 1{\cdot}445$ kilogramme, or 14·45 per cent.

As the steam at 100° occupies a volume 1646 times greater than that of the water from which it has been formed, 1·445 kilogramme will occupy 2378 litres, in which must be disseminated the remainder, or 8·555 *kilogrammes*=8·555 *litres* of the water. The ratio of 8·555 to 2378=0·0036 may be termed the dose of water in the wet vapour.

Repeating this calculation for different pressures, and on the supposition that the injection pipe has one square inch section (5 centimètres carrés), or is 1⅛ inch diameter, the discharge of water per minute being 10 kilogrammes, or 22·05 lbs., we obtain the following table :—

Absolute Pressure in Atmospheres.	Temperature in the Boiler (Centigrade).	Proportion of Steam formed °/.	Volume of Steam formed per Minute.		Proportion of Water in the Mixture.	Velocity of Flow of the Mixture in	
			Litres.	Cub. Ft.		Metres per Second.	Feet per Second.
10	180°·31	15·33	2533 =	89·5	0·0033	84·10 =	275
9	175·77	14·45	2378 =	84·5	00·036	79·26 =	260
8	170·81	13·49	2220 =	77·5	0·0039	74·00 =	243
7	165·34	12·43	2066 =	71·0	0·0042	68·86 =	226
6	159·22	11·26	1853 =	66·0	0·0048	60·27 =	206
5	152·22	9·92	1633 =	57·5	0·0055	54·44 =	180

[1] See Zeuner, *Grundzüge der Mechanischen Wärmetheorie*, pp. 78 to 88, and columns 7 and 13 of Table I. p. 200.

The numbers in the table show distinctly the nature of the fluid which is presented for induction to the cylinders on the return stroke of the pistons, when the water is taken from the boiler at high pressure, and which is found to satisfy the condition of perfectly cooling the cylinders. It is a nebulous vapour, a dense wet mist.

It may indeed be said, that the system which consists in sending the water of the boiler to the cylinders is only an injection of steam containing the maximum quantity of water with which it is possible to impregnate it. For the dose of water in the mixture could only be increased by admitting cold water into the injection tube, or by submitting the stream issuing from the boiler to some external cooling process,—passing it through a worm, for instance.

Experience has proved that an injection of this vapour, in quantities varying with the position given to the reversing handle for regulating the admission when reversing steam, according to the dimensions of the cylinders and the speed of the engine, answers every condition of the problem.

The water which arrives in the cylinder as wet vapour is there converted into dry steam. The heat disengaged by cushioning and forcing back the steam at the return stroke of the piston, in proportion to the work of resistance produced by the locomotive, is completely absorbed. The thermometer shows that the only rise of temperature in the current of steam forced back to the boiler is that which corresponds to the increase of pressure necessary to produce the flow backwards, and is not more than one or two degrees Centigrade.

During the period of induction, that is, during the very short time in which the cylinders are in free communication with the exhaust pipe and with the atmosphere, all the steam necessary for filling the cylinders is formed, and even an excess is produced, which escapes in the usual visible form as a cloud from the funnel, so that the gases of the smoke-box cannot penetrate to the cylinders, nor to the boiler, and thus the Giffard injectors work undisturbed. If the injection of water is insufficient, either from mistake or from negligence of the driver, the gases get forced into the boiler, the index of the pressure-gauge oscillates rapidly, and the Giffard injectors cease to deliver the feed water. If the injection of water be in excess, the steam which is produced in the cylinders carries a part of the water with it to the funnel, and it falls into the smoke-box, or is showered out from the funnel. More or less of the water gets into the cylinders, according to the point at which the injection pipe enters the exhaust pipe. The nearer the cylinders the more the water. But save for the projection of water from the funnel, the choice of this point is indifferent. All that is necessary is, that the boiler should send constantly to the exhaust-pipe a quantity of water sufficient to form steam to fill the cylinders.

As I shall show hereafter, the pistons and the slide valves are always bathed in an atmosphere impregnated with water, which lubricates the rubbing surfaces, and thus places them in the most favourable conditions, more favourable indeed than in the ordinary working of the engine.

The best method of getting thoroughly to understand these different effects, is to take a practical example, which I shall borrow from one of the many experiments which I have made.

Goods Engine—8 *wheels coupled. Paris and Orleans Railway.*
No. 1118.

Diameter of driving wheels, .	1·30 mètre	= 4·25 feet.
Diameter of cylinders, . .	0·50	= 20 inches.
Stroke of piston, . .	0·65	= 26 inches.
Speed per hour, . . .	30 kilom.	= 18·6 miles.
Admission (hundredths of stroke),	58°/o	
Injection of water per minute,	18 kilog.	= 40 lbs.
Absolute pressure in boiler,	7·75 atmos.	

Fig. 3, Pl. II. is the diagram illustrative of this experiment. It gives approximately 40°/o of the stroke as the volume taken into the cylinder, cushioning deducted, and the mean pressure of the steam determined by the area of the diagram measured in the original, of which the Fig. 3, Pl. II. is only a reduction, is 1·77 kilo. per square centimètre = 2·5 lbs. on the square inch.

We have therefore—

Total pressure on the piston, kilog.	3474·80	= 7644 lbs.
Work per cylinder full, . kilog. m.	2258·62	= 16335·7 ft.-lbs.
Number of revols. of wheels per minute,	122·52	
Number of cylinders full per minute,	490·08	
Total work done per minute, k. m.,	1,107,176	= 8,004,493 ft.-lbs.

Equivalent quantity of heat (calories), 2611·20 = 10,372 British Thermal Units.

Temperature of boiler at 7·75 atmosph., 169°·50

Number of calories required to convert into steam one kilogramme of water at 169°·50 C., . . 486·72

Quantity of injection water required per minute, . . kilogrammes 5·36 = 12¾ lbs.

In other terms, the first condition for the absorption of all the heat disengaged by reversing the steam would be fulfilled, if, of the 18 kilogrammes or 40 lbs. of water injected, a fraction equal to 5·36 kilogs., or 12¾ lbs., were converted into steam. Experience demonstrates that this effect of evaporation is produced, and even a greater effect still, for the whole, or nearly the whole of the 40 lbs. of water, is converted into steam during the period of induction or aspiration. The metal of the cylinders and their accessories transfers to the water the quantity of heat necessary for evaporation; what is otherwise carried off is refunded in part by the disengagement of heat during the cushioning and forcing back of the steam, which immediately succeed this transfer, and by the steam coming from the boiler during the admission of counter-pressure steam.

In order perfectly to understand that this is the mode of action, it is only necessary to bear in mind that the two cylinders, the pistons and their rods, the cylinder bottoms, the valve cases, the slide valves, etc., make up a mass of metal weighing about 2½ tons. In round numbers, the specific heat of this mass of cast-iron, malleable iron and steel, may be taken as a mean = 0·12. A lowering of temperature of 1° C. in this mass represents 300 calories in French units, or for one cylinder only 150 calories.

The 40 lbs. of water (18 kilogs.) per minute, for a fall of temperature from 169°·50 Cent. to 100° Cent., give approximately 13·25°/₀ of steam, and there remain therefore only 34·5 lbs., or 15·61 kilogs., of water to be evaporated under atmospheric pressure, or per cylinder full 32 grammes, or 0·0704 lbs., requiring an expenditure of 17 calories. It is sufficient, therefore, that at each period of aspiration into a cylinder, its mass should transfer the quantity of heat corresponding to ⅑th of a degree, in order that all the water injected may be vaporized.

If the vaporization of 18 kilogs. of water injected per minute be fully accomplished, there will be formed—

1°. In issuing from the boiler, . .	2·39	kilogs. of steam.
2°. In the cylinders, ...	15·60	„ „
The total volume of which at 100° is .	29628	litres
or for each cylinder full, . .	60·45	„
The volume aspired at 40% of the stroke is	51·20	„
There is therefore an excess of steam of .	9·25	„

which goes off by the funnel.

Finally, reducing all the quantities to the weight expended per minute, the injection water will have been applied as follows:—

Quantity necessary for cooling the cylinders, .	A=5·36	kilogs.
Quantity necessary for completely filling the cylinders,	B=9·89	„
Quantity in excess, projected from funnel, . .	C=2·75	„
Total,	18·00	„

Experience proves that it is in this way that the water acts. In the example from which we have taken the above data, and which happens to be the first experiment on injecting water alone, there was no introduction of air into the boiler, the indexes of the two pressure-gauges underwent no vibration,—they were steady. The Giffard apparatus always acted at once, when turned on, with perfect ease, and there was always a discharge of steam from the funnel. When the admission was reduced, without at the same time reducing the injection, a fine rain issued from the funnel—a part of the water in excess carried off by the steam formed in the cylinders.

It is easy to understand that the wet vapour should reach its destination without difficulty, despite the long passage it has often to make to get into the cylinders, and although this passage is interrupted by the alternate discharges of steam when the eduction ports are closed during the expansion, and the forcing back to the boiler. Its volume is, in fact, only 9 litres for each cylinder full, and the volume aspired is 51 litres; and at a certain moment even much greater; that is, before it is reduced by the forcing back of the steam. The cylinder does not refuse the admission of this mixture until it has been quite filled up, and has produced the excess of steam which escapes at the funnel.

The experiment was repeated under many different conditions, at great and small speeds; at full admission and at very feeble admission; for descending steep inclines, and for stopping at stations in the ordinary service of the engine. On several railways, the injection of steam has been abandoned, and the water-cock alone is opened. The only practical difficulty consists in uniting the orifice of the cock when the injection of water has to be reduced to small quantities. The cocks hitherto used open too rapidly, and are too large. It is difficult, therefore, to limit their discharge so as to prevent the projection of water from the funnel; there is, however, little inconvenience from this. The water does not penetrate into the cylinders beyond a certain limit, and is discharged by the exhaust nozzle by the steam forced from the cylinders.

It is interesting to examine more narrowly what goes on in the cylinders. Of the quantities of water, A, B, C, converted into steam during the period of aspiration, by contact with the metallic surfaces, the whole, or nearly the whole, is converted into steam, if it be not in too great excess. This production of steam deprives the metallic mass of a proportional quantity of heat, which may be represented by A_t, B_t, C_t.

The compensation for the first of these quantities (A_t) is the heat disengaged by the work done by the counter-pressure steam, and is returned to the boiler in the state of steam; but for the two other quantities B_t, and C_t, there cannot be compensation, and the mean equilibrium of temperature of the metallic mass cannot be re-established, save by the condensation of a part of the steam coming from the boiler during the admission in counter-pressure. The result is that steam which arrives dry or simply saturated from the boiler returns to it charged with water, and that the metallic surfaces are constantly bathed and lubricated by wet vapour. When working with an injection of water, even at full admission, and at exaggerated speeds, the packings of the stuffing boxes are not damaged in the least, the piston-rods do not even become dry, the rubbing surfaces acquire a beautiful polish, and the reversing handle is easily moved. The same effects are observed in working with the mixture of water and steam at present in general practice, but only when the water is preponderant, and never so satisfactorily.

I feel justified in concluding from my observations that the engines do not work under favourable conditions when the admission is above the lower notches of the sector, unless the injection of steam be suppressed, and water from the boiler be alone used. I do not hesitate even to record my opinion that the systematic injection of water *in excess* will be the practice when counter-pressure steam is employed for stopping at stations, for the purpose of repairing the rubbing surfaces —pistons and slide valves—injured in the ordinary working in the run from one station to another. I shall show, in what follows, the consequences of a systematic and excessive injection of steam.

§ 4. *Injection of Steam and Water.*

The new system of reversing steam has been, until recently, limited to the use of a mixture of steam and water. The engineers to whom I had intrusted the task of making the first trials, followed my instructions with some apprehension, endeavouring as much as possible to avoid the injection of water into the cylinders. The result has been that, even now, in Spain, where these first trials were made, the use of counter-pressure steam has not had the success which it has had elsewhere. In France, the part played by the water was better understood; it has been abundantly injected, and the results have been most satisfactory; but up to the moment when I had an opportunity of personally experimenting, in order to verify the correctness of my first conceptions, steam was universally considered as a necessary agent, and was used in a greater or less proportion. It was supposed that its function was to fill the cylinders during the period of aspiration, and that it served as the vehicle for the water which was shut in with it, behind the piston, at the moment the period of cushioning and forcing back commenced. It was supposed that the water led from the boiler was applied directly to the absorption of heat.

In the preceding chapter I have shown that the water is converted into steam from the moment that it enters the cylinder, even during the period of aspiration, and the conclusion is that not only is it not required to take steam directly from the boiler, but that the addition of steam to the water, beyond a certain limit, might become prejudicial. This will be obvious when we consider attentively the preceding example. In that case the injection was 18 kilogrammes per minute, divided thus—

A. For absorption of heat disengaged,	.	5·36 kilogs.
B. For completing the filling of cylinders,	.	9·89 „
C. For formation of cloud at funnel,	.	2·75 „

If an equal weight of steam, 18 kilogs., were added to this water, the total volume of steam formed or to be formed in the cylinders would be doubled. For a cylinder full, the volume of aspiration of which is 51·20 litres (= 1·8 c. ft.), there would be offered a volume of steam of 60·45 litres × 2 = 120·90 litres,—there would escape by the funnel 79·70 litres, or 72°/₀. The water being intimately diffused in the steam from the moment of issuing from the boiler, the same proportion of water would be lost, and would be diverted from the cylinders. There would remain, therefore, only 5·27 kilogs. of water for the cooling of the cylinders, instead of 5·36 kilogs. The external cooling coming in aid in a certain measure, and the difference being small, there would be no sensible elevation of temperature, but the steam in the cylinders would be dry steam, and consequently the friction would become great, and the rubbing surfaces would have to be constantly greased. Besides, the loss of steam by the funnel would amount to a considerable loss of heat taken from the boiler.

Instead of proceeding by way of addition, we might proceed by way of substitution, and replace, for instance, half the water by steam; that is, inject 9 kilogrammes of water and 9 kilogrammes of steam. Of this mixture there would be lost 2·75 kilogs. for the cloud on the funnel, of which 1·37 kilogs. is water. There would, therefore, remain 7·64 kilogs. to penetrate to the cylinders, of which 5·36 kilogs. is required for absorption of the heat disengaged, and would be returned as steam to the boiler. The evaporation of the remainder 2·27 kilogs. would cause a precipitation of water in the space in which cushioning and forcing back takes place; thus the steam returning to the boiler would be infinitely less moist, to the detriment of the rubbing surfaces.

If it be supposed that ⅓ of water is injected, and ⅔ of steam, the mixture issuing from the funnel will carry off 0·92 kilogs. of water, and there will remain only 5·08 kilogs., which quantity is insufficient for the complete cooling of the cylinders.

That these calculations may be strictly accurate, it would be necessary that the volume aspired in a stroke should be accurately determined. In supposing it 40°/₀ of the total volume, I have made a liberal estimate. Besides, in the combination adopted for the distribution, according to the volume of the clearance (prejudicial space), the volume of aspiration may be greater or less. If we suppose that the proportion is only 30°/₀, or 38·40 litres, the injection of $\frac{1}{3}$ water and $\frac{2}{3}$ steam would represents 6 kilogs. water, sufficient for cooling the cylinders, and 12 kilogs. of steam. The volume of a cylinder full would then be only 38·40 litres, and the 60·45 litres offered for aspiration would give an excess of 22·05 litres, or 35°/₀. There would thus be 2·10 kilogs. of water carried off, and the remainder would be quite insufficient to prevent the heating of the cylinders.

We see, from these examples, that in every case the substitution of steam for, or the addition of steam to, water, results in a discharge of a less moist steam from the cylinders into the boiler, and it is the same with the steam in the exhaust-pipe used for aspiration. The rubbing surfaces are therefore drier, and the friction greater. The more the proportion of steam is increased, the more these effects become sensible. At last the steam actually diverts the water indispensable for the absorption of the heat, although large quantities of steam escape by the funnel, and although no gases from the smoke-box get into the cylinders.

The intervention of steam during the working with inverse admission, unless required for some particular purpose, which I shall point out presently, is always more or less prejudicial. The rule in fact should be, to add the least possible quantity of steam to the water. The wet steam, on the water issuing from the boiler, gives this minimum proportion.

It is well to remark, in reference to the quantity of water sent up the funnel, that the injection of water alone is more advantageous (for it is a loss of heat, to be made good in practice, at the expense of a certain amount of fuel), than the injection of a mixture of water and steam. In all weathers, the cloud of steam will be more marked with equal escape of steam when water alone is injected; the steam will be more moist—more cloudy than with the mixture. In very dry weather, the loss of steam by the funnel might be considerable in the use of the mixture of steam and water, without the driver being able to perceive it.

When the application of counter-pressure steam is made only for facilitating the driver's stopping and shunting, etc., at stations, or in case of imminent danger of an accident, the injection of water alone, or in preponderating proportions with steam, is no longer necessary to preserve the rubbing surfaces from damage; steam alone may be employed. Experiments have proved that, with the injection of steam alone into the exhaust-pipe, the engine running at twenty miles an hour, the packings did not commence to burn till two to three miles had been run, or in six to nine minutes of time. If the steam be reversed for stopping a train, counter-pressure need not be used for more than one to two minutes, and thus the rubbing surfaces and packings are quite safe. The increase of friction in these special cases may even be considered as a favourable circumstance for stopping the train, being an addition of the resistance of the engine to that of the counter-pressure steam.

When the admission is limited, when it amounts to only 15°/₀ to 30°/₀ of the stroke, the diagrams of Plate II., taken in various circumstances,[1] show that the resistance becomes very feeble, and, at a certain limit, Fig. 9, it becomes *nil*, or may be used for acceleration, in consequence of the greater expansion of the moist steam shut into the cushioning space. It is thus possible to use counter-pressure steam with injection of steam alone, without injuring the moving parts of the engine, when all that is required is a slight effort of resistance to moderate the speed of light trains on gradients of 1 in 80 to 1 in 100, or of a heavy train on a less gradient. If any heating takes place, the external radiation limits it. In like manner, very steep, short inclines may be descended.

Nevertheless, the practice of injecting steam alone is not to be recommended even for these special cases. It will always be better to have two valves or cocks attached to the same handle, and to inject a mixture of steam and water in propor-

[1] **Diagram 4 was taken with injection of water, the regulator having been left closed by mistake.**

tion to the work to be done; the injection of water alone, or as predominating, being systematically adopted whenever the engine has to do a prolonged and important amount of work of resistance.

It is only as an accessory steam alone can be usefully applied. At the moment that the counter-pressure steam is going to be used, the injecting tube, which is necessarily a bent tube, may contain condensed water, accumulated in the lower parts, and it may be therefore useful to blow through to avoid sending this comparatively cold water into the cylinders. At the moment that a train comes on to an incline, to descend it under the brake of counter-pressure steam, the driver reverses the steam gradually until the speed is reduced to that required. The injection of water should at first be very small, and should gradually be increased up to the point of admission, regulating the speed, on each side of which there are but slight variations necessary for maintaining uniform speed. It is convenient in this case to begin with an injection of steam alone, and to wait till the admission is at the second or third notch, and then to open the water-cock gradually, and close the steam-cock as soon as the injection of water is in action.

The pressure in the boiler may have fallen very low at the moment of coming on to the incline; the mixture of water and steam issuing from the boiler may therefore be too much loaded with water, and it may then be useful to heat it by adding a little steam taken from the boiler, to force it through the injection tube with greater speed, and pulverize the large drops of water which it may contain. Again, an engine may have to work at one time with a large, at another with a very small, admission; and as the injection tube, suitable for a large injection of water or wet steam, when the engine is working with full resistance, may be too large for a very small injection, the mixture may not have sufficient speed and undergo condensation. In such a case, it may be useful to add steam to prevent an accident.

Finally, when it is desired to stop a train by means of the counter-pressure steam, the injection of water must in the first place be increased, and at the same time the admission of the counter-pressure steam must be pushed to the end of the stroke, and then the water be gradually reduced till the train is brought to a stand-still. If the injection of water were continued to the end, it might happen that, the speed of the train being much reduced, the water injected would accumulate in the ports and in the exhaust-pipe. It would be best, therefore, to terminate the operation by opening the steam-cock, and closing the water-cock before the train is quite stopped.

In none of these cases is the injection of steam indispensable. A larger or smaller jet of water drawn from the boiler would suffice ; nor is the blowing through necessary, although the intervention of steam may simplify the working. There are drivers who, of their own accord, have adopted the practice of shutting the water-cock and using steam alone when half or three-quarters of the *vis viva* has been overcome. Other drivers, having the water and steam-cocks at their command, shut the steam-cock when once fairly on the descent of an incline. I have insisted on the injection of water alone, in order to make the question of counter-pressure steam thoroughly understood; but I am not the less in favour of the application of two cocks; the steam-cock being used chiefly as an auxiliary.

CHAPTER III.

APPARATUS FOR WORKING COUNTER-PRESSURE.

THE apparatus to be fitted to the locomotive to admit of working counter-pressure steam as a brake, is as simple as the principle itself. It consists of a tube of an inch to an inch and a quarter (20 to 30 or even 40 millimètres) in diameter—one inch diameter is very convenient—which communicates between the boiler and the exhaust-pipe, and a distributing cock by which the driver regulates the supply. If, as I advise, although it is not indispensable, it is desired to have the power of injecting water and steam alternately or simultaneously, a second cock is placed, with a short tube as a branch from the first, at a short distance from its origin. The one tube enters the boiler below the lowest level of the water, the other above the highest, so that steam only shall pass through the latter.

When the engines have external cylinders, the exhaust-pipe divides into two branches. The injection tube must therefore have also two branches; one going to the under side of each branch of the exhaust-pipe. The bifurcation should be perfectly symmetrical, so that the water held in suspension in the steam may not take the line of steepest descent, and that the distribution to each cylinder may be equal.

Fig. 3, Pl. I., shows how the injection tube is joined to the exhaust-pipes at two distinct places; but various other arrangements may be adopted.

Fig. 4, Pl. I., shows the arrangement adopted at the point of bifurcation. The branch piece should be of brass, and should be joined on to a *straight* length as long as possible. The drops of water in suspension in the steam tend to continue to move in a straight line, by virtue of their inertia and of their quantity of motion. If the bifurcation be not symmetrical, the distribution is unequal. Again, it is essential that beyond the point of bifurcation the two branches of the tube should have the same length, the same form, and the same section. Thus it will be found convenient to carry the tube under the centre of the boiler; or if room can be found for it, along the back of the boiler, in order to place the bifurcation at equal distances from the two cylinders. Want of symmetry might, of course, be compensated by difference of section in the tubes; but it is better to use a greater length of main tube in order to reach a point which allows of a perfectly symmetric arrangement.

Having satisfied this first condition, the distributing cocks or valves for varying the quantity of steam and water injected must be fixed.

For the water supply, the difficulty arises from the extremely small section of the orifice which is necessary. An opening of 6 to 10 millimètres square, or from ¼ to ⅜ inch square, is generally sufficient to take from the boiler the quantity of water practically required; for, in extreme cases, all that is required is 25 kilogrammes, or about 5½ gallons per minute.

As an example of discharge, I shall cite the results of a measurement made with care on an engine of the *Chemin de Fer du Nord* (French), having the apparatus of M. Marié; the aperture of the small slide-valve was 4 millimètres (= ⅙ inch) in width, and the diameter of the injection tube 1½ inch throughout the greater part of its length; the pressure in the boiler was 8 atmospheres (absolute).

Opening of Valve, Millimètres.	Section of Orifice, Millimètres, square.	Discharge in Kilogrammes per Minute.
1·5	6·	14·0
2·5	10·	20·5
3·5	14·	29·5
4·5	18·	33·0
5·5	22·	36·0
6·5	26·	42·0
11·5	46·	62·0
26·5	106·	83·0

The discharge, to a certain limit, depends principally on the length of the tube, and, above all, on its section. The experiments which I made with the engine with this apparatus were rendered difficult by the minuteness of the motion of the valve for regulating the discharge. There were often 30 to 40 kilogrammes of water supplied per minute, when 15 to 20 was all that was required.

When the slide-valve is used, I recommend that the *port* or opening should have a width of only 1 millimètre ($\frac{1}{25}$ inch), which would allow of a movement of the slide of 15 to 20 millimètres, and would admit of the position of the indicator being readily observed on a graduated scale. If the rod of the slide have a screw, and be moved by a crank handle, supposing the pitch of the screw 5 millimètres, the driver would have to give it three or four turns, and could then regulate the injection to a nicety, almost with his eyes shut. If he should make a quarter of a turn of the handle, more or less, the discharge would not be increased or diminished more than 1 or 2 kilogrammes.

An arrangement, suggested by M. Brüll, civil engineer, might be adopted. This consists in replacing the narrow slit—the *port* of the valve—by a series of small holes one above the other, which would be uncovered one after the other as the slide was moved up. The driver would then work with "*four, five, or ten holes of injection.*"

There is no difficulty in the injection of steam. An orifice of $\frac{3}{8}$ to $\frac{1}{2}$ inch square, under the usual pressure in the boiler does not discharge more than 4 to 5 kilogrammes of steam.

For the application of counter-pressure steam, especially at first, it is advisable to have an apparatus that will allow of the quantities of water and steam injected being determined exactly, till such time as the driver becomes familiar with the appearance of the jet of steam issuing from the funnel, and can judge thereby of the necessity for increasing or diminishing the injection. When water alone is injected, the drivers, with a little care, can soon regulate the quantity so as to avoid almost entirely any loss of steam by the funnel, and consequently any loss of fuel. When water alone is injected, the weight of water necessary to absorb the heat disengaged by counter-pressure is only a fraction of the total which enters the cylinders. The entrance of gases into the cylinders, indicated at once by the disappearance of all steam-discharge at the funnel, has no other inconvenience than to introduce permanent gases into the boiler. This inconvenience is of no importance if the boiler be fed by pumps, and it would be easy to remedy it if the boiler were fed by Giffard's apparatus. It would be sufficient either to open the blow-off for a few seconds, or to revert to full forward gear for a few turns of the wheel so as to discharge the gases.

The apparatus, of which I recommend the application, is the system of distribution of M. Marié, which is used in the greater number of engines in France. It consists of a small box of brass, separated by a partition in the direction of its greatest length into two compartments, and subdivided into two others by another transverse partition. The water is taken from the boiler to one of these compartments, and the steam to the other. Each of these has, in the principal partition, a vertical *port* or slit shut by a slide-valve, the rod of which has a screw thread at its end, and works into a female screw moved with a graduated disc. The female screw has a small crank-handle, and an index corresponding to the divisions of the disc. Each valve uncovers the ports as much as is required for the discharge of the water and steam required. The water or the steam, or the water and the steam, pass into the general compartment, where the water begins to be transformed into an emulsion or wet vapour; or where the steam and water mix, and from whence the injection tube starts, and is carried to the exhaust pipes as already described.

The rod of each valve carries an index, which indicates, on a scale cast in the same piece as the distribution box, the throw of the valves, one division corresponding to one or two turns of the screw; and the index of the female screw indicates the fractions of a turn.

This apparatus, complete in itself, of small dimensions, is described in all its details, and in full size, in three engraved plates, prepared by M. Marié, for the instruction of the engineers under his orders, of which copies have been sent to the Institution of Civil Engineers, London, and to the Institution of Engineers in Scotland. Extra cocks are placed on the pipe taking the steam to the boiler for distribution.

The injection may be regulated by means of ordinary cocks, by putting indexes to the handles, which, by means of divided arcs, indicate the discharge of water or of steam according to the openings of the cocks. But for the injection of water, special precautions have to be adopted for preventing the discharge from exceeding 25 to 30 kilogrammes (from 5½ to 6½ gallons) for the cock fully open, so that the index may pass over a large part of the graduated arc.

The following results were obtained in experiments with a cock made in the usual way; that is to say, the passage in the key elongated in the direction of the axis—width of passage, 8 millimètres (about ⅓ inch), length, 10 millimètres (or $\frac{4}{10}$ of an inch), or the total section, 80 square millimètres, or ⅛ of a square inch. The diameter of the tube leading to cock, 14 millimètres (⅝ inch), and 20 inches in length; the rest of the tube, 26 millimètres, or 1 inch in diameter. The effective pressure in the boiler, 8 kilogrammes per square centimètre (= 7·75 atmospheres).

Opening of the Cock, in Millimètres.	Section of the Passage, square Millimètres.	Water discharged per minute, Kilogrammes.
0·5	5·	5·80
1·0	10·	12·37
1·5	15·	19·67
2·0	20·	27·57
2·5	25·	35·77
3·0	30·	44·12
4·0	40·	61·00
5·0	50·	77·88
6·0	60·	94·45
7·0	70·	109·65

After a traverse of the index on the arc of a few degrees, the discharge exceeded the maximum required.

The slit which gives passage to the water must be wide in the direction of the axis of the key, and very narrow in the direction at right angles to this.

If counter-pressure steam is to be used only as a break for stopping trains, the two cocks may be united by a small connecting rod, when once they have been adjusted by actual trials to the suitable proportions of discharge.

Perhaps a double injection cock, analogous to the distribution box and valves of M. Marié, might be arranged, by cutting two slits or two holes in the key of the cock, each communicating upwards with an isolated compartment, into which the steam on one side and the water on the other would be led downwards to a mixing chamber, from which the injection tube would start. I only indicate this arrangement which, in the hands of an intelligent draughtsman, would suggest a simple and convenient apparatus.

Also cocks with lifting valves might be used. M. Forquenot, Engineer-in-Chief of the Paris-Orleans Railway, has under consideration a cock with a sort of spindle valve, which resembles the injection tube of Giffard. This arrangement, which will allow of a long traverse to the screw for small increments of orifice, ought to be effective.

It is essential, in putting a counter-pressure-steam apparatus on an engine, to gauge the discharge of the apparatus. For this, it will be necessary to experiment on the apparatus complete, with its branches (if there be a bifurcation), and by condensing the steam completely. The tubes are taken off the boiler, and by means of a template maintained at the same curvature as when they are on the boiler. The ends are plunged into buckets placed on the opposite scales of a balance, and filled with cold water. The boiler being at its normal pressure, the cocks are opened for some minutes, and thus at one weighing the discharge of each branch may be ascertained. The same operation is repeated for each division of the scale or arc successively for water and steam; and also, if desired, for different admixtures of steam and water. By operating thus the equality of distribution in the two branches is adjusted.

When apparatuses of this kind are fixed on similar engines, a few experiments with each apparatus is all that would be required.

The verification of the discharge of steam may be done in a very summary manner, by experiments made at points near the two extremities of the scale. Facts well known admit of our supposing that for intermediate points the discharge is proportional to the section of the orifice.

We have assumed that the quantities of water and steam discharged separately combine when a simultaneous injection of the two is made, but that there is a small loss, amounting to about 5°/₀ on each quantity. This is a point which it would, however, be well to clear up. Still, if the injection of water alone be used for the descent of gradients, and if the regular use of steam be limited, as I propose, to passenger engines with one pair of driving wheels, or with two pair coupled, to provide them with a break for stopping the train, it can be only considered of secondary importance.

The position to be adopted for inserting the injection tube, or its two branches, on the exhaust pipes, is not a matter of indifference.

Fig. 3, Plate I., represents at one view two arrangements. In the one the insertion is made on the branches of the exhaust-pipe, and the wet vapour has two distinct ways to traverse to reach the cylinders, viz., the part of the pipe near the cylinders, and the admission ports. This wet vapour does not get into the cylinders until after the steam, more or less dry, has been discharged from them at the end of the expansion, nor until that at the end of the cushioning has returned. If there be excess of injection water, it is projected through the exhaust nozzle by the funnel.

In the other arrangement, the insertion is made under the slide-valve itself in the side of the discharge port. In this case the wet vapour has only to traverse the passage to the ports; one part enters directly at the moment of induction, the other mixes with the discharged steam, returns in part to the cylinder, and goes off in part with it to the nozzle. Experience proves that for equality of injection much more water is projected by the funnel, and falls in rain on the engine, in the first arrangement than in the second. This arises from the greater quantity of water that enters the cylinders and the greater quantity of steam generated, in the first arrangement; whereas in the second the water is held in suspension by a greater quantity of steam.

These effects are important when a large quantity of water is injected, as happens when the cocks are ill proportioned. The engineer does not feel sure of preventing the entrance of air and gases by insufficiency of opening of the cock, except by opening beyond the points marked on the scale; and, as experiments show, only a few millimètres of movement give a great excess of water. This is not the case when the cock has a long traverse for the limits of injection really necessary for the maximum work of the counter-pressure steam.

In the example which has been given of the gauging of an engine of the *Chemin de Fer du Nord* (French), 1 millimètre (0·04 inch) of excess of opening increases the injection by 13 to 15 lbs., and 2 millimètres by 30 lbs. If the proportions are arranged so that 1 millimètre of opening gives only 2 lbs. of discharge of water, there is no longer any difficulty. With the injection thus made, the driver can easily avoid any great excess of injection, and can regulate the quantity according to the notch of admission of steam, and the speed of the train, by depending on his acquired knowledge of the effects of different openings of the cock, and the appearance of the steam cloud issuing from the funnel. Thus the position of the point of insertion of the injection tube loses its importance. It is no longer necessary to insert it under the escape ports, but only to put it as near the cylinders as the mode of the construction of the engine will admit.

It is not without good reason that I insist on these details. On every occasion that the injection of steam has been suppressed, and water taken from the boiler alone has been used, most satisfactory results have been obtained; but there have been frequent complaints of the projection of water from the funnel. This arose from excess of injection caused by bad construction of the cocks or valves—a small difficulty, which must, however, be avoided.

The injection of water might be used with the ordinary lever arrangement of reversing gear, where the consequences of a sudden spontaneous return of the handle would be unimportant. But the application is only quite satisfactory when the screw motion is used, as adopted by M. Marié, after Mr. Kitson's model. This apparatus, as a complement to the counter-pressure steam, has rendered most important service. Without it there must have been a long struggle against the natural repugnance of the drivers to reversing the steam. With it, the continual changes of the degree of admission, in order to maintain a uniform speed on lines with many changes of gradient, or for stopping trains at the right point in stations, are made without fatigue or anxiety to the driver. There are no longer sudden jumps from one notch to another; the regulator remains open, and consequently all the manipulations are more quickly effected, even when the steam has to be rapidly reversed. It is to this happy combination that the rapidity is to be ascribed with which the Paris, Lyons, and Mediterranean Company have already adopted (May 1869) the counter-pressure-steam apparatus for not less than 1400 engines.

Designs of the screw reversing-gear, as definitely adopted by M. Marié, are deposited at the Institution of Civil Engineers, London, and at the Institution of Engineers in Scotland, Glasgow: five plates engraved full size, designed for use in workshops. It may be well to consult the details of an arrangement which has been sanctioned by experience on an extensive scale.

Various combinations have been suggested as improvements on the system actually in use for working with counter-steam. I shall mention them summarily, in order to prevent persons from making useless researches in this direction.

M. Laurent, engineer-in-chief of the *Chemin de Fer du Midi*, has adopted an arrangement for closing the exhaust nozzle hermetically during the working of counter-steam. The injection of steam and water, as first used (end of 1867), or of water alone, as is M. Laurent's present practice, goes into a closed space, which has to the cylinders the relative position of the condenser in an ordinary engine. If the space be hermetically closed, all the steam generated in the cylinders returns to the boiler, with probably a part of the injected water, not vaporized if there be much excess. When the injection is much in excess, the pressure in the exhaust-pipe may rise to 2 or 3 atmospheres. If the injection be insufficient, there may be a partial vacuum formed. These effects do not present any difficulty in working the counter-pressure steam. The advantage of M. Laurent's system, which is now in regular use, is the prevention of all loss of steam and heat, and the dispensing with the necessity for the driver's continual attention being directed to the admission cock or valve. It will be necessary, however, to provide the driver with a sensitive pressure-gauge, communicating with the closed space, so as to enable him to avoid excess or insufficiency of injection. I recommend, as an extension of this system, the consideration of an arrangement which would admit of regulating the injection automatically. For this, all that would be required is a cock opening or shutting off the injection, and a regulating valve on the tube, the lifting rod of which would be acted on by a spiral spring, analogous to that of the metallic gauges; or by a piston carrying a weight, or pressed by a spring. When the pressure in the exhaust-pipe rises above a certain point, $\frac{1}{10}$ to $\frac{1}{4}$ atmosphere, for example,—the slide of the regulator would shut the orifice through which the mixture of steam and water passes, and would reduce the supply.

One of the difficulties of injecting into the exhaust-pipe is the necessity of bringing the water into the cylinders through a channel of irregular form, and often of considerable length, in which there is periodically a discharge of steam in opposite directions, which gives rise to ejections of water from the funnel. A partial improvement is obtained by inserting the two branches of the injection on the exhaust ports.

M. Bourson, engineer, attached to the locomotive department of the *Chemin de Fer du Nord del'Espagne,* has proposed and tried various arrangements, the principal of which consists in injecting water taken from the boiler into the valve cases, and mixing it with the steam at the moment it comes from the boiler to fill the cylinders. A branched tube, on the blow-through pipe, provided with a cock to limit the alternate movement of the steam, would give a communication between the two sides of the piston. During the admission of the counter-pressure steam, a part of the steam, at pressure, would pass into the induction space,—would fill it, would give an excess, and cause an escape of the exhaust to the funnel, and prevent the return of gas.[1]

M. Bourson has also tried an automatic system of injection which proportions the discharge of the injection cock to the degree of admission of counter-pressure steam. The difficulty of an arrangement of this kind arises from the variable condition of the water, the degree of admission, the speed, and, in a certain degree, the pressure in the boiler. There must be a means of regulation by the hand, and the driver would not be relieved of all care of the injection. As a means of providing for variations of discharge, resulting from variations of speed, a hand-cock for the admission of steam would answer.

[1] At the moment I write, I learn that the trials commenced in Spain give favourable results. This is the report of the engineer who has had the direction of these trials. He observes, "I am much satisfied with the new mode of injecting the water above the slide valves. The reversing handle is easily worked, and the cylinders are cooler than when we work the counter-pressure steam by the other apparatus. There is no longer any ejection of water at the funnel, and all entrance of air is avoided, and this without constant attention to the injection cocks. The expenditure of water varies from 16 to 24 kilogrammes (=35 to 53 lbs.) of water per minute, when working at the 6th, 9th, or 10th notch, and a speed of 30 kilomètres (=18$\frac{3}{4}$ miles) per hour. The blast is as distinctly marked as in ordinary running."

To sum up, the system of working counter-pressure steam is still, in principle and in practice, what it was when first laid down. We may expect that improvements of various kinds will be suggested; experience alone can prove their relative value; nevertheless, the mode of injection actually in use has a simplicity, and facility of regulation of the discharge in proportion to the requirements of the cylinders, etc., which will probably render it difficult to improve.

It only remains for me to point out the best means of employing the agents put at the command of the driver for the use of counter-pressure steam as a brake. The details which I have given in the preceding chapter render it unnecessary for me to do more than to simply enunciate my proposition.

For engines with six or eight wheels coupled, drawing heavy trains in descending moderate inclines of 1 in 200 to 1 in 100, for example, and also for those working a traffic of variable loads,—sometimes goods, sometimes passenger trains, on heavy inclines of 1 in 66, and steeper, and which, therefore, have to work at advanced notches of admission of steam, there should be an independent system for the injection of water, which the driver should habitually use. This arrangement should be supplemented by an injection of steam, which would serve to blow through the injection tube, to heat and froth up the mixture coming from the water-cock, should the pressure fall low in the boiler, and above all, to facilitate the setting to work the counter-pressure at the moment a train is entering upon an incline, or to take off the counter-pressure at the moment the train is stopping.

For passenger engines with only one driving axle the counter-pressure steam is not of much use, except as a brake in cases of imminent danger, and for stopping at stations. I propose for these engines a simultaneous injection of steam and water, making the steam predominate. The cocks may be so arranged, that, for the same dimension of the scale, there is one of water to two of steam, and the cocks may be worked by one handle. The total supply of the two fluids may be limited to 15 to 20 kilogrammes per minute.

For engines with four wheels coupled, the cocks may in like manner be worked by one handle; but in such case I should propose to increase the quantity of water towards the end of the scale; supposing twelve divisions on the scale, the openings should be arranged so as to have—

At the first notch, .	Water, 0·	Steam, 2·0 kilogs.
„ second notch, .	„ 1·5	„ 2·5 „
„ third, „ .	„ 3·0	„ 3·0 „
„ fourth, „ .	„ 4·5	„ 3·5 „
„ twelfth and last notch,	„ 16·5	„ 7·5 „

If the engine has to descend steep inclines with a heavy load, it would thus be well supplied as to injection.

It must be understood that I do not give these figures as absolute; but solely as indications which may guide engineers in their arrangement of a system of counter-pressure steam.

The rules of service of the Paris, Lyons, and Mediterranean line prescribe that the safety-valves are to be relieved so as to diminish the maximum pressure of the steam in the boiler by one atmosphere whenever the train enters on a steep incline. This wise regulation is made to meet the rise of pressure which may take place in working counter-pressure steam. If a tube were to burst, the engine would be inefficient, and the brakes alone would be available to regulate the speed of the train on the incline. The safety-valves very rarely blow off in such cases, and the rule of relieving them to the extent of one atmosphere may be but imperfectly attended to by the engineer; I should therefore recommend, in preference, the use of a cock, which the engineer could open when he sees the safety-valves rise so as to blow off. When the water of the tender is sufficiently heated the steam would then be sent into the atmosphere and lost.

CHAPTER IV.

INCIDENTAL CONSIDERATIONS.

I PROPOSE in this chapter to treat of questions which are directly connected with the study of counter-pressure steam, but the examination of which would have complicated the discussion of the system itself. I shall have to revert to the question of the use of the counter-pressure steam as a *means of stopping at stations,* not in order to demonstrate its advantages, which are quite evident, but to discuss the only objection that can be made to this application.

§ 1. *Gain of Heat.*

Theoretically, in working counter-steam, the heat developed, equivalent to the work done by gravity continually overcome, or to the *vis viva* of the train absorbed, is carried to the boiler by the steam which has been produced. The greater proportion of this steam is condensed, and raises the temperature of the boiler; a small portion goes to the steam space, where the density and pressure increase *pari passu* with the increase of temperature of the water. By degrees, viewed theoretically, the pressure should increase and the safety-valve should blow off.

It is even possible that experiments directed to obtain effects of this kind—by not feeding the boiler, or feeding it only in very small quantities; by avoiding all notable loss of steam and of heat by the funnel; by sending to the cylinders only steam with so small an excess of water that the friction would of itself generate heat,—the pressure might be raised without the heat of the fire, and even if the fire were extinguished.

But this would only be a philosophical experiment. When the pressure really rises in the boiler so as to cause the steam to blow off, the rise of temperature must be looked upon as the effect of the fire. In practice, the working of inclines of great length, on which it is possible to take note, approximately at least, of the consumption of fuel, it is found that the use of counter-pressure steam gives rise to a consumption of 5 to 6½ lbs. of fuel per mile run, beyond what is consumed in the descent with the ordinary friction brakes. This is easily understood when we bear in mind that the funnel remains open for the escape of the steam-cloud, instead of being close covered, as is done by careful drivers in descending inclines with the brakes on; but we can account for the fact by more direct reasoning.

It is necessary in the first place to keep in mind the essential difference between the applications of heat in the ordinary working of a train, and in regulating its speed by counter-pressure steam. In the first case, the useful effect applied to traction is scarcely 10°/₀ of the heat of evaporation expended. Such is the nature of the steam-engine. On the other hand, in working counter-pressure, the water converted into steam in the cylinders represents absolutely all the heat equivalent to the work of resistance; and as, besides, the work of the counter-pressure, with full admission of steam, does not amount to 60°/₀ of the work done in traction, as will be explained further on, it will be found that the production of 6 kilogrammes (13·2 lbs.) of steam in this case corresponds to an expenditure of 100 kilogrammes in ordinary working. Where the counter-pressure steam would furnish 6 units of heat to the boiler, the ordinary working would *absorb* 100. If we assume that in an engine in ordinary running 6°/₀ of the fuel consumed is expended in supplying the loss from external cooling of boiler and cylinders, escapes of steam, etc., as there is no reason why the loss of heat should be less in working counter-pressure steam, it would appear that the heat generated in the cylinders is just sufficient to compensate for external cooling.

There is then, in fact, a cause, variable in intensity with the season, which in great part, or almost entirely, prevents the heat generated in the cylinders from producing any marked effect in the boiler. But there are other causes not less important.

In the mode of injection at present practised, so long as the exhaust-pipe is not hermetically closed, on the system of M. Laurent, and so long as the gases are not allowed to be forced into the boiler, a certain quantity of steam must be lost by the funnel in order to produce the steam-cloud, which serves as an indication to the driver. This loss is a fraction of the quantity of steam required to fill the cylinders, and the quantity of steam to be generated in the cylinders is itself but a fraction ($\frac{1}{3}$ to $\frac{2}{5}$) of the total quantity required to fill the cylinders.

If the driver has a heavy hand, if he does not sufficiently close the injection-cock, losing perhaps 15% to 20% of the quantity injected, this will be a loss equivalent to half of the heat generated in the cylinders, and there will be only the other half left to compensate for the external cooling.

Again, the descent of an incline is generally a favourable moment for feeding the boiler, if the descending gradient has been preceded by an ascending one, as is often the case. Of this the engineer will naturally take advantage. He will feed his boiler in the descent, having in fact no steam to expend. A Giffard's injector in full work sends 120 kilogs. (26½ gallons) of water per minute into the boiler; and this water, supposing it taken from the tender at 25° C., absorbs 150 calories (French units of heat) per kilogramme, or altogether 18,000 calories, in order to attain a temperature of 175° C. in the boiler. The 5·36 kilogs. of the example taken at page 31, correspond to 2611 calories, which, neglecting all other losses, represents the gain of heat in the same time. It would be sufficient, therefore, that the driver fed the boiler for one minute in every seven in the descent, to have all the heat generated in the cylinders and forced into the boiler absorbed.

We can perfectly understand, therefore, that practically the temperature and the pressure during the working of counter-pressure can only be maintained by the action of the fire, and we need not be surprised to find that the stoker frequently adds fuel to the fire in the descent of long inclines.

The end which should be kept in view is not to store up heat in the boiler, but to reduce as much as possible the expenditure of fuel. We may feel sure that when the safety-valves blow off abundantly, the heat is supplied by the fire.

§ 2. *Practical Calculation of the Quantity of Injection.*

The quantity of water from the boiler required for injection, may be determined approximately by calculation, when the engine is to be worked with counter-pressure steam under fixed conditions.

If, for a certain type of engine, a number of diagrams were taken by Watt's indicator, in a great variety of conditions of working, the volume of the space of induction or aspiration might be measured on these diagrams, and for each notch mean co-efficients might thus be found (30, 35, 40°/o) which will serve to determine the volumes of aspiration of the total capacity of the cylinder. This would be equivalent to making calculations analogous to those on pages 31 and 32 for each notch of admission. But as these elements are seldom available, we can supply them, and ascertain the maximum by approximation, always taking care that these are verified practically, and that the quantity of water thus calculated gives off a steam-cloud.

The capacity of the prejudicial space (cushioning space and passages to ports) has to be measured, either on the working drawings of the engine, or by direct gauging, by filling the space with water. The same measurement is made for each side of the piston, and the mean is to be taken. The weight of saturated steam filling this space at the temperature due to the normal pressure in the boiler is then calculated. It is assumed that this steam expands to the atmospheric pressure, yet remaining saturated. By dividing the space by 0·607, we have the new volume occupied. The volume of the prejudicial space is deducted, and we have a fixed quantity, representing the portion of the capacity swept by the piston, which the steam has filled. The advance of the exhaust is measured on the diagram of distribution, and this is slightly increased to represent the supplement of exhaust corresponding to the retardation of the slide. We thus have an approximate measurement of the volume of aspiration when working with an injection of water alone, or with a large proportion of water; for the steam is loaded with water at the moment of being forced back to the boiler, and it is in this state that it is shut into the prejudicial space. The volume taken up in the cylinder after the expansion is increased by the vaporization of this water. This is a source of error, but the result is only to give a too great volume of aspiration. At the moment the expansion ceases, the pressure has not fallen to that of the atmosphere, and a certain quantity of steam escapes; but as it returns as soon as aspiration commences, it will be unnecessary to take it into consideration.

The following Table gives, as an example, all the elements of calculation of the volumes of aspiration for an engine with 8 wheels coupled—Engerth's system—of the *Chemin de Fer du Nord*, French:—

Stroke of piston, . . .	mètre,	0·66 index.
Diameter of cylinders, . .	„	0·50
„ wheels, . . .	„	1·25
Absolute pressure in boiler, .	atmos.,	8·
Capacity of prejudicial space, .	litres,	8·00 parts.
Total volume of cylinder, . .	„	129·36
Volume occupied by expanded steam,	„	48·36
Volume corresponding to retardation of slide-valve, . . .	„	4·90

Notches of Distribution.

2 — 3 — 4 — 5 — 6 — 7 — 8

Mean Volume of Exhaust, or Rejection to Exhaust-pipe in Litres.

55·94 | 45·15 | 36·21 | 29·44 | 24·73 | 20·81 | 17·86

Mean Net Volume of Aspiration.

16·36 | 31·15 | 40·09 | 46·66 | 57·37 | 55·29 | 58·24

For the first notch, calculation gives a negative volume of aspiration, which accords well with the results furnished by the Watt indicator (Pl. II).

With the above elements we can form a Table, giving the injection of water for different notches of admission, and for different speeds, *V* expressed in kilomètres per hour. The examples of speed have been taken so as to correspond to a whole number of cylinders full per second:—

Table of Injection Water in Kilogrammes per Minute.

Number of Notch.	$V = 21.$	$V = 28.$	$V = 35.$	$V = 42.$
2	3·5	4·6	5·8	8·0
3	6·3	9·1	11·3	13·6
4	3·7	11·7	14·6	17·5
5	10·2	13·6	17·0	20·4
6	11·2	14·9	18·7	22·5
7	12·1	16·1	20·1	24·3
8	12·7	17·0	21·2	25·4

These calculations, with a table of the discharge of the injection cocks, will be found useful to an engineer desiring to make experiments. They might also be verified and corrected by practical trials, and serve as the basis for making a table to be put into the hands of the drivers, and in which might be substituted for *kilogrammes* the division on the scale of *discharges* corresponding.

The elements calculated are in excess, especially for the lower notches. The means of correcting them would be to make a number of trips on gradients of various inclinations, and at different speeds, and to observe to what point the cock has to be opened or closed for each notch of admission, so as only to have such a steam-cloud formed at the funnel as is really necessary. On comparing the results with the numbers calculated in the table, it will be seen in what proportion the number must be reduced. These would serve as the sketch for the picture, so to speak.

§ 3. *Limit of the Mechanical Effect of Counter-Pressure Steam.*

The use of counter-pressure steam is limited by the mean resistance which can be obtained in the cylinders. An examination of the diagrams of Plate II., which were taken under various circumstances of admission and injection, shows that, for equal admission of steam to the cylinders, this mean pressure is much lower than in the ordinary working. This arises chiefly from the fact that, during the period of exhaust, there is no work of resistance produced. During the compression following on the close of the exhaust-port, the work is but small; and finally, the pressure of the steam admitted directly from the boiler attains its maximum only gradually. The diagrams are *hollow*, instead of the *full* diagram of ordinary working.

The expansion of the steam in the prejudicial space eats into the diagram much more than the cushioning in ordinary working.

These causes of reduction of the mean pressure, or of the area of the diagram of counter-pressure steam, are such that for low degrees of admission the mean pressure becomes *nil* or negative.

In order to satisfy myself as to the maximum work obtainable from counter-steam upon the diagram of Fig. 5, Pl. II., and by means of diagrams taken at similar degrees of admission in ordinary working, I formed a diagram of direct action, and on comparing the areas or mean pressures, I found the ratio to be $\frac{2}{87} = 0{\cdot}54$.

The admission in this example being only 67°/₀, it may be assumed that for a full admission of 75°/₀ to 80°/₀, we may easily reach 60°/₀ as the ratio.

This limit depends both on the capacity of the prejudicial space, and on the system of distribution adopted. The system of distribution hitherto has been arranged, especially for passenger engines, with the view of obtaining a great expansion; or, more exactly, to obtaining a good distribution when the engine is working with great expansion. With this object a large angular advance is given to the excentric, and to facilitate the exhaust at great speeds, a long lead is given to the exhaust. The maximum admission in full forward gear is nil for more than 75°/₀. It is often reduced so much that to start the train becomes a matter of some difficulty. All this is favourable for ordinary running, but unfavourable for the working of counter-steam, the maximum effect of which is diminished by so much.

Goods engines work under different conditions, and are generally subjected to much less of this weakening effect of the distribution, which, combined with Stephenson's expansion link, gives a variable expansion, generally accepted as sufficient for practical purposes. The results with these engines in working counter-steam are much more advantageous than with passenger engines. If these engines had the excentrics fixed square with the cranks; if there were no play in the mechanism of distribution, and if the link were so constructed that at each end the slide-valve rod should not receive motion save from the corresponding excentric rod, the diagram of counter-pressure for full gear would be a rectangle, as in ordinary working. It would even have a greater area, giving a higher mean pressure. During direct working of the engine, when the speed is considerable, the pressure in the cylinder is something lower than in the boiler, on account of the resistance to the flow of steam through the pipes and ports. From the same causes, acting in an opposite direction during the exhaust, the pressure does not fall quite to that of the atmosphere. The same causes would render the pressure in the cylinders higher than that in the boiler during the period of forcing back the steam into the boiler.

The ratio between the maximum work of the counter-steam, and the maximum work of traction, is in the hands of the engineer who determines the elements of distribution, and who, in order to obtain from counter-steam the maximum power to overcome the anticipated resistance, should bear in mind the traffic which the engine is to work. And, if the use of counter-steam is likely to be frequent, he should endeavour, by reducing the prejudicial space, and above all the volume of the ports,—by the choice of the angle of the excentric,—by the extent of the lead for admission and exhaust, and by a construction of link which would allow of the admission during the greatest possible length of stroke, he should obtain with the goods engines actually in use 60% of resistance. An effort might be made to obtain 70% or 75% in case of need.

There is, of course, a natural limit to the work of counter-steam, viz., the slipping of the wheels. In the actual conditions of working with a maximum resistance taken at 60% of the work of traction, the wheels sometimes slip under counter-pressure. This effect would be much more frequent if it were important to increase the effect of counter-pressure. This increase has therefore its limits. It is useless to supply a brake of exceptional power to have it frustrated by want of adhesion at the moment it is desirable to make use of it. I consider that the limit of 70% to 75% is all that can be useful. This is, however, a matter of opinion. It must not be lost sight of, that in certain cases engineers make large cylinders with the sole object of enabling them to work with prolonged expansion. These engines could not work at full admission, not only from insufficient adhesion, but from insufficient evaporation. Still, this arrangement is of advantage in working counter-steam, and would be a means of supplying additional power of resistance. It is evident then that the question of counter-pressure steam must become a special consideration in *designing* locomotive engines.

When once the ratio of the work of resistance to that of traction is established, it is easy to calculate the supplementary load which an engine could take down an incline, compared with that which it could take up.

Suppose an engine with 8 wheels coupled, weighing 46 tons, or with its tender 62 tons, sufficiently powerful to take fifteen waggons of goods of 14½ tons each = 218 tons gross, greased with half oil half grease, at the speed of 10 miles per hour on an incline of 0·018 = $\frac{1}{55\cdot6}$, the permanent effort of traction, according to the formulas of MM. Vuillemin,[1] Guebhard, and Dieudonné, for resistance of friction of waggons would be as follows:—

Resistance of train, 217·5 tons, at 2·77 kilogs. per ton, .	602	kilogs.
Resistance of the engine and tender considered as vehicles, 62 tons, at 10 kilogs., ...	620	„
Additional resistance of the engine when working, at 10 kilogs. per ton on 46 tons, ...	460	„
Action of gravity, 279·5 tons, × 0·018, ...	5031	„
Total,	6713	„

Let x denote the supplementary load, which the engine could take down the incline at a speed of say 20 miles per hour, which would raise the co-efficient of resistance of the waggons to 3·47 kilogs. per ton, and suppose that the maximum work of the counter-pressure steam at full backward gear is equal to 0·60 of the work of traction developed in the ascent; then we should have

$$(279{\cdot}5+x)\times 18^{\text{kg.}}-(217{\cdot}5+x)\times 3{\cdot}47^{\text{kg.}}-1080^{\text{kg.}}=0{\cdot}60\times 6713,$$

and hence $x = 57{\cdot}11$ tons.

or nearly four waggons of 14½ tons. The engine which took up fifteen waggons could take down nineteen. These calculations correspond with results obtained in a series of experiments which I have had an opportunity of making.

A similar calculation allows of our determining approximately on what gradient a train taken up the incline by a given engine may be further loaded for the descent when it is desired that the engine alone should command the speed.

Taking the same data as above, 10 and 20 miles for the speed, and 6700 kilogrammes, in round numbers, for the tractive effort which the engine can develop in ascending,—

Putting i for the inclination in millimètres per mètre, and T (rate of inclination) for the load or train taken up, we have

$$T \times 2{\cdot}77 + 1080 + (T \times 62)\, i = 6700 \text{ kilogrammes, and}$$

$$(T + 62)\, i - 1080 - T \times 3{\cdot}47 = 0{\cdot}60 + 6700 = 4020 \text{ kilogrammes.}$$

Hence $T = 83{\cdot}33$ tons,

And $i = 37{\cdot}08$ millimètres, or 1 in 27.

[1] *De la Résistance des Trains et de la Puissance des Machines, par MM. Vuillemin, Guebhard, et Dieudonné.* 1868. Lacroix, Éditeur. Paris.

If we assume a speed of 10 miles an hour for the descent as well as for the ascent, the load T remains the same, and the inclination $i=36{\cdot}88$ millimètres, or sensibly the same.

The conclusion to be drawn from these calculations is, that on an inclined plane of 1 in 27, the traffic in both directions may be carried on without brakes for the down traffic, with 8-wheel coupled engines, running at 10 miles per hour, taking up six or seven waggons of goods, of 12 to 13 tons each, gross weight; or ten or eleven passenger carriages. These quantities would be doubled by having two engines, one in front and one in rear for the ascent, and the two in front for the descent.

We may, again, easily conceive the importance of the assistance which we have at command in counter-pressure steam, for stopping trains, compared with ordinary brakes.

Numerous experiments have been made on the friction of brake-waggon wheels on the rails when they are completely stopped by the shoes of the brakes. The mean co-efficient, 0·16, may be taken as expressing the ratio between the resistance to motion of a brake-waggon and the weight of this waggon, or more exactly, the weight on the rails in contact with the wheels acted upon by the brakes. We may reckon also that, either by the adjustment of the distribution, or by the excess of volume given to the cylinders, we can secure, as already shown, from 0·60 to 0·70 of the work obtained in ordinary traction.

Lastly, experience has shown that the resistances inherent in the engine are much greater when the slide-valves are loaded under steam, than when they work without pressure, or with the regulator closed, as is the rule when the tender and van brakes are employed as the only means of stopping the train. The friction of the slides in their beds,—that of the collars of the excentrics on the excentrics, etc., etc., represent a resistance which may be compared to the forward motion of the engine, equivalent to 10 to 12 kilogrammes per ton of the weight of the engine—say 11 kilogrammes, or 24 lbs. per ton as a mean.

If, again, we suppose that the engines are constructed on the basis of an adhesion of one-sixth, that is to say, so that the effort of traction on the pistons is equal to one-sixth of the weight on the rails at the points of contact of the driving-wheels, we can establish the following equation. Let

P = the weight in tons of the engine without tender.

Π = the weight for adhesion, or the weight on the driving-wheels, in kilogrammes $P \times 1000 = \Pi$ when all the wheels are coupled.

F the total weight in kilogrammes, or the total load on the rails of the brakes, which would produce a resistance to motion equal to that of the counter-steam taken at 0·65; then

$$\tfrac{1}{8}\Pi \times 0{\cdot}65 + 11P = 0{\cdot}16F$$

If we suppose that there are 12 tons on each pair of driving-wheels, and that a brake-waggon weighs 10 tons, we have the following results:—

	Valves of F in Kilogrammes.	Equivalent number of Brake-Vans.
Engine with 8 wheels coupled, . .	35,800	$3\frac{1}{2}$
Engine with 6 wheels coupled, . .	26,850	$2\frac{5}{8}$
Engine with 4 wheels coupled, . .	18,725	$1\frac{3}{4}$ to 2
One pair driving-wheels, ...	15,000	1

But this comparison is not perfectly accurate, unless we take into account the conditions under which the two brake-powers are employed.

The counter-pressure steam acts instantaneously, *three or four seconds* being in fact sufficient to make the change from full forward gear to full backward gear with injection of water, and without shutting the regulator. If, on the other hand, the brakes have to be applied, the driver has to give his signals to the brakesmen by whistle; and if the case be urgent to repeat them. The brakes have then to be brought into action; but this cannot be done in a moment, even when the brakesmen are quite alive to the importance of their duty, and when the brakes are in good working order,—and even then the state of the rails may paralyse the action of the brakes; whereas, up to the limit of slipping, which may be prevented by sanding the rails, the counter-pressure steam is *always* effective.

It may be further added, that experiments made on brakes appear to prove that, at great speeds, the co-efficient of friction of the wheels stopped is diminished; whereas the action of counter-pressure steam is in no way modified.

From all these considerations it results, that, if it were possible to establish an exact comparison between ordinary brakes and counter-steam, in reference to the distance passed over during the operation of stopping a train, there would be an advantage of from 40 to 60 yards in favour of counter-pressure steam.

Practically, then, it may be assumed that each driving-axle of a locomotive provided with the apparatus for counter-pressure steam is equivalent to a break-van of 10 to 12 tons weight, in the *best working* condition.

§ 4. *Effect of Counter-Steam in passing Curves.*

There is one objection which naturally presents itself when it is proposed to work the system of counter-pressure steam. Steep inclines are generally accompanied by sharp curves in hilly districts. The trains also have often to pass crossings of 12 chains radius and under for entering stations. The question arises, whether inconvenience may not occur from all the resistance to motion being employed at the *head* of the train, and whether the front waggons pressed between those behind and the locomotive in front are not liable to be thrown off the rails.

A simple calculation, sufficiently accurate, shows that if this danger exists, it is only in a very slight degree, and quite out of proportion to the advantages resulting from the facilities with which the speed can be regulated in the descent of inclines, and moderated in the vicinity of stations.

A waggon with spring buffers, in a curve of short radius, presses on the waggon in front unequally; rather less on the convex side of the curve than on the concave. It is itself pressed in the same manner by the waggon which follows.

Before and behind, the pressure which it exerts, and the reaction which it undergoes, are directed obliquely to its axis, and these efforts give rise to transverse components which would tend to push it off the line, if it were not retained by the pressure of the flanges of the wheels against the outer rails. The effort exerted in front is not exactly the same as that behind; because the waggon in the descent of an incline is subjected to the resultant action of two forces soliciting it in opposite directions—the component of gravity which tends to urge it forward, and the inherent friction which tends to arrest its progress. The calculations are simplified by replacing the efforts exerted separately on the two buffers by their resultant, or by their sum, and by supposing that the pressures take place at the point of intersection of the axes of the waggons, as shown in Fig. 5, Plate I., in which these intersections form the polygon $a - a' - a'' - a'''$, etc.

Let $a\ a'$ be the first waggon following the tender, and at the head of a train of forty waggons of 10 tons gross each, descending at a speed of 30 kilomètres (= 20 miles nearly) per hour, an incline of 1 in 100, at which speed it is retained by the counter-steam of an 8-wheeled coupled engine working with full admission.

The pressure upon the tender from the whole train, supposing the mean resistance of waggons to be 3·47 kilogrammes per ton, as in the preceding example, is equal to (10—3·47) 400=2612 kilogs. This result would agree with a dynamometrical measurement made under analogous circumstances.

If the train enters a curve of radius R, and if l= length of waggon between the buffers, the pressure exerted at the front of the waggon would be decomposed into two forces,—the one in the direction of the axis of the waggon, equal to $2612 \times \cos a$, and the other perpendicular, and equal to $2612 \times \sin a$. At the other end of the waggon, at a', the pressure and equal reaction (the motion being supposed uniform) which arise at the point of contact are $2612 \sin a - 10^{T} \times 6·53$. 6·53 being the difference 10 − 3·47 — of the co-efficient of gravity, and that of the inherent resistance of the waggons to motion. The component perpendicular to the axis of the waggon is

$$(2612^{k} \cos \alpha - 6·53) \sin \alpha.$$

The waggon will therefore be pushed towards the convexity of the curve by the two forces, the value of which we have given.

If we suppose $l = 7$ mètres = 23 feet, and $R = 17$ chains = 350 mètres, we have

$$\sin \alpha = \frac{\frac{1}{2} l}{R} = 0·01, \text{ and } \cos \alpha = \sqrt{1 - (0·01)^2} = 1·00.$$

The value of the two components will therefore be 2612 $\sin a = 26·12$ kilogs., and $(2612 \cos a - 65·3) \sin a = 25·46$ kilogrammes. The effort soliciting this loaded waggon to leave the rails will therefore equal 26·12 + 25·46 = 51·58 kilogs. This quantity is less than the increase of centrifugal force under very small variations of speed.

The speed of 30 kilomètres per hour gives $V = 8·333$ mètres per second. If we take a curve of 350 mètres radius, the effort of centrifugal force on a waggon of 10 tons, or 10,000 kilogrammes, is equal to

$$\frac{10{,}000\ V^2}{g\ R}\ *$$

which gives 202·2 kilogs.

If the speed rise from 30 to 36 kilomètres, that is to 10 mètres per second, the centrifugal force of the 10-ton waggon rises to 291 kilogrammes.

Thus the effort soliciting the waggon to leave the rails is much less than the increase of centrifugal force produced by an acceleration of 6 kilomètres.

If we suppose the radius reduced one-half, the value of the components due to the *push* of the train and to the resistance of the engine become equal. Taking, then, the radius of the curve to be the distance from its centre to the centre of the waggon, we have

$$\sin a = 0{\cdot}02, \text{ and } \cos a = \sqrt{1-(0{\cdot}02)^2} = 1{\cdot}00.$$

The value of the two components will now be 52·24 kilogs. and 50·93 kilogs., and the effort soliciting the waggon to leave the line will be 102·17 kilogs.

But at the speed of 30 kiloms. per hour, on a curve of 175 mètres, or 8½ chains radius, the centrifugal force equals 404·4 kilogs., and at the speed of 36 kiloms., equal to 582 kilogs. And here, again, the effort soliciting the waggon to leave the rails is much less than the increase of centrifugal force resulting from an increase of $\frac{1}{5}$ of its normal speed. To produce an equality of the two forces, the waggon should be empty, or of only 6 tons weight (gross).

To counteract entirely this effect, it would be sufficient to raise very slightly the outer rail, supposing it had been laid under exact calculation for a given speed. But it must be held carefully in mind, that the great advantage of working counter-steam is to enable us to maintain a *uniform speed with the greatest precision;* whilst, for a train descending under the action of ordinary brakes, the speed is very irregular; it varies from 1 to 2, and even more. Indeed, the retardation of speed is obtained by means of whistle-signals from the driver directing the brakesmen to screw up or slacken the brakes. Thus it is found, that in order to work at a mean speed of 30 kilomètres

* $g = 9{\cdot}808$ mètres $= 32{\cdot}2$ feet.

by brakes, there are variations of 10 to 15 kilomètres above and below the mean;—that is, variations from 10 to 20 up to 40 to 45 kilomètres per hour.

Engineers who have had an opportunity of comparing the working of trains on the two systems, do not hesitate to consider the use of counter-steam for the descent of inclines, even without an increase of the normal elevation given to the outer rail, as a precious source of safety.

It is the same in stopping at stations. The driver is in fact himself master of the speed, and can regulate it at his pleasure, whether in passing through points and crossings, or at branch lines, where the train is not required to stop.

In France, where upwards of 1800 engines are now at work with the counter-pressure-steam apparatus, no objection on this score has ever arisen.

§ 5. *On Running with the Regulator shut.*

Observation of the remarkable lubricating effects obtained in working counter-steam with injection of water alone has led the engineers of the Orleans Railway Company to an interesting application, as yet only in the stage of experiment, but which will probably lead to results of practical use.

When a train descends a gradient at which the accelerating force of gravity just equilibrates the resistances of the train at normal speed, the engineer shuts the regulator and puts the reversing handle in full forward gear. Experience shows that under these conditions there is a great wear of the rubbing surfaces, particularly of the segments of the piston, and it has been found that there is considerable rise of temperature of the cylinders.

Without seeking to analyse in detail the complex effects of compression and dilatation, the lifting of the slide-valves, etc., which running with regulator shut gives rise to, it is known that there is admission of the gases of the smoke-box during the period of the lead of the exhaust. If the regulator shuts the communication between the boiler and cylinders exactly, the steam which fills the steam-pipes and the slide-valve cases rapidly disappears; either by condensation in these spaces, or by mixing successively with the gases.

If the pistons and slide-valves work in a dry hot atmosphere, the rubbing surfaces are dry, and generate heat, which is added to that produced by the compression at the end of the exhaust. During the period of admission, and that of expansion, the gases expand, and there is a partial vacuum made, provided the slide is not lifted by the atmospheric pressure acting from below in the exhaust-port, and that thus an indirect means of filling the cylinders occurs. But this expansion, if it occurs, does not appear to be an element of compensation for the heat produced.

This state of things might be improved by profiting by the injection tube of the counter-pressure-steam apparatus to change the nature of the deleterious atmosphere in which the pistons move. It would be only necessary to inject some steam, or water,—or better still, some water and steam.

With steam the entrance of the gases would be prevented, and with water the rubbing surfaces would be lubricated; while the heat produced by compression would be absorbed.

The circumstances are not the same when working counter-steam. There is no restitution of the heat applied to internal vaporization by the metal of the cylinders. When water alone is injected their temperature falls rapidly to 100° C., and probably even lower, if there be a partial vacuum formed during the admission and expansion. The wet vapour which comes from the boiler at 100° contains much water and little steam, and this latter may condense. Experience proves that the lubrication is perfect; but there is an accumulation of water in the cylinders, and if the blow-through cocks be not frequently opened by the driver some mischief might occur.

If steam alone be injected, the phenomena of heating and wear are very sensibly lessened; but the steam is super-heated, and the friction is dry.

The experiments now going on will show where the greater advantage lies. It is probable that it will be found best to inject steam with a moderate quantity of water, the driver being careful to open the blow-through cocks from time to time to discharge any accumulation of water that may take place.

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