Purification of Sewage and Water.

W. J. DIBDIN, F.I.C., F.C.S.

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BY

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PREFACE.

The substance of the present Work appeared in serial form in the pages of the "Sanitary Record," in response to numerous appeals for information respecting the new departure in Sewage Treatment, &c.; and now, after careful revision and some additional matter, it is presented for the perusal of the student in a more convenient form. Some apology is doubtless due for the condensed style in which it has been written. It would have been an easier task to have enlarged the subject-matter very considerably, but it was thought that the Work would be of more value if kept as concise as possible, and this, as far as is consistent with continuity, has been done.

The major portion of the text was written during the winter of 1896-7, and much of the work with which it deals was carried out during the previous fifteen years. The "new departure at Sutton" was inaugurated in November, 1896, as the results of the work carried on in that direction during the previous five years, and is the natural sequence of the forecast by Dr. Dupré and myself in 1886-7.

As the two reports on the experimental bacterial treatment of sewage effluent at the Northern Outfall Works at Barking Creek have now almost world-wide interest, I have ventured to print them in full in the Appendix, together with some other useful matter. The first report on the Sutton experiments on the treatment of crude sewage will be found in the text of the Work, and need not, therefore, be repeated. Probably it would have been more in order following the above.

Owing to press of work I have been unable to give many interesting results of experiments and observations made with the view of ascertaining the *modus operandi* involved in the bacteriolysis of organic débris, but I hope on a future occasion to present these for the information and criticism of my readers.

It is to be hoped that the information now placed before the public will not fail to accomplish its work by inducing those responsible for the disposal of the waste matters of the community to give the system of bacterial treatment a fair opportunity of demonstrating its efficacy, and thus assist in accomplishing that most desirable result—pure rivers, and pure water supplies.

Although much has been done in removing from the noble River Thames the reproach to which it was formerly so deservedly open, I yet hope to see the day when, by the adoption of the bacterial treatment for the sewage of London, far better results will be obtained, with a considerable reduction in the cost of the present system, which even now is the cheapest of its kind in existence.

In conclusion, I have to tender my sincere thanks to many friends, far and near, who have by their kindly criticism, advice and encouragement, materially helped to smooth over many difficult and stoney paths, and made the work, indeed, a labour of love.

W. J. DIBDIN.

SUTTON, SURREY,
October, 1897.

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PURIFICATION OF SEWAGE AND WATER.

INTRODUCTION.

The advance which has been made during the past few years in sanitary knowledge has resulted in such marked improvement in various ways that it will be of interest, as well as of use, to place on record some of the results which have been arrived at in the course of the personal experiences of the writer. The work involved in the purification of the river Thames has revealed facts, the statement of which, when first made public, was met with no little scepticism, but which have at length come to be acknowledged as well founded; and the principles involved have been adopted in almost every community where the disposal of foul waters has been necessitated by the introduction of modern systems of drainage.

With the view of placing these experiences in an available form, and of combining with them the latest features in connection with the work, it is proposed in the following articles to set out in a clear and succinct manner points on which many replies to frequent questions have hitherto been answered by letter or in papers before various societies.

In due course the work will deal with the consideration of the character of foul matters in sewage and waters, their composition, and the processes involved in their ultimate destruction, either by combustion, which may be oxidation by the aid of fire, or by the action of organisms acting in the presence of air, accompanied or not by putrefaction, which is brought about by the action of organisms acting in the absence of air; and the effect of various antiseptics resulting in the preservation of objectionable matters, for more or less prolonged periods. This will lead to a consideration of the different methods proposed from time to time for the purpose of effecting ultimate purification, such as precipitation by different chemical reagents, farming operations, and filtration. In this connection it may not be out of place to glance at some of the eccentricities which have been put forward, considering them merely with a view of showing how easy it is to go astray with even the very best intentions.

Following this *résumé* of the general considerations, the experiments which have been made in London and Massachusetts on the treatment of sewage matters, and the results of the experimental operations on the filtration of sewage, will be of interest. As these experiments will lead to a further consideration of Nature's method they will be fully dealt with, and their practical application will be considered under different conditions.

As no work in this connection can be proceeded with, without a full knowledge of the means by which the results of the various experiments can be checked, the necessary analytical methods most suitable for that purpose will be described, and the most simple and effective processes given at sufficient length to enable the experimentalist to conduct such tests for himself. Having obtained the results of these tests as may be required, he will find their bearing upon the work in hand fully dealt with and explained.

The duties of Local Authorities will be considered, and some of the most obvious causes of failure indicated. No work of this kind can be complete without a discussion of the much-vexed question of the ventilation of sewers and the most suitable means of preventing offensive emanations. This subject is one which has given rise to considerable debate; but space will be occupied by a recital of only those features which are essential to the question.

In the consideration of such a widespread subject it will be impossible to avoid giving a full description of the process in use for purifying the river Thames. When the question as to what process should be adopted for the purpose of effecting that great work was under consideration, no small discussion took place on the matter; and the scheme proposed by the author, which was ultimately adopted, was submitted to a most searching criticism. Even after the necessary works were in progress many persons who evidently considered themselves authorities on the subject continued to propose alterations of the most fantastic character, and presumed to call these schemes economical, when, as a simple matter of fact, they involved from five to twelve times the expense of that which it pleased them to call "extravagant." However that may be, all the froth has now disappeared, and we may consider the whole question at the present time free from bias and the passing passion of the moment, with the hope of arriving at the truth of the matter; thus laying a foundation for still better work in the near future.

As a useful guide to further developments of the process of treating sewage by means of bacterial action, an outline of a scheme for works for treating one million gallons of sewage per day is offered for consideration, which may serve to indicate the direction in which future improvements may be anticipated. In making this suggestion, which is merely a systematised arrangement of known working conditions, the author does not desire to make dogmatic assertions, or in the slightest degree to indicate more than a desirable direction of procedure. For instance, what may be done on a clay soil is obviously not always possible on sand or chalk. In the case of Berlin, the Authorities have thousands of acres of sand on which to turn their sewage, an ideal bacteria bed, rendering the use of coke-breeze or burnt ballast unnecessary, the only requisite being that care is taken not to overwork one particular area. In the clay soil of the Essex marshes these conditions are absent, and yet it has been frequently proposed to follow the example of Berlin thereon.

As a collateral branch of our subject, the question of the artificial purification of water for potable purposes will afford matter for a chapter not without interest; therefore, the author has put together some facts relating to the history of the various methods which have been proposed from time to time for effecting that object. The value of these will, perhaps, be as much in showing what not to do as in showing what should be done. Water filtration on a large scale will also receive due consideration. Another chapter will be devoted to some recent features in connection with the London water supply, the investigation of which by the writer has brought out some points relating to the quantity and quality of the matters held in suspension hitherto unsuspected; which, however, it is satisfactory to observe, having been pointed out, have been taken note of by those concerned, with the result that such defects as undoubtedly existed a few years back have been in great part remedied.

It will, perhaps, be observed that the scheme of work involves a new departure in some respects from the course usually adopted by those who have produced various excellent volumes on the subject of sewage treatment; as on the present occasion the writer has endeavoured to deal with principles rather than details of existing works—information on which is already freely accessible—and to put into a comprehensive form the results of personal experience.

The writer desires to tender his sincere thanks to many friends for their assistance in the preparation of the matter, and especially to the staff of chemists with whom he has the honour to be associated in connection with the Chemical Department of the London County Council, and particularly so to Mr. George Thudichum, F.C.S., who for the past thirteen years filled the position of the author's chief assistant in connection with the work of the purification of the River Thames, and who has rendered material help in the preparation of the present volume by kindly reading the proofs, and contributing many valuable suggestions.

CHAPTER I.

FOUL MATTERS, THEIR CHARACTER AND COMPOSITION, COMBUSTION AND OXIDATION, PUTREFACTION, BACTERIA.

As the following chapters will deal with the various methods of purifying foul matters, it will be necessary to indicate as clearly as possible what it is that we have to purify. For this purpose let us consider the character of those substances predominating in foul water. First, then, sewage may be considered as containing animal substances, largely composed of fibrine, gelatine, chondrine, albumen, &c., and, secondly, vegetable substances, such as starch and woody fibre (cellulose), gummy matters, with tannin, &c. In the first instance we have to deal with matters which speedily undergo decay by putrefaction when there is not a sufficient supply of oxygen, in which case, however, the decomposition takes place by the action of organisms opposed in general character to those which are the active agents in bringing about the process of purification unaccompanied by offensive adjuncts. These aërobic organisms, as they were called by Pasteur—in contradistinction to the anaërobic organisms—live only in the presence of air, as their name implies, whilst the anaërobic organisms live in the absence of air. When air is freely present, and the conditions generally favourable, the aërobic organisms destroy the organic matters in an inoffensive manner. The nitrogenous matters are resolved with either the production of ammonia or the oxides of nitrogen, or possibly the evolution of uncombined nitrogen. In passing, it may be remarked that the question of the various transformations which the nitrogen in combination undergo have not yet been fully determined, and will be referred to later on. The oxygen and hydrogen, forming a considerable portion of the matters, are recombined into water, and the carbon into "carbon dioxide," or carbonic acid gas, as it is generally called. Similar transformations take place with these elements in vegetable matters, but a longer time is usually required for the completion of the process than is the case with animal substances, as they do not form so suitable a medium for the support of the microbic life. Woody fibre, especially paper pulp, is more refractory, and will require a much longer time for its disruption, but in the end the same transformation occurs, and carbonic acid, water, &c., are formed as a result.

As showing the actual character of the above-mentioned substances, the following table of their chemical composition will be of interest:—

TABLE I.

Substance.	Nitrogen per cent.	Hydrogen per cent.	Oxygen per cent.	Carbon per cent.
Gelatine	18·3 ..	6·6 ..	25·1 ..	50 0
Chondrine	14·4 ..	7·1 ..	29·4 ..	49·1
Albumen	16·0 ..	7·1 ..	22·0 ..	53·0
Cellulose (woody fibre)	— ..	6·2 ..	49·4 ..	44·4
Starch	— ..	6·2 ..	49·4 ..	44·4
Fat (stearic acid) ..	— ..	12·7 ..	11·3 ..	76·0

It will be observed that each of these substances already contains oxygen, and the inquiry naturally follows how much more do they need to complete the oxidation of the nitrogen, hydrogen, and carbon? This is best answered by the following table, showing the actual conditions in each case :—

TABLE II.

Pounds of Oxygen required to oxidise every 100 *lb. of substance.*

Substance.	Oxygen required.				Oxygen already present.	Difference or additional oxygen required for complete oxidation of substance.
	By the nitrogen.	By the hydrogen.	By the carbon.	Total required.		
Gelatine	52·3	52 8	133·3	248·4	25·1	223·3
Chondrine	41·1	56·8	131·0	229·0	29·4	199·6
Albumen	45·7	56·8	141·4	253·9	22·0	231·9
Cellulose, woody fibre ..	—	49·6	118·4	168·0	49·4	118·6
Starch	—	49·6	118·4	168·0	49·4	118·6
Fat, stearic acid	—	101·6	202·5	304·1	11·3	292·8

The last column shows the excess of oxygen required, beyond that already present in combination, for the complete resolution of the elements into the condition of harmless nitrates, water, and carbonic acid, and will enable the reader to form some idea of the work which has to be accomplished, the problem being to bring, in the case of gelatine, for instance, 223⅓ lb. of oxygen existing as a gas in the atmosphere in intimate mixture with five times its volume of nitrogen, into chemical combination with 100 lb. of gelatine; and so on for each substance in the table. It will be understood that the half-dozen substances mentioned are intended to represent only types of compounds actually present in such a heterogeneous mixture as that which we are considering, and to assist in indicating generally the work which has to be accomplished.

A further excellent example may be found in the case of urea. This has long been known to be capable of rapid alteration and decomposition under the influence of a ferment resembling yeast, or those derived from putrefying animal matters, such as albumen. Urea, CH_4N_2O, is first changed under these circumstances, by the addition of the elements of water, to carbonic acid (CO_2) and ammonia (NH_3). In order to complete the oxidation, the ammonia has to be converted into nitric acid. This, as is well known, is effected by the action of a micro-organism, or of a series of such; and it is thus established that a typical excretory substance can be entirely destroyed by the aid of fermentative or allied action of minute organisms without any adventitious assistance.

The mineral matter present in combination with these substances is generally very small, and is but of little interest; and however valuable for manurial purposes, may be left without further consideration, so far as our present purpose is concerned.

In foul water there is generally a large proportion of mineral matters, such as sand, &c., which has to be dealt with, but this presents no difficulty whatever, as, if necessary, they may be separated by simple subsidence. They may, therefore, be neglected in the present considerations.

In the process known as combustion, or burning, the organic matters, as already indicated, combine with oxygen, but the same action is brought about by the life processes of animals, however small. In the case of the higher animals, when the food is taken into the stomach it there undergoes the process of digestion, and a portion is absorbed into the system, where, by the action of the blood, it is eventually oxidised as it rushes through the lungs, in which it is freely exposed to the air taken in by the breath. Thus is kept up a slow process of oxidation, marvellous in its character and action. It matters not whether it is meat and bread eaten by human beings; grass, &c., by horses or fowls; or a mixture of these things by microbes, or by the direct action of fire ; the final result is precisely the same, viz., combustion, fast or slow, as the case may be.

But in bringing about this result we must not run the risk of incurring putrefaction. If we do so by neglecting to ensure an ample supply of oxygen, we shall have foul gases formed, such as sulphuretted hydrogen, with certain volatile organic substances in place of inodorous compounds, which, in ordinary cases, will create a nuisance. How, then, are we to insure the satisfactory accomplishment of the desired object? Here we must further consider the action of the minute organisms already referred to as "bacteria" or "microbes." These are minute living bodies, some of which are ever present in various forms in or on every substance known ; and whenever the circumstances are favourable they bring about the destruction of the organic matters simply by living upon them. In reference to their general character it may be remarked that while at first they were thought to belong to the animal kingdom, it is now generally accepted that they are plants. They were first noticed by Leuwenhoeck, whose construction of high-power simple microscopes in 1687 gave rise to the present marvellous increase in our knowledge of minute living matter. It may be remarked in passing, that the microscopes of Leuwenhoeck, with which he made his wonderful discoveries, to the world's astonishment, were constructed in the most simple manner possible, being only a single lens, set between two plates of silver perforated with a small hole, with a movable pin before it to support the object, and adjust it to the eye of the observer. In the case of liquids he enclosed these in fine capillary glass tubes.

When referring to the discoveries made by this and similar instruments, Baker, in 1742, wrote as follows:—

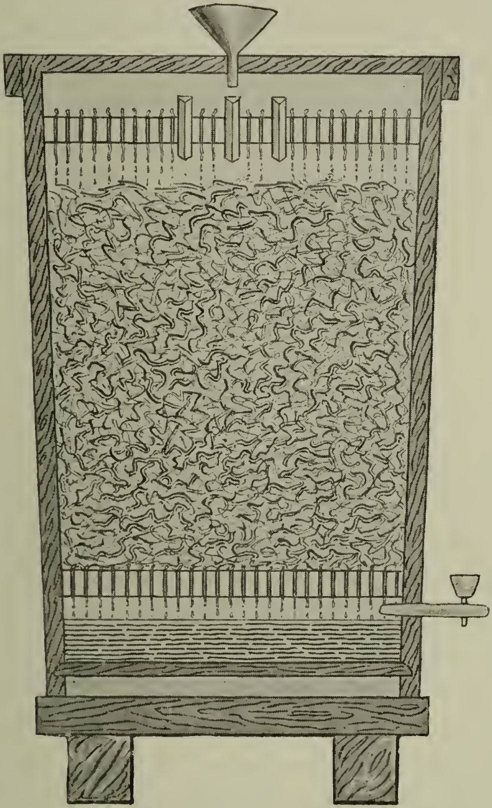
"Nothing is therefore now wanting but a general inclination to employ these instruments for a further discovery of the minute wonders of the Creation, which may not, perhaps, improve our knowledge less than the grander parts thereof. Bears, tigers, lions, crocodiles, and whales, oaks and cedars, seas and mountains, comets, stars, worlds, and suns are the *capitals* in Nature's mighty volume, and of them we should not be ignorant; but whoever would read these with understanding must make himself master of the *little letters* likewise, which occur a thousand times more frequently, and, if he does not know them, will stop him short at every syllable."

With reference to the size of the bacteria, it is indeed difficult to describe them in popular language. They vary in length from one five-thousandth to one twenty-five thousandth of an inch. When viewed under our highest microscopical powers they appear to be a little larger than dots of ink on paper. If, say Pearmain and Moore, in their work on "Applied Bacteriology," we could view an average human being under an equal degree of magnification, he would appear to be about four miles in height, or higher than Mont Blanc. A milligramme is about the sixty-sixth part of a grain. Yet in this small volume no less than eight thousand millions of microbes were counted by Bujivid. With reference to the incredible rapidity with which the bacteria multiply under conditions favourable to their growth and development, Cohn writes as follows:—"Let us assume that a microbe divides into two within an hour, then again into eight in the third hour, and so on. The number of microbes thus produced in twenty-four hours would exceed sixteen and a-half millions; in two days they would increase to forty-seven trillions; and in a week the number expressing them would be made up of fifty-one figures. At the end of twenty-four hours the microbes descended from a single individual would occupy one-fortieth of a hollow cube, with edges one twenty-fifth of an inch long, but at the end of the following day would fill a space of 27 cubic inches, and in less than five days their volume would be equal to that of the entire ocean." Again, Cohn estimated that a single bacillus weighs about 0·000,000,000,024,243,672 of a grain; forty thousand millions, one grain; 289 billions, one pound. After twenty-four hours the descendants from a single bacillus would weigh $\frac{1}{2666}$ of a grain; after two days, over a pound; after three days, sixteen and a-half million pounds, or 7,366 tons. It is quite unnecessary to state that these figures are purely theoretical, and could only be attained if there were no impediments to such rapid increase.

Fortunately for us, observe Messrs. Pearmain and Moore, various checks, such as lack of food and unfavourable physical conditions, prevent unmanageable multiplications of this description.

The figures show, however, what a tremendous vital activity micro-organisms or "bacteria" possess, and it will be seen at what speed they can increase in water, milk, broth, and other suitable nutrient media. The reader will, from these observations, be prepared to realise the enormous force which the sanitarian has at his disposal for the rapid and effectual destruction of waste animal and vegetable matters by the action of the life processes of these minute scavengers, provided that the conditions of their environment are carefully arranged, so as to afford them the freest possible scope.

How, then, is this desirable end to be attained? The following well-known facts will help us to answer the question:—In the process of making vinegar a suitable vessel or "vat" is filled with birch twigs, and over these the product obtained by the fermentation of malt is pumped. The twigs become coated with an organism known as the *Mycoderma Aceti*, or vinegar plant, and by this organism the alcohol produced by the fermentation of the malt is converted into acetic acid. This is a case of transformation by oxidation, and not of complete destruction, such as we desire to obtain in the case of sewage; but it serves to illustrate the powerful effect that is produced by the action of living matter. First, we have the organism known as yeast to the brewer, or *Saccharomyces Cerevisiæ* to the biologist, bringing about the



SECTION OF VINEGAR VAT (after Muspratt).

change of saccharine matter contained in malt, into alcohol, &c.; and then the further change of the alcohol by means of the *Mycoderma Aceti* into acetic acid. If we can find an organism which will make this change complete, and resolve the matters presented to it into its constituent elements, or harmless combinations of them, such as carbonic acid, water, &c., we shall be able to bring about all that we desire.

There are many such organisms doubtless, as we know of their work; but it is fortunately not necessary to enter on a long description of them in order to describe the results. It is sufficient to know that they exist, and that we have them at our command to use as we please. They are present in the air, and in the waters, however pure, and in enormous numbers in sewage water. All that is required is to give those most suitable for our purpose the opportunity of exerting their beneficial characteristics, when they will infallibly multiply to a degree inconceivable to those who have had no experience of the remarkable manner in which they greedily eat up all that is presented to them under favourable conditions.

If any porous material, such as coke breeze, burnt clay, &c., be placed in a vessel or tank, and sewage water admitted thereto, a large proportion of the filth, which is only another name for the complex organic matter containing gelatine, chondrine, albumen, starch, &c., contained therein will adhere to the rough sides of the coke, or other material; and the organisms, whether known as *bacilli*, *micrococci*, &c., will commence their work by feeding and multiplying, so that in a short time the whole surface of each particle of coke, or other material which may be employed, will be covered by them. Let the water be drawn off gently, after sufficient time has been allowed for the adherence of the fine particles of matter to the coke. Air will be admitted as the water is lowered, and a fresh impetus will be given to the little workers, who will soon be ready for another supply of food to be given to them in the form of a second quantity of foul water. It will be at once seen that if the supply of air and food is maintained regularly and at proper intervals these processes may continue indefinitely, and that we can bring about the destruction of the objectionable matters completely and economically for as long a time as may be desired. Of course the question will at once arise as to what becomes of the dead bodies of those bacteria which succumb in the struggle for existence. In reply, I would point out that a dead bacterium will be only so much food for his friend, who does not show much feeling in the matter, and evidently considers that all is fish that comes to his net.

Such, then, is Nature's method of purification. In succeeding chapters we shall see how these principles may be more particularly applied in practice, and what are the difficulties to be met with in the course of the work.

CHAPTER II.

ANTISEPTICS, OR PRESERVATION FOR LIMITED PERIODS. BACTERIOLOGICAL METHODS.

At various times proposals have been made for the treatment of sewage by numerous methods calculated to preserve the organic matters so that they will not putrefy, in the hope that they will disappear by direct combination with the oxygen of the atmosphere. Amongst these may be placed carbolic acid and the other various tar compounds, sulphurous acid and its combinations, excessive doses of lime, &c.

All these substances have the property of acting as envelopes, wrapping up the matters, as it were, and killing the microbes, on which, it has been shown, we have to depend for their destruction. Let us follow out the action which will take place in the case of such a treatment. At first the antiseptic, as such substances really are, destroys the organisms, and for a time prevents further decay. The result will be an accumulation of the filth. Then the preservative becoming altered in character no longer effects its object, and putrefaction results, the last state of the case being worse than the first. This position was clearly indicated by Dr. Sorby, in his evidence before Lord Bramwell's Commission in 1883, when he said :—" We thus see that, whilst the river mud is characterised by the loss of detritus of fæces, it is also equally characterised by the presence of an enormous number of the excrements of minute crustaceans and other small animals, which must undoubtedly feed on the fine-grained matter suspended in the river water. It therefore appears to me an obvious conclusion that a very large portion of the detritus of fæces thus manifestly lost in the river is not lost by *decomposition*, but utilised by countless thousands of living creatures. The difference between the results of these two different processes will be at once understood when we reflect on what would be the state of London if all the animals consumed as food were left to decompose in the streets."

This was, in fact, well illustrated in the case of the river Thames in the year 1887, when chloride of lime, which I had abandoned in 1884, was used in opposition to my advice, it having been employed temporarily in consequence of its being the only material available in sufficient quantity at that time, as the permanganate of soda subsequently used could not be purchased in quantity, or at a reasonable price, until I undertook its manufacture, at Crossness, in the autumn of that year. The result of the experience then obtained was most definite. Unless large and continuous doses of chloride of lime were employed and kept up, until the wet weather set in, the indications were clear that by killing off the organisms we were preparing for the fulfilment of Dr. Sorby's suggestion, only carrying out the process in the river instead of in the streets. In 1887, another chemist was consulted by the late Metropolitan Board of Works, as I was thought to be extravagant in using permanganate of soda, although I was spending on *temporary* measures only from a quarter to one-half the annual sum which was contemplated for the *permanent* cure. That gentleman, looking at the question solely from the chemical standpoint—although I put the biological side before him at our first interview—recommended a renewed trial of chloride of lime, as it was thought to be cheaper so far as its power to liberate oxygen was concerned.

While the effect of the chlorine remained no great harm was apparently done, but when this fell off the whole portion of the river affected became one stinking black mass of corruption—so bad indeed was it, that some persons drew samples of water at Blackwall, and used them for ink to write letters to the newspapers.

Surely this experience was on a scale sufficiently large to have effectually settled all dispute on the point; yet at this present moment there are cases in which the same principles are still at work, although not on so large a scale, and thousands of pounds sterling per annum are still being worse than wasted on such processes; and the teachings of modern science are thrown aside, because they interfere with the views of interested persons.

In the previous chapter it was clearly shown that the ultimate destruction of organic matter was the end to be aimed at, and not a method of preservation. Therefore the antiseptic must be abandoned as worse than useless. Nothing must be employed which acts as a destroyer of microbic life, unless, like the permanganates, it is itself destroyed in the act of oxidising such portions of the organic matter as are subject to its influence. The use of permanganate for the temporary deodorisation of the London sewage was much misunderstood in consequence of the generally-received idea that its action was only that of a disinfectant, and that, therefore, all other disinfectants were equally as efficacious, if not more so, as they could be obtained at a cheaper rate, and therefore would do more work. So the lecture-table chemist, without considering the biological aspect of the case, declaimed against permanganate with the results above referred to. In addition to its power of killing foul odours, permanganate has no odour of its own to set up in the place of that destroyed; it is a complete deodoriser; but in *small quantities* it is not an antiseptic, as in doing its own work it is itself destroyed, and there is nothing left to injure the living organisms. Its method of action is the reverse of that of the antiseptics, for it accomplishes its work by destroying the putrescent matters presented to it. Of course, the argument in reply to this is that the quantity which can be used within financial limits is so small as to be of but little effect, and is only a trifling proportion of that required to oxidise the whole of the objectionable matters in the sewage. This is, so far, true, but it deals with the first portion of our oxidation scheme.

The matters in an actually foul state are the only ones that require immediate attention, the rest may be left for the organisms to eat up, if they are left undisturbed, and not killed outright by poisonous compounds. Consequently, the quantity of permanganate required is only a fraction of that which would be necessary for the complete destruction of the whole of the organic matter. It is a remarkable and most valuable characteristic of permanganate acid that it exerts a selective action on those matters which are in an advanced state of decomposition. For instance, a cold dilute solution of fresh gelatine is but very slowly affected, but when once putrescence has commenced, its action is instantaneous. The value, therefore, of permanganate is that while it at once stops the nuisance, it does not create another in its place, but leaves nature to follow its usual course, and where suitable conditions prevail for the ultimate purification of sewage, to proceed with her work without let or hindrance.

The attempt to control nature instead of assisting her has been the great obstacle in the way of all improvements for so many years, and even when the right path has been pointed out many have declared that the satisfactory solution of the sewage problem was almost as far off as ever. With this I do not agree. As I once remarked, in reply to such a suggestion, "The great stumbling-block in the way of a proper solution of the difficulty was the interested motives and unfounded statements of many who were absolutely unacquainted with the practical difficulties of the case. If the efforts made to tear aside the veil from these various mysterious processes were in any way successful, an enormous stride would have been made. Immediately sanitarians recognised the fact that the power of chemistry in this matter was limited, that sewage had to be got rid of at the cheapest rate, whether profitably or not, and that common sense was in many respects the best guide, a new era in the treatment of sewage would have arisen, and rapid progress might be anticipated." Looking back on the experience of the past ten years, I can read these remarks and repeat them with ten-fold force. The antiseptics for sewage treatment have faded, or are rapidly fading, out of sight, and it has come to be recognised that the microbic action is the chief one now worth further study.

When I first proposed to treat the London sewage on biological principles I was laughed at and thought to be a madman. But time has justified my action, and many have rushed forward and would seem as if desirous of claiming the credit.

It may, therefore, not be out of place to put on record the way in which the present scheme of treating the London sewage came to be worked out.

In my earlier years I was, like many others, a lover of aquaria, and spent much time in roaming over the delightful fields of Hampstead and Highgate in search of specimens, being out at five o'clock on many a fine morning, and returning home to breakfast with trophy rich and rare, in addition to a hearty appetite. The loving study of the specimens so obtained (never shall I forget my first gathering of *Volvox Globator* in a pond at West Hampstead) prepared me to listen with eager ears to Dr. Sorby's chats on the results of his microscopical examination of the river Thames in 1880-2. From this it will be readily gathered that when, in the early summer of 1884, the Metropolitan Board of Works gave me the order to deodorise the whole of the London sewage, I was prepared to deal with the river in the light of a big aquarium, and looking upon my early experiences, and having Dr. Sorby's observations in my mind, I came to the conclusion that whatever chemistry could do, it must be subordinate to the biological considerations. In order, however, that in a matter of such vast importance I should not make a mistake, I obtained official sanction to consult Dr. Dupré, who heartily worked with me.

That he was in close agreement with me in these views will be seen from the following extracts from a report presented by him during that year to the Local Government Board, on "Changes in the Aëration of Water as Indicating the Nature of the Impurities therein":—

"If a perfectly pure water, fully aërated, were kept in a bottle in such manner that it could neither lose nor absorb oxygen, it would no doubt remain fully aërated for any length of time. If, however, the water contained any kind of impurity capable of combining with oxygen, the proportion of oxygen remaining in the water would after a time diminish. The amount of oxygen thus disappearing might, to a certain extent, be taken as a measure of the amount of matter present capable of combining with or consuming free oxygen. In this respect a changed degree of aëration would stand on a footing with the older method of estimating the relative amounts of organic matter present in various samples of water by the amount of oxygen absorbed by them, under certain conditions, from permanganate of potassium. If this were all the information to be got by the aëration method, it would have nothing to recommend it over the permanganate method; but on the contrary there would be much, and notably the length of time taken by an experiment—to render the examination of the aëration of a sample of water far less suitable as an analytical operation.

"Some experiments, however, which I made some time since, with sewage-polluted water, led me to the belief that observation of the changes in aëration of a water would enable us to distinguish between living and dead organic matter—a problem which no merely chemical method had so far solved. While engaged in this work a paper was published by Dr. Angus Smith (it appeared shortly before his death) in which he also endeavours to deal with this problem by means of a chemical method. This, however, differs from my own, which I shall now proceed to describe.

"My method has been to bring the samples of water under experiment to the desired temperature, generally 20 deg. Cent., doing this in the bottle in which it had been collected, and ensuring its being fully aërated by vigorous shaking. It was then transferred to the experimental bottle. The air used for aëration was sometimes filtered through cotton wool, but was generally taken unfiltered. The necessity for having the water to begin with fully aërated, while at the same time the bottle in which it is to be kept is to be completely filled with it, is one of the chief difficulties of the method. Indeed, there are a good many difficulties in it, and I have not yet overcome all of them.

"Especially is there difficulty if any cultivating material has to be added or if the water has not to be heated above a moderate temperature. On the other hand, little difficulty is to be met with if the water is used without cultivating material or if the water after aëration and bottling is heated to a greater extent and not allowed to come in contact with air during continuance of the experiment. But if even after the water has been boiled and carefully aërated with air passed through cotton wool it has to be transferred when cold to the experimental bottle, the success of the experiment becomes doubtful, and especially doubtful if any cultivation material has subsequently to be added.

"The bottles were filled with a sample of water that was under analysis, and were then kept in a constant temperature chamber (usually at 20 deg. Cent.) for a period of several—commonly ten—days.

"In brief, I may say that the consumption of oxygen from the dissolved air of a natural water is, in the vast majority of cases, at all events, due to the presence of growing organisms, and that in the complete absence of such organisms little or no oxygen would be thus consumed."

In May, 1886, in the course of some remarks during the discussion following on a paper read by the late Dr. Tidy at the Society of Arts, Dr. Dupré said :—"There was a remarkable unanimity on the part of those who had spoken, that the dissolved organic matters, where the sewage was mixed with a certain quantity of water, would disappear rapidly as they became oxidised. He had often thought that a very good thing would be to cultivate the low organisms on a larger scale, and to discharge them with the effluent into the river, as the power which these low organisms had was remarkable."

In these observations Dr. Dupré clearly set out the line of thought upon which we had been working, and which, as it will be seen, was but a development of Dr. Sorby's conclusions some years previous. In the following January in a paper which I read before the Institution of Civil Engineers, I pursued the point further. In discussing the question of the use of an excessive quantity of lime for the purpose of precipitating the solid matters in sewage, I wrote as follows: "One object claimed for the use of an excessive quantity of lime, and also for some other substances, is that they destroy the living organised bodies, such as bacteria, &c., which give rise to the phenomena known as putrefaction. This question is one of such vital importance to the after-character of the effluent, that it is necessary to discuss the subject at length."

"The researches of Warington have demonstrated that the process known as nitrification of the complex nitrogenous bodies existing in sewage during its filtration through land, is brought about by definite organisms, who in their life processes feed upon the sewage matters, and evolve the nitrogen in the form of nitric acid. As with the nitrogen, so with the carbon, which is absorbed as food, and evolved as carbonic acid. Without these life processes, whether they be of an animal or vegetable nature, no destruction of the objectionable matters can take place. As the very essence of sewage purification is the ultimate destruction, or resolution into other combinations of the undesirable matters, it is evident that an antiseptic process is the very reverse of the object to be aimed at. If a preservative process be required, a receptable should be provided for the preserved matters, and in order to ensure that the antiseptic process should be a continuous one, any subsequent treatment or method of disposal must avoid the destruction of the antiseptic employed. In the case of lime, which, in the form of strong solutions, is a solvent of organic structures, what time will elapse before its neutralisation by absorption of carbonic acid and consequent loss of antiseptic properties will take place after the discharge of the effluent into running water? Obviously only a very limited period, after which the growth of organisms, so zealously destroyed, will recommence by reason of the numerous spores in the water of the river and in the air, with which it is constantly in contact, and there will thus be an end to the antiseptic properties of the system.

"The lesson to be learnt from the numerous experiments, published by various authorities, both in this country and on the Continent, is that bacteria and other low forms of organic life are most potent in the destruction of all objectionable refuse. Modern experience shows that, when this subject is better understood and thoroughly worked out, in all probability the true way of purifying sewage, where suitable land is unavailable, will be first to separate the sludge, and then to turn into the neutral effluent a charge of the proper organism, whatever that may be, specially cultivated for the purpose, retain it for a sufficient period, during which time it should be fully aërated, and finally discharge it into the stream in a really purified condition. This is, indeed, only what is aimed at and imperfectly accomplished on a sewage farm. It is true that knowledge on the subject is not yet sufficiently advanced to put such a system into practical operation, but sufficient is known to show that the antiseptic treatment of sewage is the very reverse of Nature's method. The author has not the slightest doubt but that the future treatment of sewage will be a combined chemical and biological one, as suggested elsewhere by Dr. Dupré." As will be seen from the foregoing, that suggestion was the one thrown out by Dr. Dupré a few months before, when referring to the experience we had gained during the previous three years in connection with the deodorisation of the sewage of London, and was in conformity with Dr. Sorby's views as to the cause of the disappearance of the effete matters in the river.

It will now be easily understood that in the light of these views I was enabled to recommend a simple and economical scheme for the removal of the gross solid matters, leaving the remainder for my allies, the lower forms of life, as one leaves the scraps of the domestic table for the benefit of the chicken yard.

Following the publication of these statements in 1886 and

1887, which thus clearly laid down the proposed new departure in sewage treatment, the Massachusetts State Board of Health commenced a series of experiments, and during the next three years entirely confirmed these views, as well as those relating to the principles of the chemical treatment best adapted to separate the solids from the liquid matters in the sewage. Their carefully-conducted and liberally-published experiments completed the rout of the sceptics as to biological treatment of sewage, and one of my most bitter opponents handsomely acknowledged in plain words that "you were right and I was wrong." But he was an old soldier, who could fight like a tiger and behave as a gentleman! May there be many more such!

Valuable as were the results of the Massachusetts experiments, they still left the question in an imperfect form, as the quantity of sewage treated was too small to serve as a guide as to what could be done in practice. Doubtless this was due to the aiming at too high a degree of purification, as would happen in most laboratory experiments. It therefore became necessary that more precise data should be obtained on a working scale, and this I have had the opportunity of putting on record in connection with the experimental filter beds at the Northern Outfall Works of the London County Council from 1892 to the present time. Without going into details—which will be found in another chapter—it will here suffice to say that I am still more than ever convinced of the truth of my earlier prophecy referred to above. If there be an exception, however, it is that the bacteria may be made to do all the work, and chemistry may stand aside, except as a handmaid in the hands of the experimentalist, to show the rate and amount of work which is being done.

CHAPTER III.

VARIOUS PROPOSED METHODS OF ARTIFICIAL PURIFICATION—PRECIPITATION.

We are constantly hearing of meetings here and meetings there, and as constantly reading letters and articles in daily and other papers, setting forth the great evils occasioned by the pollution of this or that stream, and the benefits, both monetary and otherwise, to be derived from the adoption of so-and-so's last new patent. Local Boards are told in sonorous phrases that their troubles will be over as soon as some particular scheme is at work. Large sums of money are raised, after costly and elaborate inquiries by high officials; lunches are eaten and jaunts undertaken by inquiring deputations to distant spots; and reports with well-rounded periods are published. The works are opened with mutual congratulations, and happy officials go home to bed to dream that all their troubles are over, and that their particular charge will be for ever free from reproach. Alas! the temporary joy is soon damped. Somehow or other, the grand scheme is not found to answer in such a manner as all hoped for. Complaints come in, dry seasons arise, and the "great question" is again to the fore. Again and again the same sequence has been repeated. Sanitarians—save the mark!—grow fat, and the ratepayers groan under an ever-increasing burden, and sigh for the days of their forefathers, who worked, lived, and died at a good old age, untrammelled with the multitudinous problems of modern civilisation.

It will be at least amusing, as well as profitable, to run over a list of some of the schemes which have been before the public from time to time in connection with the disposal of sewage. The prevalent idea in the minds of inventors seems to have been the possibility of making immense fortunes out of the filthy matter. This is evidently the starting-point of the majority; without more specifically mentioning any particular company or proprietary process, the great "sanguinary" scheme may be instanced. The ingenious inventors of this scheme imagined evidently that the "blood is the life," and that as a living and vital substance it attacked in some way the manurial properties of the foul liquid, and dragged them into captivity for the benefit of the farmer, and thereafter mankind. Unfortunately for the energetic proprietors of this method, it has been given up by one authority after another, after making a gallant stand. Peace to its ashes!

Another great scheme, of which there was much talk a few years ago, was one in which a profoundly "scientific" process was involved, so "scientific," indeed, that no one could understand it, not even the inventors themselves, although they succeeded in raising considerable sums of money to start it. Clay, caustic soda, muriatic acid, chalk, sulphuric acid, copperas, with various other ingredients, were mixed up and sent into the sewage stream. A mud was naturally obtained in a tank, and this was dubbed "manure." But the unhappy shareholders failed to reap their expected reward, and we have heard no more of the inventor's efforts in this direction.

One scheme in particular for treating sewage claimed with a loud voice that it completely destroyed all the organisms and preserved the sewage from decomposition, and that the sludge obtained was good for treating a further quantity of sewage, and so on for a succession of such treatments. Unfortunately, the effluent contained more organic matter than the liquid of the original crude sewage, the effect of the process being to dissolve some of the solid matters. This plan seems, fortunately, to have died out.

To enumerate all the wild theories and plans for obtaining money out of sewage would require volumes, and even a condensed account would soon tire the reader. Almost every substance imaginable has been proposed by the believers in the doctrine "that the water won't have it, and the land wants it." One imaginative gentleman proposed to gather "all the sewage of England and Wales into a big receiver, fitted with working sluices," there treat it by some mysterious means, and make "many millions sterling" profit out of the results. This joyful suggestion has been only equalled by the grand discovery, not long since announced, that a new electrical battery had been invented which turned the chemicals used into still more valuable products. The criticism of this splendid plan by a well-known technical journal was unique. "It only remains for the Government to buy up the patent, light up the country with the electric light, and pay off the National Debt with the proceeds."

The great stumbling-block to progress has been this one all-absorbing idea of making a profit out of sewage, and the natural consequent cupidity of both inventors and authorities. The sound common-sense brought to light by the labours of Royal Commissioners and others has dissipated this erroneous idea from the minds of all unprejudiced students of the question. The late Lord Bramwell and his colleagues spoke out boldly, as well they might. "Sewage disposal costs money; it involves an expense which must be met," said they. They put their feet down with all the weight of their authority upon the worn-out notion that the manurial value of sewage is to be taken into consideration as part of the general question. Where the small manurial value present in the sewage can be realised, let this be done by all means; but the primary consideration must be that of the effectual disposal of the impure flood without nuisance, and next, if possible, the reduction of the expense in those few limited cases in which surrounding conditions are favourable.

One of the most frequently misunderstood points is that of disinfection. Disinfection direct, as applied to sewage, is but rarely if ever attained. Partial deodorisation is frequently and easily applied, but absolute disinfection *plus* deodorisation can only be obtained by one of three systems—First, by preliminary defœcation, followed by filtration *through* large areas of suitable soil. Secondly, by sufficient dilution with very large volumes of well-aërated and comparatively pure water. In this case enormous numbers of organisms rapidly dispose of the welcome food. This is naturally a simple process, and is apt to fail when most required, namely, during dry and hot weather, when the supply of sufficient water fails, and the diminution of dissolved air in the water, by reason of the enormous increase of the living organisms using it at a faster rate than the water can dissolve fresh quantities of air, is such that these minute servants of man are suffocated as surely as the poor folk in the Black Hole of Calcutta. Thirdly, by the direct bacteriological treatment under conditions hereafter described.

Precipitation of the solid suspended matters is an admirable and advisable proceeding as a preliminary process in certain cases, although here again the bacteria are coming rapidly to the front, and are placing this method in the category of the past. Its great misfortune is that well-intentioned but mistaken folks have promised such great things from the use of the method, that its virtues are in danger of being overlooked, and the good really effected lost sight of in the oft-repeated disappointments. Chemical precipitation, so far as it is applicable to sewage, mainly effects one thing only, and that is the separation of the suspended matters from the liquid matters. Under favourable circumstances a certain percentage of the dissolved impurities may be carried down, but in no case is this fully secured. Whatever may be claimed to the contrary, there is not a workable process of precipitation yet invented which will do more than effect a separation for all practical purposes of the solid from liquid matters. That is to say, that if a thoroughly good effluent, as we now understand it, be required, the "tank" effluent, as it is called, obtained by chemical precipitation, must be submitted to further treatment. The chemist in the laboratory can certainly attain this happy result, but the expense would be so enormous, and therefore prohibitory, that no one would listen to such a proposal. The salts of aluminium and iron, with lime, will effect much, but their use in even preposterous quantities will not materially reduce the dissolved impurities in sewage-polluted water.

SOLUBILITY OF THE SUSPENDED MATTERS.

The solubility of a portion of the suspended matters in solutions of lime seems to have been entirely overlooked by the many writers on the subject. The results of numerous experiments made by myself, on both large and small quantities of sewage liquid, have fully demonstrated the fact that the use of an excessive quantity of lime, while affording a rapid settlement of the sludge, and a more or less clear effluent, dissolves a by no means inconsiderable quantity of the offensive matters previously in suspension, and this is apt to render the last state of the liquid worse than the first.

In proof of this statement, I would point to the following results of a special experiment made for the purpose of demonstrating the fact clearly. Carefully-washed sewage sludge was diffused in clean water, the mixture was agitated for five minutes and a sample withdrawn; an excess of lime was then added, and the mixture again agitated for another five minutes. If the action of the lime were purely one of precipitation, no increase should have been observed in the soluble matters previously in the water. The limed liquid, however, instead of containing less dissolved oxidisable organic matter, was found to absorb about three times the quantity of oxygen required by the unlimed liquid. The actual result being :—

Experiment to Ascertain the Effect of Lime upon Sludge.

	Oxygen absorbed from Permanganate in 4 hours.
Aqueous extract of thrice-washed sludge (filtered through paper)...........................	0·23 grain per gallon.
The same, after the addition of lime, agitation for five minutes, and filtration through paper	0·71 ,, ,,

The well-known objectionable character of the liquid pressed from sludge, which has been treated in the usual way with lime, is a striking instance of its action on the solid matters.

This solvent action of substances used as precipitants may also be illustrated by the action of alum and sulphate of alumina upon chondrine, previously mentioned as an organic constituent of sewage. This compound is thrown out of solution by a small quantity of alum, but the precipitate is immediately re-dissolved by even a slight excess. Common salt will also effect this re-solution.

The obvious lesson to be learnt from these results is, that before any system of precipitation is adopted for a particular sewage, care should be taken to ascertain that the intended process in no way exerts a solvent action on the matters which it is desired to remove. Having determined this primary point, the next question is, "To what extent are the matters in solution affected?"

DISSOLVED IMPURITIES AND THEIR PARTIAL REMOVAL.

This point has given rise to no little controversy. Authorities on either side have differed widely, and it is only in view of the unmistakeable results obtained in the course of many experiments that I ventured to set aside all statements hitherto made on the subject, and to place on record the outcome of work, specially conducted for the elucidation of this important branch of the inquiry.

It must be obvious to the most superficial observer, that in dealing with so variable a substance as water-carried sewage, results of an equally varying nature are likely to be obtained. If a large quantity of a soluble organic substance be diffused in half a pint of water, it might be thought that little trouble would be experienced in precipitating a considerable portion of it, with only a moderate quantity of the chemical agents suitable for the purpose. On the other hand, if the same quantity of matter were diffused in several gallons of water, it would not be surprising if the desired precipitation were not so readily effected.

This consideration is not a suggestion merely, but the outcome of actual demonstration, and it explains the cause of the various contradictory statements on the subject. To exhibit the facts in a clear light, I have tabulated the results of the examination of varying samples of sewage and other solutions, both before and after treatment by the usual precipitation agents employed on sewage works (Table III.). For the purpose of ascertaining the degree of impurity present in the samples, the standard adopted is the quantity of oxygen absorbed by the organic matters from permanganate of potash, acting in an acid solution at a temperature of 80 deg. Fahr., during four hours in a closed vessel. In some cases these results have been checked by the albuminoid-ammonia process, but the former method is one peculiarly

TABLE III.—*Showing the Percentage Reduction of Oxidisable Organi*
(All quantities are state

LIQUID USED FOR EXPERIMENT.	PERCENTAGE REDUCTION OF DISSOLVED											
	1	2	3	4	5	6	7	8	9	10	11	12
Raw sewage from	Lime in solution ... 3·7	Lime in solution ... 5·0	Lime in solution ... 10·0	Lime in solution ... 15·0	Lime as milk ... 15·0	Lime in solution ... 3·7 Iron sulphate ... 0·3	Lime in solution ... 3·7 Iron sulphate ... 1·0	Lime in solution ... 3·7 Iron sulphate ... 2·5	Lime in solution ... 3·7 Iron sulphate ... 5·0	Lime in solution ... 5·0 Iron sulphate ... 2·0	Lime in solution ... 5·0 Iron sulphate ... 4·0	Lime in solution ... 5·0 Iron sulphate ... 5·0
Metropolitan system	20	26	29	37	30	27	27	29	33	31	33	35
,, ,, ...	6	10	28	64	12	10	10	18	32	27	34	32
,, ,, ...	18	21	14	19	22	12	19	25	24	26	21	27
,, ,, ...	26	26	26	37	10	24	25	38	33	30	31	32
,, ,, ...	10	9	10	12	11	10	12	13	27	26	24	24
,, ,, ...	23	29	29	34	27	23	27	35	37	33	33	39
,, ,, ...	2	8	15	29	0	0	5	17	20	12	16	22
,, ,, ...	12	25	30	33	25	16	22	24	32	26	30	34
,, ,, ...	7	19	21	27	10	18	9	20	22	17	14	25
,, ,, ...	5	12	13	18	4	5	3	11	16	13	15	17
,, ,, ...	3	12	9	18	3	10	13	15	17	14	13	17
,, ,, ...	15	16	19	48	44	11	15	17	20	17	21	20
,, ,, ...	12	15	21	25	17	10	16	20	22	17	20	22
,, ,, ...	9	15	19	23	19	11	17	20	21	18	18	19
,, ,, ...	10	14	22	19	9	8	16	14	14	16	17	21
,, ,, ...	12	12	17	24	12	7	12	12	22	19	19	21
,, ,, ...	15	16	16	15	9	9	11	13	17	13	14	15
,, ,, ...	8	8	20	35	8	11	8	14	17	14	20	19
,, ,, ...	8	7	19	34	7	10	7	13	16	13	19	18
,, ,, ...	3	4	4	4	9	4	4	4	8	7	6	8
,, ,, ...	4	5	5	0	7	5	5	7	5	7	7	9
,, ,, ...	12	20	26	28	16	15	22	23	24	23	22	23
,, ,, ...	6	9	9	14	3	5	5	7	11	9	12	12
Average	11	15	19	25	13	11	13	18	21	18	19	18
Cost per annum for chemicals	£ 13,505	18,250	36,500	54,750	54,750	15,695	20,805	31,755	50,005	32,850	47,450	54,750
Other sources	—	52	—	—	—	—	—	—	—	58	61	—
,, ,, ...	—	—	10	—	—	—	—	—	—	—	—	56

	£	s.	d.	
Lime taken as costing	1	0	0	per ton.
Iron	2	0	0	,, ,,
Alumina	3	10	0	,, ,,

tter in Solution by Various Methods of Chemical Precipitation.
grains per gallon.)

IDISABLE ORGANIC MATTER BY TREATMENT OF LIQUID WITH

14	15	16	17	18	19	20	21	22	23	24	25	
Lime in solution ... 5·0 Iron sulphate ... 10·0	Lime in solution ... 10·0 Iron sulphate ... 10·0	Lime in solution ... 5·0 Alumina sulphate... 5·0	Lime in solution ... 5·0 Iron sulphate ... 5·0 Animal charcoal ... 5·0	Lime in solution ... 5·0 Iron sulphate ... 1·0 Alumina sulphate... 5·0	Lime in solution ... 7·0 Iron sulphate ... 1·5 Alumina sulphate... 5·0	Lime in solution ... 10·0 Iron sulphate ... 2·0 Alumina sulphate... 10·0	Lime in solution ... 14·0 Iron sulphate ... 3·0 Alumina sulphate... 10·0	Lime in solution ... 15·0 Iron sulphate ... 3·0 Alumina sulphate... 15·0	Lime ... ... 28·0 Iron sulphate ... 6·0 Alumina sulphate... 20·0	Lime ... ... 56·0 Iron sulphate ... 12·0 Alumina sulphate... 40·0	Lime ... ...700·0 Iron sulphate ...100·0 Alumina sulphate 500 0	Average.
36	36	33	40	32	32	34	37	39	44	49	53	34
38	36	32	32	33	36	67	46	45	40	43	58	33
30	28	15	27	19	17	25	22	23	21	28	45	23
36	30	26	32	30	31	30	25	36	30	30	45	30
25	24	16	24	14	14	16	12	29	14	26	41	19
36	40	37	38	38	39	33	37	39	44	55	62	36
28	32	16	21	19	24	22	11	26	20	24	59	19
41	32	24	26	28	32	29	25	31	28	43	59	30
25	26	21	26	19	21	16	19	22	29	31	54	22
22	21	16	22	21	25	25	25	26	25	25	45	18
21	16	14	15	13	15	16	11	14	8	18	39	15
25	38	24	24	25	24	26	27	38	40	46	59	27
25	24	16	22	25	21	21	24	22	25	40	54	22
32	19	23	18	19	19	18	18	20	19	18	48	20
20	21	21	19	16	17	22	27	19	17	21	47	19
23	24	15	19	17	18	22	26	25	28	39	62	21
11	17	10	19	15	14	15	13	17	16	17	45	16
27	31	20	23	18	23	28	29	31	30	41	58	23
26	29	19	22	17	22	26	18	29	29	40	55	20
10	10	0	7	7	11	12	13	12	13	29	58	10
7	11	0	12	11	12	13	14	11	13	16	44	10
22	23	22	20	20	20	22	21	25	22	33	59	23
13	14	10	10	11	28	18	12	12	14	19	50	17
25	30	18	22	20	22	24	21	26	24	31	52	—
91,250	109,500	82,125	237,250	89,425	100,375	178,850	200,750	268,275	401,500	803,000	9,672,500	—
69	—	—	—	—	—	—	—	—	—	—	—	—
—	—	33	—	—	—	—	—	—	—	—	—	—

Volume of sewage taken at 156,800,000 gallons per day.

adapted for indicating the work required to be done in the ultimate purification of the objectionable matters. The various chemicals used were first dissolved in portions of the sewage treated, to avoid errors due to the apparent removal of the dissolved matters which would have been indicated if the solutions had been made with clean water.

The conclusions indicated by the results given in Table III. are tolerably clear. The first portion of the table shows the results of the examination of twenty-three series, each consisting of twenty-five different effluents, obtained by as many processes, resulting from the treatment of a given sample of sewage collected from the metropolitan system. This exhaustive examination fully confirms the statement, made elsewhere, that no practical process of chemical precipitation is capable of removing more than a limited quantity of the oxidisable organic matters in solution in London sewage.

The results further demonstrate the striking superiority of iron over alumina for sewage purification. By the use of iron sulphate in conjunction with lime, as much work is effected (on the basis of the London sewage) for 31,000*l.* per annum as would be obtained by an expenditure of 82,000*l.* for alumina and lime. Even when lime and alumina, with the help of only one-twentieth of their weight of iron sulphate, were added to an extent of 178,000*l.* per annum, not so much work was accomplished as by an expenditure of only 54,000*l.* for lime alone when used in solution. Alumina is valuable chiefly for its effect in removing some of the colour from the effluent, and thus appealing to the eyesight; while the matters actually dissolved are there nevertheless. The observations with regard to the action of alum upon chondrine already made will help to explain this. The experiments with animal charcoal—column 17—show that if this substance were used to an extent of 182,500*l.* per annum the benefit would be practically *nil.* The table also indicates most clearly the danger of drawing conclusions from the examination of one or two samples only.

The second portion of the table gives some results which will explain the remarkable differences of opinion expressed by various authorities as to the percentage reduction of dissolved solids by various processes, when acting on sewage of a character different from that of London. The sewage used for this purpose was obtained from other sources, and was evidently of such a character that the oxidisable dissolved solids were readily precipitated by even a small quantity of lime in solution, viz., 5·0 grains, no less than 52 per cent. being removed. The addition of an iron salt to the limed sewage effected a further reduction of from 9 to 17 per cent., or, in the latter case, a total reduction of the dissolved oxidisable matters of 69 per cent.

In order to test this point further, and to show that no benefit is derived from the use of an excessive quantity of chemicals, the results of a series of precipitation experiments on solutions of clear mutton extract are given in Table IV. The results show that the same quantity of chemicals is capable of removing from 46 to 90 per cent. of the total oxidisable matter, according to the strength of the solution, and that a very large increase in the quantity of the chemicals used affords no advantage whatever, the results being practically the same, the differences, such as they are, being in favour of the smaller quantity of re-agents employed.

It is thus seen that statements which have hitherto met with a great deal of scepticism on either side may be perfectly correct, the difference being solely due to the variable nature of the sewage operated upon.

These various considerations unquestionably point to the general conclusion that where it is intended to treat the sewage by chemical means, the following rules should, as far as practicable, be observed, viz. :—

(1) That the sewage should be diluted as little as possible.

(2) That the flow of sewage should be adjusted so that the agitation of the particles in suspension should be of a minimum character.

(3) That, unless absolutely necessary, no pumping should take place before precipitation.

TABLE IV.

Percentage reduction of Oxidisable Organic Matter in a Solution of clear Mutton Extract by Chemical Precipitation, as estimated by the Absorption of Oxygen from Permanganate of Potash in Four Hours acting at a temperature of 80 *deg. Fahr. in closed vessels.*

SOLUTION USED.	Oxygen absorbed by untreated solution.	Percentage reduction of dissolved matters by treatment of liquid with		
		Per gallon. 3·7 grains lime 1·0 grains sulphate of iron	Per gallon. 7 grains lime 5 grains sulphate alumina 1 grain sulphate iron	Per gallon. 14 grains lime 10 grains sulphate alumina 2 grains sulphate iron
Solution containing :	Grains per gallon.			
20 p.c. of clear mutton extract	100·0	90·3	90·1	91·2
10 ,, ,, ,, ,,	50·0	87·2	87·0	—
5 ,, ,, ,, ,,	25·0	86·7	86·6	—
3 ,, ,, ,, ,,	15·0	83·5	82·5	—
1 ,, ,, ,, ,,	5·0	82·2	81·2	—
0·5 ,, ,, ,, ,,	2 5	78·4	76·4	—
0·2 ,, ,, ,, ,,	1·0	59·0	55·0	—
0·1 ,, ,, ,, ,,	0·5	56·0	46·0	—

The consideration of these results leads to the inevitable conclusion that excessive expense in striving to attain the impossible, viz., perfect purification of sewage liquid by chemical precipitation, is not permissible. The minimum cost at which a fair separation of the liquid from the solids can be effected should be aimed at. The money so saved will be spent to far better purpose in constructing porous filter beds for the final purification by bacterial action, as previously pointed out.

In the case of farm irrigation with either the effluent or crude sewage, the process is essentially a bacterial one. The usual practice is to run the sewage or effluent, as the case may be, over fields prepared by means of drainage trenches, and by ploughing from time to time; and thus to allow the light suspended matters to be retained on the soil, where they are eaten up by the various organisms, bacterial and otherwise. The objections to this method are that, in the first instance, the expense of the land and laying it out is very considerable. After a time, when the land has become clogged with filth from the sewage, where this is used crude, a nuisance is apt to be created by the odours from the fields. It must be obvious that if an equally satisfactory result can be obtained by more economical means, such a method must be preferable, especially if the freedom from nuisance be considered. It will be seen later on that such a result is now obtainable.

As showing the character of the matters obtained from ordinary water-carried sewage after they have been pressed in the form of "cake," the following table will be of interest:—

Table V.

Average Composition of Pressed Sewage-Sludge from Crossness.

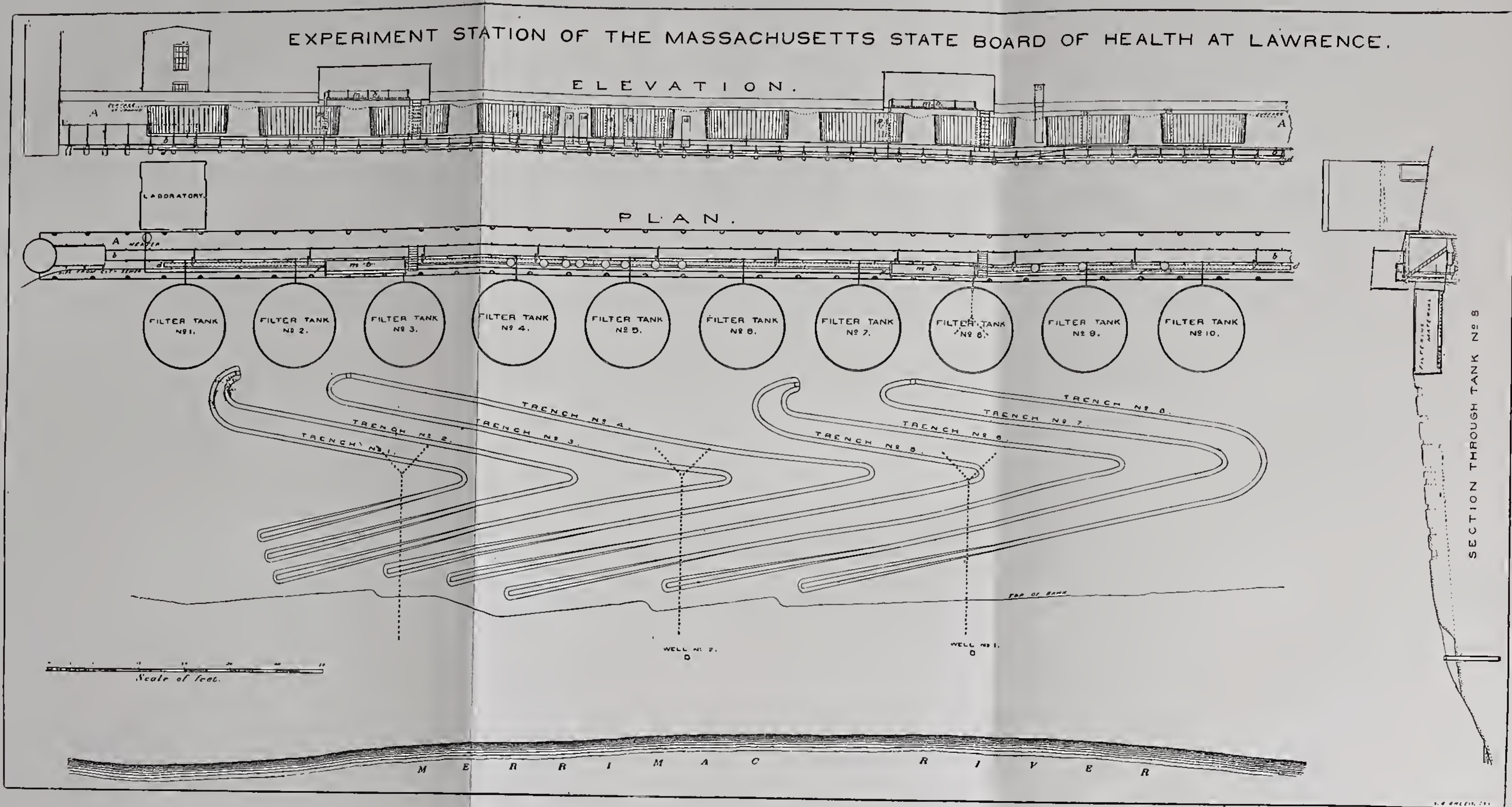
	Per cent.
Moisture	58·06
Organic matter	16·69
Mineral	25·25
	100·00

The organic matter contains—

	Per cent. on pressed sludge.	Per cent. Nitrogen.
Saline ammonia	0·035	0·87
Organic nitrogen, calculated as ammonia	1·025	

The mineral matter contains—

	Per cent.
Carbonate lime	7·94
Free lime	2·45
Silica	8·08
Oxide of iron	0·97
Oxide of alumina	3·39
Phosphoric acid (= phosphate lime 1·44)	0·658
Magnesia	traces


EXPERIMENT STATION OF THE MASSACHUSETTS STATE BOARD OF HEALTH AT LAWRENCE.
ELEVATION.
PLAN.
LABORATORY.
FILTER TANK No 1.
FILTER TANK No 2.
FILTER TANK No 3.
FILTER TANK No 4.
FILTER TANK No 5.
FILTER TANK No 6.
FILTER TANK No 7.
FILTER TANK No 8.
FILTER TANK No 9.
FILTER TANK No 10.
TRENCH No 1.
TRENCH No 2.
TRENCH No 3.
TRENCH No 4.
TRENCH No 5.
TRENCH No 6.
TRENCH No 7.
TRENCH No 8.
WELL No 2.
WELL No 1.
Scale of feet.
M E R R I M A C R I V E R
SECTION THROUGH TANK No 8

[To face p. 41.

CHAPTER IV

EXPERIMENTS AT MASSACHUSETTS, LONDON, AND SUTTON.

Having now arrived at the point where we may proceed to discuss the experience gained up to the present time, it will be advisable first to consider very carefully the various experiments which have been made in America and in England. As shown in the second chapter, I pointed out in 1887 that without the intervention of living organisms no material destruction of the complex bodies existing in sewage could take place. This was the fundamental idea underlying my work in connection with the purification of the Thames.

Following the publication of these views, the State Board of Health of Massachusetts commenced their series of elaborately-conducted experiments in November of the same year, and during the years 1888, 1889, and 1890 obtained very valuable results. So thorough were these that no apology is needed for including a *résumé* of them in a work such as the present.

The filtering grounds are situated in the easterly part of the city of Lawrence, on the north bank of the Merrimack River, and comprise about two-thirds of an acre. On the northerly side of the grounds is a building 300 ft. long and about 10 ft. wide and 10 ft. high, nearly all below the surface of the ground, and lighted by windows in the roof. Running lengthwise through the building is a drain, and above this an open wooden conduit, about 2 ft. wide, and 1 ft. high, resting on piles, and sloping with the building, viz., 1 ft. in 100 ft. This conduit is now divided at each 25 ft. of its length by a tight partition. Each section thus formed is used as a measuring basin, being 25 ft. long, about 2 ft. wide, and 1 ft. high, and holding between 200 and 300 gallons, and has an outlet by which the contents may be turned into the drain beneath.

Outside of the building, where the surface of the ground is 7½ ft. above the top of the measuring basins, are ten large wooden tanks, sunk their full depth into the ground, one opposite each of the measuring basins.

These tanks, numbered one to ten, were made of cyprus, circular in plan, 16 ft. 8 in. in diameter inside at the bottom, 17 ft. 4 in. at the top, and 6 ft. deep inside. They were set with the bottom sloping 4 in. towards the building.

In each tank an underdrain, 15 ft. in length, of horse-shoe section of about two square inches in area, is set with open part downwards, and half an inch above the bottom, resting on blocks 6 in. apart, and the floor is covered with one layer of coarse gravel stones, about 1 in. by 2 in., this by another layer of smaller size, upon which follow layer upon layer of gravel, decreasing in size to ⅛ in. in diameter, and making a thickness of 3½ in. This fine gravel is covered with very coarse mortar sand, with top surface level, 3½ in. deep in the middle of the tank. Above this substratum, which is the same in all the tanks, the several tanks are filled as follows:—

Tank No. 1.—Filled 5 ft. in depth with very coarse clean mortar sand.

Tank No. 2.—Filled 5 ft. in depth with very fine, nearly white sand.

Tank No. 3.—Filled with peat from a cultivated field, 4 ft. in depth, with the previously undisturbed lower layers, and covered 1 ft. in depth with the original top layer.

Tank No. 4.—Filled 5 ft. in depth with river silt, being mostly a very fine sand.

Tank No. 5.—Filled 5 ft. in depth with a good quality of brown soil, taken in the fall from a garden which had been manured and cultivated that season.

Tank No. 6.—Filled 3 ft. 8 in. in depth with coarse and fine sand and gravel.

Tank No. 7.—Filled 3 ft. 8 in. in depth with the same as No. 6, above which are 10 in. of yellow sandy loam, and 6in. of brown soil.

Tank No. 8.—Filled 3 ft. 8 in. with the same as No. 6, above which is 8 in. of yellow sandy loam like that in No. 7, and this is covered with 8in. of sand and gravel like that beneath the loam.

Tank No. 9.—Filled 4 ft. 3 in. in depth, with a very compact sandy hard pan of clay, sand, and gravel, covered with 9 in. of brown soil.

In each case the filtering material was thrown from the shovel, scattering into water which partly filled the tank. After filling each tank to the height given, which was generally 3 in. below the top of the tank, a little sloping bank 1ft. wide was filled around the inside of each tank to prevent the liquid applied reaching the side of the tank too freely. The area of the surface to which sewage is applied and the effective area of the filtering material is regarded as being $\frac{1}{200}$ of an acre.

Tank No. 10 has been used for the measurement of the rainfall and the evaporation.

From the end of the underdrain at the lowest point in the bottom of each tank, extends through the bottom a short brass pipe 2 in. in diameter, to which, by a quarter turn, is connected a 2in. iron pipe, which, passing through the ground and into the building, conveys drainage from within the tank to its measuring basin, where the quantity is read from a scale indicating gallons.

During November and December, 1887, water from the city mains was applied to the several tanks. Sewage has been brought to the building in a $2\frac{1}{2}$ in. pipe of galvanised iron from a point in the main sewer of the city about 1,000ft. above its outlet, and above the entrance of the streams from the manufacturing establishments. This sewage from perhaps ten thousand people may be regarded as ordinary city sewage, similar during very dry weather to sewage separate from storm water, but during wet weather very much diluted by surface drainage.

The sewage was raised by means of two pumps into two measuring basins within the building at a higher level than the top of the filtering tanks, where the quantity to be put upon any tank was noted by a scale of heights indicating gallons, and was distributed by movable hose to either of five tanks from one measuring basin, and to the other five tanks from the other measuring basin.

Besides these large filtering tanks there was placed within the building ten galvanised iron tanks, having about the same depth, but a diameter of only 20 in., giving an area of surface of one-hundredth of that of the large tanks, or one-twenty-thousandth of that of an acre. These tanks are numbered 11 to 20. These were filled with various materials, such as sand, &c., as with the larger ones.

All the large tanks and the trenches were exposed to snow and rain through the first winter and summer, and until November 20th, 1888, when tanks numbered 1, 2, 4, 5, 6, and 7 were covered with canvas, and trenches numbered 5, 6, 7, and 8 were covered with boards to keep out the snow. The canvas coverings were removed March 13th, 1889.

The experiment station at Lawrence was arranged, and the experiments conducted, for the purpose of determining the fundamental principles of filtration not previously established, and to learn what can practically be accomplished by filters made of some of the widely varying materials found in suitable localities for filtration areas, that there may be deduced from these results the probable efficiency of other materials to be found throughout the State.

About four thousand chemical analyses of the sewage applied to the tanks and of the filtered effluent were made in the twenty-two months. Observations upon the number of bacteria living in the sewage and in the various effluents have been made during the two years; while examinations were made of the microscopic organisms.

Thus equipped, the officers of the Board proceeded to conduct a series of experiments of the most elaborate and valuable character, and those who desire to follow them in detail should procure or obtain access to the reports of that Board for the year 1890, as the present abstract can only point out the general nature of the work and the conclusions at which they arrived. In their "General View of Results" the Board proceeds as follows: —

"We have now filtered sewage intermittently through clean gravel stones, larger than robins' eggs, through filters made of various grades of gravel and sand, to a sand whose particles average but 0·004 in. in diameter—a fine granular dust—as well as through soils and peat. With the gravels and sands, from the coarsest to the finest, we find that purification by nitrification takes place in all when the quantity of sewage is adapted to their ability and the surface is not allowed to become clogged by organic matter to the exclusion of air.

"With fine soils, containing, in addition to their sand grains, 2 or 3 per cent. of alumina and oxide of iron and manganese and 6 or 7 per cent. of organic matter, we find that, when only 6 in. in depth, resting upon fine sandy material, they retain water so long that the quantity that can be applied is so small, and the interval in which this must settle and drain away to allow air to enter the field is so long, that the amount of sewage that can be purified is very small. When the quantity applied is adapted to its ability, such a filter may give excellent results, quite free from bacteria.

"With greater depth of soil the quantity that can be filtered will evidently become less; and, with the depth of 5 ft. of such a soil, we have found that nitrification did not take place; and, although it was probable that no bacteria came through, the organic matter in the effluent was at the end of two years nearly as great as in the sewage. This soil remained continually so nearly saturated that, when only 5,000 gallons per acre were being filtered daily, although free to drain over every square foot of the bottom, sufficient air could not be taken in to produce nitrification; and the chemical result with this material was, throughout the two years of its trial, nearly the same as would be expected if the filtration had been made continuous instead of intermittent.

"With peat upon the surface of a filtration area, even to the depth of only 1 ft., its imperviousness to liquid, and the quantity that it will retain until it evaporates, renders intermittent filtration impracticable; and a sand area thus covered with peat can be rendered efficient for filtration only by the removal of the peat from the surface.

"The experiments with gravel stones give us the best illustration of the essential character of intermittent filtration of sewage. In these, without straining the sewage sufficiently to remove even the coarser suspended particles, the slow movement of the liquid in thin films over the surface of the stones, with air in contact, caused to be removed for some months 97 per cent. of the organic nitrogenous matter, a large part of which was in solution, as well as 99 per cent. of the bacteria, which were, of course, in suspension, and enabled these organic matters to be oxidised or burned, so that there remained in the effluent but 3 per cent. of the decomposable organic matter in the sewage, the remainder being converted into harmless mineral matter.

"The mechanical separation of any part of the sewage by straining through sand is but an incident, which, under some conditions, favourably modifies the result; but the essential conditions are very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact with the films of liquid.

"With these conditions it is essential that certain bacteria should be present to aid in the process of nitrification. These, we have found, come in the sewage at all times of the year; and the conditions just mentioned appear to be most favourable for their efficient action, and at the same time most destructive to them and to all kinds of bacteria that are in the sewage.

"The coarse sand filtered 117,000 gallons per acre per day for three months, after which the quantity was increased, and averaged for five months 177,000 gallons per acre per day. The purification was less complete for the first month after the change, but in the second and third months it was more complete than with the quantity given above. The fourth and fifth months, however, gave less satisfactory results, showing that the filter was becoming overburdened, and the surface became much clogged with organic matter. The filter was evidently overworked. The other filters, filtering quantities decreasing with their perviousness from 60,000 gallons per acre per day to 9,000 gallons, indicated that they would continue giving as good results indefinitely.

"The results of experiments as to the effect on filtration of exclusion of air, *i.e.*, by continuous instead of intermittent filtration, was that no nitrification takes place, and the effluent gradually becomes worse until it contains as much organic matter as the sewage."

London Experiments.

Valuable as were these results, they still left the question in an all but impracticable form, as the quantity of sewage thus treated was so small. Doubtless this was due to the use of too fine filtering materials, and the high degree of purification arrived at. It therefore became necessary that precise data on a working scale should be obtained; and, with this object, the Main Drainage Committee of the London County Council instituted a series of experiments at the Northern Outfall Sewage Precipitation Works with the most successful results.

Before proceeding further it may be interesting to point out that the general results fully confirm the opinion expressed by myself in 1887, already quoted, as to the biological treatment of the sewage effluent; the only departure from the suggestion then made being the fact that, instead of its being necessary to feed the sewage with any specially prepared organism, we now know that the sewage already contains these in abundance, and that all that is required is to give them free scope under favourable conditions to enable them to fully exert their special function of breaking up the organic matters to any extent that may be desired. Recent experience, however, has shown that by proper preliminary sowing with suitable bacteria, a filter may be much more speedily got into its best working condition.

The experiments made at the Main Drainage Works at

Barking Creek may be conveniently divided into two main groups, viz. :—

(1) Experiments with small filters using various filtering materials.

(2) Experiments with a one-acre filter, using coke breeze only as material.

The latter may again be sub-divided into—

(*a*) Preliminary trials on velocity of passage, &c.
(*b*) Experiments on biological lines.
(*c*) Experiments with doubled means of filling.
(*d*) Experiments with increased facilities for emptying.
(*e*) Experiments on recuperative power.

Series No. 1.

The tanks for filters used in the first series of experiments were built of wood, and were each equal in area to $\frac{1}{200}$th part of an acre. They were four in number, and were filled with pea ballast, coke breeze, burnt clay, and a proprietary material (with gravel and sand) respectively. All four were worked at the same rates and during the same hours. During the first six weeks sewage effluent was passed through at the rate of 500 gallons per square yard per day, whilst from the middle of July to the end of August the rate was reduced to one-half, or 250 gallons per square yard in twenty-four hours. The filtration was intermittently continuous, the filters passing effluent constantly for eight hours daily and resting during the remaining sixteen hours, being allowed to run dry at the end of each day's work. The outlet valve was closed just sufficiently to keep the filters full, the effluent being level with the surface of the filter material.

The whole quantity of effluent passed through amounted to 185,000 gallons, in a total of 2,160 hours, of which the filter worked 484 hours and rested empty 1,676 hours. The average rate, therefore, inclusive of rest periods, was 411,000 gallons per acre in twenty-four hours.

Filter No. 1. Burnt Ballast.—The material for this filter was obtained by burning clay taken from the marsh land adjoining, and was placed in the tank to a depth of 4 ft.

The purification effected by this filter was less than that attained by any of the remainder. The clarification was also less than in the case of the pea ballast and proprietary filters, being exactly the same as effected by the coke breeze. This was undoubtedly owing to the extreme looseness and porosity of the materials. The filtrate was free from putrefactive odour, remaining sweet for many months in either stoppered or open bottles.

Filter No. 2. Pea Ballast.—This filter was filled with Lowestoft shingle, of pea size. The clarification effected in the filtrate was 75 per cent. more than in the case of the burnt ballast. The purification was also greater, the reduction of oxidisable organic matter amounting to 52·3 per cent.

Filter No. 3. Coke Breeze.—This filter was filled with coke breeze to a depth of 4 ft., and 3 in. of gravel was placed on the top to prevent the coke from floating. As far as clarification is concerned, this filter ranked just even with the burnt ballast; but the purification effected was higher than in the case of any of the other materials, the reduction of the oxidisable organic matter in solution amounting to 62·2 per cent. No renewal of the material was required.

Filter No. 4. Sand.—This filter, having an area of 16 square yards, or $\frac{1}{300}$th of an acre, was filled with gravel, walnut size 5 in., bean size $2\frac{1}{2}$ in., pea size $1\frac{1}{2}$ in., and sand 10 in., taken in order from below upwards. It formed part of the compound proprietary filter. The rate at which effluent was passed through was one-half more per square yard than in the case of the other filters, the sand filtration being a preliminary to and part of the treatment by the proprietary article, and the areas of the two portions being together equal to one of the remaining filters, already described.

The clarification effected was much greater than in the case of Nos. 1, 2, and 3, but the purification, measured by the reduction in the amount of oxidisable matter in solution, was considerably less than in the case of the coke breeze, somewhat less than by the pea ballast, and practically the same as by the burnt clay. On two occasions the filtrate became slightly putrid, the results thereby differing from those obtained from any other filtering material employed. Doubtless this tendency to become putrid was to a great extent due to the deficient aëration of the interior of the filter, in consequence of the capillary attraction of the finer particles of sand holding the water, and thus choking the pores when the filter was emptied. This filter had to be repeatedly raked and cleared, whilst 2½ in. of sand were removed and replaced by new on the 11th of July.

No. 5. Proprietary filter.—This filter contained an area of eight square yards, and was filled with 3 in. of gravel, walnut size; 2 in. gravel, bean size; 1½ in. gravel, pea size; 1 in. sand, and 12 in. of the proprietary material; taken in order from below upwards.

The effluent which it received had already passed through filter No. 4 (sand), and had thus been greatly clarified, whilst the dissolved impurity had been removed to the extent of 42 per cent. The rate of filtration was three times that of the other filters, so as to bring up the rate of the combined filter to an equality with the rest. The filter was supplied with perforated pipes leading to the surface for aëration. In general appearance the filtrate from this compound filter was slightly superior to all the others, the clarification effected being a little more than in the case of the sand forming the first portion. The purification effected by this process of double filtration amounted to 61·6 per cent., a figure practically the same as was obtained by the use of coke breeze. None of the filtrates showed any signs of putrescence when kept for lengthened periods in either open or closed bottles.

TABLE 1.

Description of filter.	Average oxygen absorbed in four hours. Grains per gallon.		Average albuminoid ammonia. Grains per gallon.		Average purification effected, as determined by oxygen absorbed.
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.	Per cent.
Burnt ballast	1·881	1·072	0·243	0·125	43·3
Pea ballast	1·881	0·880	0·257	0·142	52·3
Coke breeze	1·881	0·711	0·262	0·103	62·2
Sand	1·725	1·001	0·250	0·132	42·0
Proprietary filter	1·881	0 721	0·267	0·106	61·6

In Table 1 are given the results of numerous analyses made in each case during the months of June, July, and August, 1892.

From the results obtained it appeared that a considerable amount of purification could be effected by any filtering material, the desiderata evidently being porosity and consequent power of re-absorbing atmospheric oxygen. For foul waters sand proved too fine, whilst the burnt ballast used was too coarse. Coke breeze seemed to unite the necessary qualifications, and as it is also a cheap material, it was selected for the further trials on a large scale. There can be little doubt, however, that the question of cost of material should be allowed to decide what should be used for a filter in any given place, since burnt ballast or gravel may be made much more effective by using a greater depth of more finely-granulated material, combined with a slower rate.

In the course of the above experiments, numerous gelatin plate cultivations were made to ascertain the effect of filtration upon the number of micro-organisms present. The number in the tank effluent before filtration, and in the filtrates, were found to vary very considerably, those in the filtrate generally being present in larger numbers; but it soon became apparent that the presence of comparatively fewer or more microbes afforded no indication of the degree of purification effected, the main point being that the presence of a large number of organisms was evidence of the activity of the process of splitting up the organic compounds in the sewage matters passing through the filters. A considerable reduction or a practically complete removal of organisms might have been effected by the use of a finer-grained material and slower filtration, but the object held in view during the experiments was the attainment of the highest degree of speed consistent with such purification as would remove all objectionable characters such as odour, colour, and liability to putrefaction.

Series No. 2.

In the second series of experiments a filter was constructed covering one acre of land. The ground was levelled, and embanked where necessary, and perforated drains laid, meeting in a common trunk for discharge. The filtering material consisted of 3 ft. of pan breeze covered with 3 in. of gravel.

(a) In the first part of the series under notice, the special object of the experiments was rather the ascertaining of the rate at which it was possible to pass effluent through the filter, and not the manner of producing the best results. The filter, however, speedily became clogged, and after the sixth week all the filtrates were putrid. The daily quantity that could be passed fell rapidly, until at the end of twelve weeks the filter was quite useless, being putrid throughout. Valuable information was thus gained, for it was shown that rest and aëration are vital, and also that, in order to obtain the best work from a filter, the quantity poured on it must increase very gradually, so as to permit of the proper biological condition being reached. The rate of working varied from close on one million to a quarter of a million gallons per diem. The filling was during several weeks continued until the water stood 6 in. above the surface; when the filter was emptied this portion ran through without having time for purification, and this fact doubtless aided largely in reducing the efficiency of the filter during this set of experiments.

The analytical results obtained during this period are given in Table 2.

TABLE 2.

DATE.	Average oxygen absorbed in four hours. Grains per gallon.		Average albuminoid ammonia. Grains per gallon.		Average nitrogen as nitrate. Grains per gallon.		Average purification effected on oxygen absorbed.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	
1893.							Per cent.
28th Sept. to 6th Oct...	3·631	2·128	—	—	0·000	0·083	41·0
9th Oct. to 13th Oct. ..	2·884	0·509	—	—	0·029	0·215	82·0
16th Oct. to 20th Oct..	3·295	0·502	—	—	0·029	0·117	85·0
23rd Oct. to 30th Oct..	3·915	1·447	—	—	0·103	0·021	63·0
30th Oct. to 6th Nov...	4·420	1·546	—	—	0·000	0·000	65·0
6th Nov. to 13th Nov..	4·404	1·285	0·394	0·110	0·283	0·203	71·0
13th Nov. to 20th Nov.	4·122	1·125	0·368	0·097	0·299	0·317	73·0
20th Nov. to 27th Nov.	4·336	1·203	0·403	0·091	0·304	0·241	72·0
27th Nov. to 4th Dec...	4·832	1·135	0·457	0·119	0·180	0 175	77·0
4th Dec. to 8th Dec. ..	4·745	1·070	0·435	0·109	0·077	0·080	77·0
11th Dec. to 18th Dec..	3·821	0·979	0·401	0·092	0·021	0·130	76·0
19th Dec. to 23rd Dec..	4·877	1.387	0·393	0·191	0·000	0·000	71·6

ONE ACRE FILTER BED AT THE NORTHERN OUTFALL WORKS, BARKING CREEK.

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(b) The first series of experiments on biological lines, conducted with the same filter as the preceding, was then commenced. The surface was raked, and the bed was allowed to rest during three and a-half months. For fully three months of that time a putrid odour was observable when the filter was disturbed, but this gradually disappeared, and during the last fortnight the coke breeze was perfectly sweet. From that time the filter was kept practically constantly at work for nearly a year, the only rest of any length being from the 17th November, 1894, to the 2nd of January, 1895, when alterations in the arrangements were made to admit of more rapid emptying.

The process adopted was to begin with small quantities, the filter being merely filled and emptied twice daily, with a view to getting it into the necessary biological condition. This was commenced on the 2nd April, 1894, and continued for a few weeks, the purification effected gradually rising. The quantity of effluent passed was about 500,000 gallons per diem, and the purification between 70 and 80 per cent. The highest state of efficiency was reached on the 3rd May, or after a full month's working. The purification reached 83 per cent., and fish placed in the filtrate lived for many weeks. In fact, fish (minnows, &c.) came up the ditch by which the filter was emptied to the very mouth of the outlet.

(c) Alterations were then made in the arrangements for filling, the feeding trough being doubled. The daily quantity was increased to over 600,000 gallons, the analytical results continuing to be highly satisfactory, as shown by the averages of the daily analyses from August 3rd to November 9th, 1894.

(d) Towards the end of 1894 the emptying arrangements were supplemented by a pump to prevent tide-locking, and later the resting time was shortened, until finally the filter passed $1\frac{1}{6}$ million gallons daily for six days, resting empty from 10 p.m. on Saturdays until 6 a.m. on Mondays. The method adopted was to fill the filter to just level with the surface, which occupied an average time of two hours, allow it to remain standing full for one hour, the emptying occupying an average of five hours, thus completing the cycle in eight hours. Working in this way, the filter passed an average of 1,000,000 gallons a day, including all times of rest, during a period of eight weeks, the filtrates being clean and sweet, and the purification effected 78 per cent. Nitrification proceeded satisfactorily, and the filter was apparently capable of continuing for an indefinite time.

A point of the greatest importance is the fact that the filter was able to do its work satisfactorily during the exceptionally severe weather in January and February, 1895. A thin coat of ice was formed on the surface, but the filtration proceeded without intermission, the only noticeable change being the decreased production of nitric acid.

(e) After the filter had been successively dealing with 1,000,000 gallons daily for about eight weeks, a large quantity of sludge, amounting to at least ten tons, was run upon it accidentally. This occurred during the week ending 23rd February. The result was an immediate falling off in the quality of the filtrate; a putrescent odour was observed, and finally the filter had to be thrown out of work. Remarkable evidence of the recuperative power of the coke breeze was, however, obtained, as after twenty days' rest it was quite sweet again, nothing objectionable being observed on digging down to a depth of about 2 ft. The coke had only the odour of ordinary earth when moist, and on being burnt gave no objectionable smell. On resuming work, twenty-eight days after resting, satisfactory results were again obtained.

From this time until the end of September in the same year the filter was kept continuously at work (except during one week in August) on the same system, viz., alternate filling, resting full, and emptying, with twenty-four hours' entire rest each week. The results are shown in the following table; the figures given are averages of daily analyses, each sample being a mixture of quarter-hour samples from each filling and emptying.

In Table 3 are given the averages of the analyses of the samples of the effluent and the filtrate from one-acre filter, composed of 3ft. of coke breeze and 3in. of gravel.

TABLE 3.

DATE.	Quantity of effluent passed daily per acre. Average of seven days.	Average oxygen absorbed in four hours. Grains per gallon.		Average albuminoid ammonia. Grains per gallon.		Average nitrogen as nitrates. Grains per gallon.		Average purification effected, as determined by oxygen absorbed.
		Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	
1894.								Per cent.
Apr. 7 to June 9 ..	500,000	4·096	0·856	0·416	0·095	0·1280	0·2378	79·3
Aug. 3 to Nov. 9 ..	600,000	3·608	0·730	0·396	0·113	0·0223	0·1414	79·6
1894. 1895.								
Nov. 16 to Mar. 2	1,000,000	4·113	0·935	0·382	0·114	0·3956	0·6990	77·5
1895.								
Apr. 8 to Apr. 20 ..	1,000,000	3·512	0·884	0·360	0·102	0·1431	0·7700	75·4
May 4 to Sept. 28	1,000,000	3·233	0·638	—	—	—	—	80·7

The experiments, taken as a whole, show that sewage, especially if previously clarified by precipitation, may be purified to any desired degree, the actual amount of purification depending upon (1) the length of time during which the effluent is allowed to remain in contact with the filter, and (2) the length of time allowed for aëration. If a reduction of 75 per cent. in the oxidisable organic matters in solution be considered as sufficient, the quantity that can be treated per diem on one acre of coke breeze under these conditions is 1,000,000 gallons, which gives a required area for the treatment of the whole of the metropolitan sewage—taken at 180 million gallons—of 180 acres only.

It will be noticed that while the above results show that so large a quantity as 1,000,000 gallons of sewage effluent can be treated per acre per day, the Massachusetts experiments with raw sewage showed that only 60,000 gallons could be continuously treated, so that the effect of the suspended solids in the sewage would increase the area of land required for filter beds constructed in the same manner per 1,000,000 gallons of sewage to 16·6 acres. This area was reduced by Lowcock, by means of his system of pumping air through the filter, to 3·8 acres per 1,000,000 gallons.

SUTTON EXPERIMENTS.

Experiments with Sewage collected on the "Separate System," excluding Rainfall.

By the courtesy of the Sutton (Surrey) Urban District Council, I am enabled to append the following statement of results obtained by similar treatment of the sewage as carried out at the sewage works of that Council. The trials in question were made during the period of office of the late Sutton Local Board, of which authority I was at that time a member, and therefore am able to speak of the results from personal experience. The works were under the direction of Mr. A. D. Greatorex, Assoc. M.I.C.E., Surveyor to the Board.

The filters employed are seven in number, as follows:—

		Square feet each.
Two proprietary, 35 ft. by 20 ft.	area	700
Two coke breeze ,, ,,	,,	700
Two sand ,, ,,	,,	700
		4200
One burnt ballast {142 ft. / 120 ft.} by 34 ft.	,,	4454
Total area		8654

The filters are constructed as follows :—

Proprietary.

Top, 6½ in., medium sand.
3 in., pea gravel.
10½ in., proprietary article mixed with sand.
5 in., extra coarse sand.
4 in., pea gravel.
Bottom, 5 in., coarse shingle round the pipes.

Coke Breeze.

Top, 8 in., medium sand.
12 in., coke breeze.
5 in., extra coarse sand.
4 in., pea gravel.
Bottom, 5 in., coarse shingle.

Sand.

Top, 8 in., medium sand.
12 in., medium sand.
5 in., extra coarse sand.
4 in., pea gravel.
Bottom, 5 in., coarse shingle.

Burnt Ballast.

Top, 4 in., soil (afterwards removed).
6 in., fine ashes.
Bottom, 18 in., burnt ballast.

120,000 gallons of effluent water are passed through the filters per day, working nine hours. The six small filters are worked one day and the large the next day, thus allowing alternate days of rest; the six filters have been at work nearly two years and the large one three months, with the exception of the bad days in winter.

The percentage purification of the oxidisable organic matters effected is shown in the following table, which is prepared from analyses made by Dr. Jacob, Medical Officer of Health for the Sutton District :—

Date 1894.	Proprietary filter.	Coke breeze filter.	Sand filter.
May 2nd	36·4	47·6	31·0
July 13th	51·5	41·0	32·2
July 13th	—	50·0	—
July 13th	—	53·0	—
October 16th	61·0	51·0	30·0
October 16th	54·0	48·0	24·0
November 24th	53·3	14·9	50·0
November 24th	44·2	26·5	51·6
Average	50·1	41·5	36·5

On the 24th April, 1895, Mr. Greatorex kindly collected for me a series of samples of crude sewage, precipitation effluent, and filtrates, the samples being averages of ten hours' working. These were analysed, and yielded the results given in Table 4.

TABLE 4.

24th April, 1895.	Sewage, including suspended matters.	Sewage, excluding suspended matters.	Effluent before filtration.	Burnt ballast filter.	Sand filter.		Proprietary filter.		Coke breeze filter.	
					No. 1.	No. 2.	No. 1.	No. 2.	No. 1.	No. 2.
Oxygen absorbed	8·98	4·29	2·92	2·54	1·13	1·08	1·22	0·85	0·85	0·66
Purification, per cent. on unfiltered effluent	—	—	—	13·0	61·30	63·00	58·30	70·00	70·90	77·40
					62·1		64·6		74·1	

From the first table of the results obtained at Sutton, it would appear that the proprietary filter gave the best results; but this was caused by the lower rate at which this filter worked, as, in many instances, in consequence of the finer grain of material and frequent choking, the quantity passing through the bed was far less than that passed by the remaining filters. In the case of the experiments conducted at Barking Creek, the rates of flow were maintained at equal speed. In the second table of Sutton results, however, the coke breeze filter excelled all the others, the proprietary and sand filters being very close together.

From the above results it appeared that the burnt ballast filter had been overworked, and required a short period of rest, as a former result was exceedingly satisfactory.

In his report of the 18th July, 1894, Dr. Jacob stated that the effluents from the various filters were quite fit to be discharged into the brook without further treatment.

At the present time the coke breeze filter is working satisfactorily, and still remains the best.

SUMMARY.

The action of a filter is two-fold. (1) It separates mechanically all gross particles of suspended matter, and renders the effluent clear and bright. (2) It effects the oxidation of organic matters, both those in suspension and those in solution, through the agency of living organisms. It is the establishment and cultivation of these organisms which is to be aimed at in the scientific process of purification by filtration.

Three conditions are essential. First, the organisms must be supplied with plenty of air; secondly, there must be present a base, such as lime, with which the nitric acid can combine; and, thirdly, the biological action must take place in the dark, *i.e.*, in the body of the filter and not in the water exposed to the light above the filtering material. Filtration on biological lines of sewage or other foul water containing in solution but little free oxygen and a large quantity of oxidisable organic matter, therefore, means:—

(1) That the filter, by cautious increments in the quantity of effluent, which in itself contains the necessary organisms, must be gradually brought to a state of high efficiency. This condition will be shown by the existence in the filtrate of a constantly increasing proportion of nitric acid.

(2) That the contact of the micro-organisms with the effluent to be purified must be effected by leaving such effluent to rest in the filter for a greater or less time, according to the degree of purification required, the process being analogous to that of fermentation.

(3) That after each quantity of effluent has been dealt with the micro-organisms must be supplied with air, which is readily effected by emptying the filter from below, whereby air is drawn into the interstices. The filter must

stand empty for an hour or more previous to another filling, and a longer period of aëration, say twenty-four hours, must be allowed every seven or eight days.

The life of a coke breeze filter worked in this way is practically without limit.

From the general results obtained by these several trials under various actual working conditions, it is apparent that there is no difficulty in obtaining any desired degree of purification by means of a system of filtration conducted on biological principles. If a higher degree of purity be required than that indicated by the foregoing, it can be obtained by an augmentation of the filtering appliances at a comparatively small cost, as, where clay is obtainable, the method of construction employed in making the new burnt ballast filter bed at Sutton may be adopted, viz., by simply digging out the clay to form a pit about 3 ft. deep, and filling it up with the same clay after burning, and thus a cheap and efficient filter bed is obtained, the cost of the large filter bed at Sutton, having an area of 4,454 square feet, or rather more than one-tenth of an acre, being less than 100*l.*, including all charges.

By such a system the necessity for costly farms is entirely obviated. The results are completely under control, and the filters can be arranged to suit all requirements it is possible to contemplate.

The following is a summarised statement of the work accomplished by the one-acre coke breeze filter at the Northern Outfall, between September, 1893, and November, 1896, during which period it had filtered 500 million gallons of effluent. Since the effluent, which is passed on to the filter, contains, on an average, seven grains of suspended matter per gallon, a quantity equal to 2,232 tons of sludge, of 90 per cent. moisture, has been entirely removed, the filtrate containing practically no suspended matter. Of the matter thus removed about 110 tons were organic, the whole of which has been oxidised; whilst the sand amounted to about 40 tons, which, calculated at 24 cwts. per cubic yard, would cover the filter to a depth of 0·267 in. if spread equally over its surface. Such sand has, however, been carried into the body of the coke, and at present there is no appearance of any danger of choking arising from this cause. The organic matters in solution in the crude effluent absorb, on an average, 3·5 grains per gallon of oxygen from permanganate in four hours, while the filtrate absorbs only 0·7 grain. The amount of oxidation effected, measured in this way, would require 90 tons of oxygen, or, in other words, is equal to the effect which could be obtained by the use of about 2,000 tons of good commercial manganate of soda. The organic matter in solution that has been completely removed, as determined by the difference between the loss on ignition of the solids in the crude effluent and the filtrate respectively, amounts to 250 tons; making, with the 110 tons of suspended organic matter, a total of 360 tons. The organic matter that remains in the filtrate is in such a condition that no signs of after-putrefaction are exhibited, however long the filtrate may be kept, either undiluted or diluted, in open or closed bottles.

CHAPTER V.

NATURE'S METHOD AT WORK—NEW DEPARTURE AT SUTTON, SURREY.

In view of the results detailed in the previous Chapter, I concluded that under proper conditions there was no reason why the whole of the suspended matters in the sewage should not be amenable to similar treatment, and therefore ventured to recommend my Sutton friends to try the experiment by filling a tank with coarse burnt ballast and running the crude sewage upon it. This suggestion was taken up, and on November 21st, 1896, the "bacteria tank" was filled for the first time, since when it has been kept constantly at work. The results of the first two and a half months' work were embodied in the following report made by me to the Sewage Disposal Committee of the Sutton Urban District Council on February 11th, 1897 :—

"As the experimental bacteria tank which I suggested in October last has now been at work for nearly three months, it will be of interest to your Committee to have the results before them for their guidance, and I therefore submit the following remarks on the present position.

"By the courtesy of your surveyor, Mr. Chambers Smith, C.E., under whose superintendence the tank was constructed, I am able to combine the details of the quantity of the sewage treated, &c., with the chemical results of that treatment.

"The tank, charged with burnt ballast, was prepared for the reception of the sewage by inoculating it with bacteria; my former experiments having shown that such preliminary treatment contributed materially to better work.

"The tank was first filled on the 21st November with the raw sewage (untreated with chemicals), which had been strained through a screen to intercept the grosser particles.

"The total quantity of sewage treated during the period of seventy-six (76) days was 2,216,000 gallons, equal to an average of 29,165 gallons per day, or 773,000 gallons per acre per day, rest period included.

"The results obtained have been of the most satisfactory character. The quantity of oxygen required to oxidise the organic matter in solution on the raw sewage was, on an average, 5·40 grains per gallon, which was reduced by the bacteria tank to 1·83 grains, or a reduction of 66 per cent. The further treatment of this effluent by the coke-breeze and other filter beds reduced this required oxygen to 0·72 grain per gallon, or a total reduction of the oxidisable matter by 86·5 per cent.

"In like manner the solid matters held in suspension in the sewage were reduced by the bacteria tank by 95 per cent., and by the combined system by 99·6 per cent.

"With the exception of the few days when the filter was overworked, the sewage odour was completely removed, there being in the effluents only an earthy odour similar to that of fresh-turned garden soil.

"It appears from these results that a bacteria tank or tanks of an area of half-an-acre will be sufficient for the complete disposal of the sludge by this system, without any expense for labour other than that necessary for turning on the valves and raking over or digging with a fork the surface of the ballast from time to time as may be required to break up the surface coating of fibrous matter. Up to the present time this has been found to be necessary on only two occasions, the second being at my visit to the works on the 6th instant.

"It may be remarked that the quantity of suspended solid matters in the sewage which has been disposed of by the bacteria during the seventy-six days they have been at work is equal to 77 tons of sludge, as the average sewage contained 54·5 grains of suspended matter per gallon. The fact that this quantity has disappeared without cost or nuisance is striking evidence of the capabilities of the process.

"It will be interesting to note the financial results of the adoption of this system for the treatment of the whole of the sewage at Sutton, estimated at about 400,000 gallons per day. I understand that at present the cost of chemical treatment, labour, sludge-pressing, farm, &c., is about 1,200*l.* per annum, or over 4*d.* on the rates. As practically the whole of this would be saved, this amount represents a capital sum, at 3½ per cent., of 34,000*l.*, or more than half the total cost of the sewerage system of the town.

"I need hardly say that I feel peculiar pleasure in having been able to point out to the District Council a means by which such a desirable result can be attained, at a capital cost which may be met by the first half-year's economy effected in the mere working expenses, and thus to present to the community at large, in the year of Her Majesty's Jubilee, the solution of a problem the monetary value of which may be reckoned in England alone, on the assumption that one half of the sewage of the country is thus treated, at not less than 60,000,000*l.* sterling.

"As soon as the new and larger bed in course of construction is at work, and the remainder of the precipitating tanks are filled with ballast so as to turn them into bacteria tanks, their united capacity will probably be sufficient for the whole of the flow from the high-level sewer; and it will only remain to construct similar beds for the low-level sewer, when the whole cost of pumping will be avoided and the alteration in the system complete.

"The importance of this method in the case of new sewage works is evident, as the whole of the elaborate machinery for chemical treatment, sludge pressing, farming operations, &c., will be avoided; and where such farms exist, as in the case of Sutton, these may be utilised for the purpose of a recreation ground, and so settle a question of no little importance; as, by the utilisation of the life processes of bacteria, the effluent from the double set of beds is more fitted for discharge into the brook than if it were allowed to run over the land, which may then be used for other purposes.

"Of course, the objection will doubtless be raised that the experiment has had only some three months' trial during the winter season. This fact is perhaps one of the most hopeful in connection with the experiment. When the temperature is higher the bacteria will be more active, and the work proceed at a greater rate."

Up to the present the "bacteria tank" continues to work with undiminished success.

Thus encouraged, the District Council gave orders for a second precipitating tank to be turned into a similar bacteria bed for treating crude sewage, and it is in contemplation to gradually extend the system to the whole of the daily flow of some 400,000 gallons per day.

The following is a short résumé of the results of the working of this bed during the first seven months :—

The analytical results are as follows, but it must not be overlooked that these are but the final results of the degree of purification, and to them must be added the substantial fact that all *uncertainty* of work is obviated, chemicals unknown, and sludge-presses and their expensive working, *Quantities stated in Grains per Gallon (except Residue*

—	Crude Sewage.								Effluent		
Date.	Chlorine.	Oxygen Absorbed in Four Hours.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Free Ammonia.	Albuminoid Ammonia.	Suspended Matter.	Residue on Micro Filter per Litre.	Chlorine.	Oxygen Absorbed in Four Hours.	Nitrogen as Nitrites.
1896 November 21	..	3·291	..	..	..	..	..	..	..	2·531	..
,, 30	..	5·200	..	..	..	..	..	..	..	1·060	..
December 8	..	4·760	..	..	..	..	..	..	..	2·340	..
,, 21	..	7·677	..	..	..	..	..	2,400	..	1·225	..
1897 January .. 4	..	2·380	..	..	..	..	..	1,800	..	1·496	..
,, 12	..	5·578	..	..	..	..	..	3,000	..	1·904	..
,, 18	..	7·711	..	..	..	..	..	2,700	..	2·372	..
February 1	..	6·590	..	..	..	..	..	4,500	..	1·720	..
,, 8	5·95	5·540	0·155	0·002	2·810	0·330	108·80	2,700	5·95	1·824	0·630
,, 15	6·30	1·911	0·022	0·000	2·700	0·258	15·06	1,400	6·30	0·588	0·159
,, 22	6·40	3·815	0·000	0·000	3·906	0·245	29·90	1,900	5·20	1·381	0·084
March .. 1	8·05	4·248	0·021	0·000	7·770	0·602	28·14	1,900	8·05	2·222	0·021
,, 8	6·00	2·993	0·015	0·000	4·197	0·680	13·58	800	5·40	1·146	0·061
,, 15	11·10	4·941	0·000	0·000	13·600	1·260	29·62	1,800	5·60	1·860	0·098
,, 22	8·40	4·727	0·000	0·000	11·464	1·700	22·73	3,400	8·40	3·000	0·420
,, 29	23·10	8·312	Trace	Lost	51·700	1·300	..	3,400		(	Lost—
April .. 5	7·00	3·209	0·000	0·000	4·860	1·330	20·72	2,200	6·30	0·679	0·196
,, 20	9·00	2·495	0·000	0·000	6·210	0·750	25·55	3,000	7·70	0·720	0·308
,, 26	8·20	3·628	0·000	0·000	4·700	0·600	241·10	10,000	6·80	0·967	0·072
May .. 3	8·00	3·480	0·000	0·000	5·250	0·570	51·85	1,800	7·50	1·044	0·113
,, 10	10·00	4·587	0·010	0·000	5·663	0·994	56·16	3,100	7·30	1·284	0·051
,, 17	9·20	2·999	0·000	0·000	3·264	0·590	54·25	2,600	8·50	2·727	0·000
,, 24	8·20	4·425	0·000	0·000	3·500	0·670	139·98	5,600	8·20	2·743	0·103
Averages..	8·99	4·543	0·015	0·000	8·774	0·792	60·03	3,000	6·91	1·674	0·165

on Micro Filter, which is stated in Millimetres per Litre).

from Bacteria Tank.					Filtrate from Coke-Breeze Filter.							
Nitrogen as Nitrates.	Free Ammonia.	Albuminoid Ammonia.	Suspended Matter.	Residue on Micro Filter, per Litre.	Chlorine.	Oxygen Absorbed in Four Hours.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Free Ammonia.	Albuminoid Ammonia.	Suspended Matter.	Residue on Micro Filter, per Litre.
..	..	..	..	..	..	0·316	..	..	..	..	..	..
..	..	..	..	..	..	1·400	..	..	..	..	..	..
..	..	..	..	..	..	0·939	..	..	..	..	..	..
..	..	..	..	75	..	0·580	..	..	..	..	..	Trace
..	..	..	..	260	..	0·748	..	..	..	..	..	12
..	..	..	..	150	..	0·476	..	..	..	..	..	19
..	..	..	..	150	..	0·677	..	..	..	..	..	25
0·450	..	..	..	250	..	..	..	..	..	..	..	..
None	2·840	0·320	3·20	25	5·60	0·675	0 053	2·714	0·140	0·270	0·800	Trace
0·112	1·350	0 118	3·45	75	5·95	0·294	0·022	0·505	0·060	0·081	0·860	25
0·539	1·337	0·128	3·73	250	6·20	0·657	0·049	1·606	0·165	0·090	2·370	25
0·000	3·860	0·304	2·83	12	5·95	0·457	0·035	1·495	0·135	0·072	Trace	Trace
0·573	0·980	0·305	1·60	125	5·40	0·764	0·033	0·601	0·112	0·190	1·230	Trace
1·746	1·275	0·325	1·11	25	5·40	0·639	0·049	2·210	0·116	0·116	0·800	Trace
0·000	3·615	0·590	2·62	450	7·50	0·772	0·059	0·758	0·930	0·290	0·617	25
Bottle	Broken.)				7·70	0·437	0·059	..	0·333	0·200	..	12
0·798	0·685	0·340	1·30	50	6·00	0·185	0·084	1·602	0·116	0·110	0·650	None
1·435	0·780	0·175	1·10	37	6·70	0·472	0·056	2·357	0·050	0·083	0·430	12
0·000	2·015	0·040	6·20	100	7·60	0·646	0·010	0·537	1·226	0·166	Trace	Trace
0·245	1·455	0·225	4·44	150	8·00	0·870	0·113	0·187	2·233	0·016	1·600	25
0·000	3·325	0·490	1·97	200	8·40	1·009	0·010	0·000	3·752	0·252	0·430	100
0·180	3·981	0·850	4·53	800	7·70	0·363	0·026	0·154	0·300	0·500	0·370	75
0·136	1·950	0·400	0·86	860	8·50	0·796	0·041	0·227	0·460	0·120	Trace	86
0·411	2·103	0·329	2·78	213	6·84	0·644	0·047	1·068	0·671	0·170	0·725	23

and the subsequent disposal of the sludge cake are absolutely annihilated.

From the average results of these analyses, it is seen that the matters in suspension in the crude sewage were reduced in the filtrate from the bacteria tank to 2·78 grains per gallon, and were still further reduced to 0·725 grain per gallon in the final filtrate from the coke-breeze filter.

The reduction of the oxidisable matters in solution was from 4·543 to 1·674, and then to 0·644 grains per gallon, thus showing an average reduction equal to 63·16 per cent. by the bacteria tank, and a total reduction equal to 85·83 per cent. by the combined beds.

The reduction of the nitrogenous organic matters, as indicated by the albuminoid ammonia, was in like manner 58·45 per cent. by the bacteria tank, and 78·54 per cent. by the combined system.

The final filtrates were free from all objectionable odour, and remained perfectly sweet on keeping in either open or closed vessels.

The table of analyses discloses some very instructive features in regard to the degree of nitrification when the filters were being overtaxed, some of them having been purposely worked up to a rate of nearly three millions of gallons per acre per day, with the result that the bacterial action was evidently checked by the decrease in the production of nitrates, and an increase in the normal quantity of organic constituents in the effluent. As the result of careful watching, however, no permanent harm was done, as the filters were immediately restored to their usual condition, when they proceeded to give good results.

Many suggestions have been made both in England and America to effect the purification of sewage on a working scale, and in sufficient quantity, by aiding the oxidising bacteria by blowing streams of air through the filter bed.

The effect of this is to save on one hand, and to expend on the other. In the case of the Sutton works no air enters the filter other than that caused by the natural process following the drawing off of the water, when of necessity the pores of the ballast must be re-charged with a supply of the revivifying oxygen.

Another collateral advantage of the extension of the system will be that the sewage brought to the lower part of the works by the low-level sewer can be treated direct on beds provided at that level, and thus the expense of pumping the sewage up to the high-level tanks will be obviated.

It will doubtless not be a very difficult task to arrange for the filling and emptying of the beds at periodical intervals by automatic changing gear, as also the clearing of the screens. At Exeter, as will be seen later on by the kindness of Mr. Donald Cameron, the City Surveyor, such a scheme is in operation in connection with the septic tank process.

The combination of mechanical skill with the bacteriological and chemical sciences is thus rapidly working towards an advance in the progress of sanitation quite in keeping with the signs of the times. It is not wise to be too sanguine, but the outlook is such that it may well be hoped that in a few years all the old ideas of precipitation, farming, &c., will be as completely swept away as the extinct Dodo, and sewage works will have nothing more offensive or objectionable in character about them than has a market garden.

CHAPTER VI.

THE EXETER "SEPTIC TANK" SYSTEM.

It will be remembered that in the last chapter I mentioned that the septic tank system, introduced by Mr. Cameron, at Exeter, would be referred to later on. After careful investigation of this process, I am enabled to place before my readers the following observations upon it.

During the months of April and June last the process was under direct inspection, with the following results.

The engineering features of the system are simplicity itself. In the first place, the sewage, without any preliminary treatment, such as screening, &c., flows direct into a covered tank, having a capacity equal to about eighteen hours' flow of the sewage. Through this it passes slowly, depositing the heavy matters carried in suspension, leaving only the lighter ones to pass onward with the water by an outflow to the coke-breeze filter beds, which are constructed on the same plan as those in use at the Barking and Sutton Works, and which have been already fully described.

One of the chief features of the plan is that the discharge of the tank effluents to the coke-breeze filters is arranged to work automatically by an ingenious system of syphons and overflows into buckets, which fall, when full, and in so doing re-set a series of penstocks, which stop the flow to the full filter, turn it on to another standing empty ready for work, and empty a third, which has been resting full. Thus, the work is carried on day and night without any attention whatever.

The preliminary examination and collection of samples extended over two periods of a week each. On Friday, the 2nd April, the plant was inspected and various samples taken for examination as to appearance and odour. On the 3rd April another inspection was made. During the following week, from the 5th to the 10th April inclusive, samples were taken every fifteen minutes from the crude sewage and the tank effluent in quantities proportional to the flow at the time; samples were collected from each filter discharge one minute, three, six, twelve, and twenty minutes after the commencement of the flow; and from these average samples were prepared, representing the crude sewage with the tank effluent and filtrate derived from it, during four periods of twenty-four hours each. These samples were subjected to a preliminary analysis, with the results set forth in the accompanying tables.

The weather during this period was very wet and unsettled, and a considerable quantity of land water was entering the sewer. The measurements taken at the V-notch at the outlet of the septic tank showed the daily quantity of sewage treated to be about 70,000 gallons.

A careful series of tests was made with a view to ascertaining whether the biological action within the tank caused any alteration of temperature; this, however, did not occur, the average temperature of the outgoing tank effluent being the same as that of the incoming sewage. The average temperature of the filtrate, however, 48 deg. Fah., was 0·7 deg. Fahr. higher than that of the crude sewage or tank effluent.

A microscopical examination was made of a sample of the leathery scum from the surface of the sewage in the septic tank. It consisted of granular *débris* with various organic remnants, such as the larva of an insect, spiral vessels, vegetable hairs, decaying entozoa, worms (Anguillulæ), decaying confervæ and muscular fibre, the whole matted together into a gelatinous mass and swarming with bacteria of various kinds.

During the second period of sampling, the land water was excluded, and the weather was far more favourable, both by absence of rain and by the temperature being better adapted to the wants of the microbes in the filters. The following table, for which I am indebted to Mr. Martin, assistant surveyor to the Exeter Corporation, shows the rainfall during the month of June, the sampling having extended from the 15th to the 23rd.

June 1st	0·09	June 16th	0·00
,, 2nd	0·00	,, 17th	0·09
,, 3rd	0·00	,, 18th	0·02
,, 4th	0·00	,, 19th	0·30
,, 5th	0·00	,, 20th	0·00
,, 6th	0·00	,, 21st	0·00
,, 7th	0·00	,, 22nd	0·00
,, 8th	1·34	,, 23rd	0·00
,, 9th	0·07	,, 24th	0·00
,, 10th	0·00	,, 25th	0·00
,, 11th	0·00	,, 26th	0·39
,, 12th	0·00	,, 27th	0·03
,, 13th	0·00	,, 28th	0·30
,, 14th	0·00	,, 29th	0·00
,, 15th	0·01	,, 30th	0·00

The daily flow of sewage from the 16th to the 22nd, on the same authority, was as follows:—

5.45 p.m., June 16, to 5.45 p.m., June 17	49,392	gallons.
,, ,, 17 ,, ,, 18	61,690	,,
,, ,, 18 ,, ,, 19	58,220	,,
,, ,, 19 ,, ,, 20	69,514	,,
,, ,, 20 ,, ,, 21	47,158	,,
,, ,, 21 ,, ,, 22	44,731	,,
Average daily flow	55,117	,,

During this period eight samples of crude sewage, nine samples of tank effluent, and fifteen samples of filtrate were collected, many of them being average samples, prepared by mixing quantities proportional to the flow, taken during each hour of the day and night, or, in the case of the filters, from each discharge. These samples were duly analysed, with the results set out in the annexed tables. It will be observed that no estimation of nitrites and nitrates was made in the crude sewage or tank effluent samples, such examination being superfluous. In the filtrates, on the other hand, the suspended matter was not determined, being so small as to be negligible.

The general results of the examination are eminently satisfactory. By the biological action in the septic tank itself, the organic matter in the sewage was so changed that the amount of oxidisable organic matter in solution was reduced by 30·8 per cent., the free ammonia by 26·9 per cent., and the albuminoid ammonia by 17·5 per cent, and the suspended solids by 55 per cent. The condition of the organic matter remaining was also changed, rendering it more easily broken up. The result of the work done by the united processes of septic tank and coke breeze filters was an average diminution of dissolved oxidisable organic matter equal to 80·9 per cent., of free ammonia 54·9 per cent., and of albuminoid ammonia 63·2 per cent., and, practically, the whole of the suspended matter was removed. Nitrous and nitric acids were also formed, the consistent manner of their production showing the satisfactory conditions of work obtaining.

The filtrates were all fairly bright and clear, and fit to be at once discharged into a river or stream, even of relatively very small volume; and none of them showed any signs of putrefaction or offensive secondary decomposition on keeping.

It is to be noted that on both occasions of the inspection of the works, although there was a considerable evolution of gas, no trace of sulphuretted hydrogen was detected, there being practically an entire absence of odour from the gas as it issued from the burner placed on the top of the septic tank.

Septic Tank System of Sewage Treatment.—Exeter (Belleisle) Installation. —Summary of Analyses.

April and June, 1897.	Grains per gallon.											
	Oxygen absorbed from permanganate in four hours.	Ammonia.		Chlorine.	Nitrogen.		Suspended solids.			Dissolved solids.		
		Free.	Albuminoid.		As nitrites.	As nitrates.	Total.	Mineral.	Organic.	Total.	Mineral.	Organic.
Crude sewage, average of 12 samples ..	2·028	3·778	0·212	5·0	—	—	24·5	10·0	14·5	29·9	14·0	15·9
Tank effluent, average of 13 samples..	1·405	2·763	0·175	5·1	—	—	10·8	3·5	7·8	30·7	16·1	14·6
Purification per cent.	30·8	26·9	17·5	—	—	—	—	—	—	—	—	—
Filtrate, average of 19 samples	0·388	1·705	0·078	5·3	0·253	0·353	Practically nil.			44·5	20·3	24·2
Purification on tank effluent per cent.	72·4	38·3	55·5	—	—	—	—	—	—	—	—	—
Purification on crude sewage per cent.......	80·9	54·9	63·2	—	—	—	—	—	—	—	—	—

I made a careful series of measurements to ascertain the depth of deposit at the bottom of the tank, which had not been emptied, or in any way cleared out, since it was started on the 15th August last, exactly six months previous to the date of inspection. The result was to show that the line of demarcation between sludge and water was about 15 in. from the bottom of the tank. At the first or grit-intercepting chamber, which forms part of the septic tank, there was about 2 ft. of grit in one corner but very little elsewhere, so that it is evident that the efficiency of the tank in this respect had not been in any way impaired by the ten months' work. It is evident, moreover, that when the deposit becomes so deep as to interfere with the flow, its removal will be a matter of mere detail, and in no way constitutes a valid objection to the system.

From the analyses of the crude sewage, it will be seen that the average quantity of suspended matters present was 24·5 grains per gallon. As the tank effluent contained an average of 10·8 grains, 13·7 grains per gallon must have remained in the septic tank. As the average daily quantity of sewage during the ten months was (Mr. Martin) 57,000 gallons, the total quantity of suspended solids arrested in the tank will have been equal to 150·7 tons of sludge of 90 per cent. moisture.

As the tank effluent contained 10·8 grains per gallon and the coke breeze filtrate practically no suspended matter, it is evident that at least ten grains must have been arrested or rendered soluble by the bacterial action in the filters, thus accounting for 110 tons of sludge during the ten months.

Summarising the general results of this examination, it is clearly demonstrated that equally with the Sutton system, this process is well adapted from the chemical and biological point of view for the efficient treatment of crude sewage without the aid of chemicals, sludge presses, &c., and that by the combined system of tank and filter, a resulting final effluent is obtained from the Exeter (St. Leonards' District) sewage of a most satisfactory character, having full regard to modern requirements.

It yet remains to be seen how the process is adapted for the treatment of sewage from manufacturing districts, but having regard to one's general experience, I see no reason why it should not be applicable in a large number of cases. It will be understood that in this, as in other cases, I am not concerned with the purely engineering features of the principle, and have therefore strictly confined my observations to the biological and chemical aspects of the case. It may be remarked, however, that the mechanical automatic changing gear was working well and easily during the periods of the inspections referred to, and I was much pleased with the simplicity and ingenuity of the method, which is well calculated to overcome an important point in connection with most systems of sewage treatment, viz., the reliance upon unskilled labour under all conditions of weather and seasons.

CHAPTER VII.

ANALYTICAL METHODS SUITABLE FOR WATCHING THE PROGRESS OF THE PURIFICATION OF SEWAGE.

When a process of sewage treatment has been adopted it is necessary to watch the operation very carefully, in order to ascertain from time to time whether the work is being effectually carried on. The usual tests by eyesight and smell are of course the first to suggest themselves, and, so far as they go, are undoubtedly of great importance. These, nevertheless, however useful as guides for any particular individual, do not admit of accurate registration in such a manner as to enable a second or third person to make comparison with similar tests instituted by him, and, therefore, some means are required by which this can be done; hence the first necessity for analysis, which in this sense may be looked upon as a process by which quality can be recognised at a subsequent date by the inspection of written records. In the second instance, analysis goes much beyond this elementary use, as it enables us to ascertain the quantity of invisible, and, for the time, inodorous impurities, but which will subsequently, under certain conditions, develop offensive qualities. By chemical analysis we thus measure the invisible, and are able to gauge the capacity of the future in respect to the ultimate condition of our effluent.

It is therefore clear that the useful and necessary guides of appearance and smell are insufficient to indicate when matters are in a critical state and the process is in danger of breaking down. Under present working conditions there may frequently come a time when a filter will require rest, and if this is not given at the proper moment the bed will eventually have to be put out of action for a still longer period than would have been necessary if it had been given a shorter rest for a few days before it became overworked. How, then, can we ascertain the degree of purification which is being effected, and, consequently, the arrival of the critical point when rest becomes necessary? This can only be done by methods of chemical analysis, which, however, need not be of a very extensive character. If the following directions be carefully attended to the student will have no difficulty in speedily obtaining the requisite skill to enable him to follow the progress of the operations with the certainty and precision born of knowledge.

In this connection one cannot refrain from remarking upon the blindness of Local Authorities in the past, and to an almost equal extent at the present time, in failing to avail themselves of the means here suggested. Numbers of Authorities have spent large sums of money upon all but useless analyses by chemists, who have looked at the works once or twice and then reported that a particular sample taken at perhaps a particularly favourable or unfavourable moment contained so and so. Such a system of inspection is, in many cases, worse than worthless, as it cannot possibly record the ever-varying changes which occur with so complex an organic mixture as sewage and sewage water, which varies from hour to hour. What is wanted on each works is a practical man trained in analytical chemistry, whose duty should be—under skilled supervision—to superintend the collection of samples, to submit them to analysis, to give instructions to the works foreman as to varying the details of the daily routine of manipulation, &c. It should also be his duty to carry out such experimental operations as he may be able to suggest from a study of the experiences of others as well as those of himself; and thus, by the mutual co-operation of one with another, there would grow up such an accumulated stock of ripe knowledge concerning the whole system of sewage purification and of collateral subjects that the advance would be great and speedy, to the benefit, both sanitarily and pecuniarily, of the ratepayers.

The expense of such a system would be but trifling compared with the many thousands of pounds sterling spent upon unnecessary works erected in consequence of our want of that very knowledge which such a staff of men would supply.

Local Authorities need not be frightened at the expense of carrying out such a suggestion. The practice hitherto prevailing of appointing a foreman to turn on the valves and to drive an engine, and to report any uncanny outlook to the Town Surveyor—who will, when worried out of his wits by cantankerous councillors, probably consider him a nuisance for his pains—will become a thing of the past, and must necessarily do so, if the most economical and perfect method of treating sewage is to be successfully carried out in the future. If the work is to be trusted to men ignorant of the first principles of the duty entrusted to them, failure will be directly invited; and no one will be to blame except those in authority who thus deliberately throw away the teachings of science. Remember, reader, *science* is only another name for *systematic knowledge;* the present-day cant use of the word is misleading many, who are loudest in exclaiming against that which they will not or cannot understand.

Hitherto the one great difficulty in the way of success is the persistence of authorities in placing in charge of what, after all, is a delicate chemical and biological process, men who, however intelligent, willing and honest they may be, have not had the training required for that systematic supervision so essential in all operations conducted upon scientific principles. Instead of appointing to the charge of a sewage works young men trained in practical chemistry and biology —of whom there are hundreds seeking for this class of work, and who have, or could soon obtain, ample mechanical knowledge for all that is required on any sewage works—an average intelligent foreman is selected because he knows how to drive an engine, but is utterly destitute of the most elementary knowledge of the principles upon which he is working; and after a time the essential work, namely, the purification of sewage, is treated as a subsidiary matter, and everyone wonders what can be the reason why, although the bricks and mortar and the machinery, and the farm, are still in evidence, the process has failed. There cannot be too plain speaking upon this matter. It has for years been a standing evil, and many who have had to do with sewage treatment have keenly felt the disadvantages they have been labouring under when they see a delicately worked out process handed over to the fumbling of a farm labourer, or superannuated foreman, or an engine driver without the slightest knowledge of the real engine which he has to drive, namely, the process entrusted to his charge.

Let those in authority ask themselves, "What would become of a brewery if entrusted to the management of a man who knew nothing of brewing?" or of a foundry; or, in fact, of any ordinary business, if placed under the direction of one who knew nothing of the scheme underlying his work? The remedy is obvious. If you want to brew—appoint a brewer. If you want engineering—appoint an engineer. If you want a chemical process properly carried out—appoint a chemist, and make him directly responsible for the results of his work. If special mechanical or other assistance be required from time to time, let it be called in and utilised with thankful acknowledgment.

In connection with the analysis of sewage, the points which it is desirable to ascertain are:—First, the quantity of oxidisable organic matter in the sewage and in the effluents; second, the quantity of matters held in suspension in each case, but especially in the effluent; third, the quantity of nitrites and nitrates in the effluent. These three points constitute the keystone of the whole process, and when properly ascertained on samples collected in such a manner as to fairly represent the *average* daily flow, will enable the person—if qualified to understand them—responsible for the proper conduct of the work to keep the various filters or "bacteria beds" in the best possible condition.

The apparatus required for the various operations necessary for this purpose is as follows:—

For the "oxygen absorbed."

1 doz. 10 oz. stoppered bottles, white glass.
2 10 c.c. pipettes.
1 50 c.c. burette on stand.
2 70 c.c. flasks marked on neck.
1 500 ,, ,, ,,
1 1000 ,, ,, ,,
6 qt. white glass wide-mouthed stoppered bottles for reagents.
1 500 c.c. tall measure, divided into 10 c.c.'s.
1 lb. pure permanganate of potash.
1 lb. ,, thiosulphate of soda, commonly known as "hyposulphite."
¼ lb. pure iodide of potassium.
¼ lb. starch (rice).
1 w. qt. pure sulphuric acid.
Small chemical balance, set of weights (1 milligramme to 50 grammes), constant temperature chamber, or Hearson's incubator, with thermostat for gas, or a regulator for oil lamp.

PREPARATION OF SOLUTIONS.

Into a Winchester quart bottle put 1800 c.c. of the purest water obtainable; distilled water, though preferable for all these operations, is not necessary.

To this bottle add 200 cubic centimetres of the strong sulphuric acid, taking care that the acid is added slowly, so as not to unduly increase the temperature of the water at the bottom of the bottle, to which the heavy acid will at once fall if the water is not kept moving, and thus run the risk of breakage. The best way is to make the water in the bottle swirl round, and then add the acid a little at a time. It is, of course, safer to make this mixture in a china pan. Now prepare a solution of permanganate of potash by adding a few crystals of the permanganate to a small quantity, say 50 cubic centimetres, of clean water, and when dissolved pour into the mixture of sulphuric acid and water until it is distinctly *tinged* with the colour of the permanganate, and remains so tinged on standing for some hours. As a very little will be required, according to the quality of the water and acid employed, the operation must be carefully performed. The object of this process is to ensure the complete oxidation of any nitrites and other absorbents of oxygen which might be present in the water, and thus to prepare a dilute solution of sulphuric acid free from any ingredients which might interfere with this method of analysis. Label this bottle "10 per cent. by Volume Sulphuric Acid."

Into another Winchester quart bottle filled with pure water put some permanganate solution in the same way, just sufficient to tinge the water red. Label this bottle—"Permanganated Water for Analysis."

Weigh out on the balance 3·94 grammes of the permanganate crystals, and dissolve them in half a litre of the "permanganated water," previously filled into a litre flask. When dissolved, make up the solution to one litre by the addition of sufficient permanganated water. Pour it into a glass quart bottle, and label it—"Standard Permanganate Solution, 1 c.c. = 1 mgrm. Oxygen." As the 3·94 grammes of permanganate will yield 1 gramme of oxygen, and that quantity is dissolved in a litre, or 1000 c.c. of water, it follows that 1 c.c. of that solution will yield one-thousandth of a gramme of oxygen or 0·001 gramme, usually called a milligramme for convenience.

As there are 70,000 grains of water in one gallon, we require to take such quantity of water for the analysis as will readily divide into one thousand parts. This we get most conveniently by taking 70 c.c. of water, which is a suitable quantity for our purpose. In this 70 c.c. there are clearly 70,000 milligrammes, as each cubic centimetre is equal to a gramme, or one thousand milligrammes; and thus we have a miniature gallon in which the milligramme bears the same relation to the whole as does a grain to the imperial gallon of 70,000 grains. Therefore, when the substances in 70 c.c. of the water, sewage, effluent, &c., "take up," or destroy, so much permanganate as is contained in 1 c.c. of the standard permanganate solution, which quantity is equal to 1 milligramme of oxygen, we know that the oxygen absorbed by the water is equal to 1 grain per gallon.

Next take about 1 gramme of rice-starch, and mix smoothly with cold water into a thin paste, then pour gradually into 200 c.c. of boiling water; continue the boiling for two minutes. Allow to settle, and decant the clear portion for use. In fact, make a starch *water*. The exact strength is immaterial. Fill one of the 10 oz. bottles with this and label it "Starch Solution."

THE PROCESS OF ESTIMATING THE "OXYGEN ABSORBED" BY ORGANIC MATTER.

To ascertain the quantity of oxygen which will be absorbed by the oxidisable organic matter in the sample to be tested, fill one of the 70 c.c. flasks with the water until it reaches the level of the mark on the neck of the flask; then empty this into one of the 10 oz. white glass bottles. Add to this

10 c.c. of the dilute solution of sulphuric acid, and then 10 c.c. of the standard solution of permanganate, which will be equal to 10 milligrammes of oxygen, or at the rate of 10 grains per gallon, as we have just seen. Next place this bottle in the constant temperature chamber previously heated to 80 deg. Fahr., and let it stand therein for four hours. At the end of that period take it out and add a crystal of iodide of potassium, when the solution will turn from a red to a yellow colour, in consequence of the permanganate which has been unused setting free iodine from the iodide of potash, according to definite chemical principles, in exact proportion to the quantity of permanganate unused by the organic matter, or, more strictly speaking, oxidisable matter, as some *might* be inorganic, in the water.

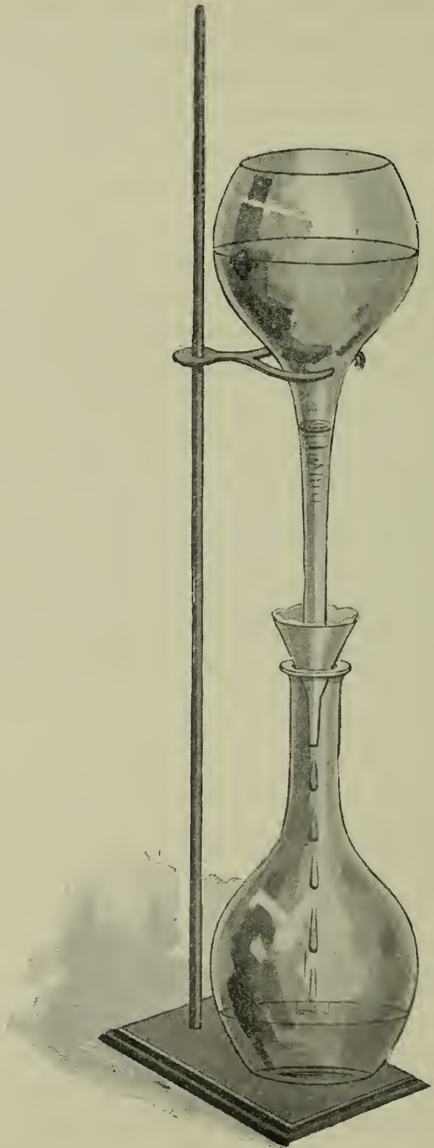
In order to ascertain the quantity of iodine so set free, we must measure it by a standard solution of thiosulphate of soda, commonly known as "hyposulphite," which is prepared by dissolving about 10 grammes of the salt in a Winchester quart bottle filled with water. When this is ready—in fact, it should be prepared beforehand—the 50 c.c. burette is filled to the top, or zero mark, with the solution, taking care that the tap is filled at the same time to displace air, which might otherwise be counted as solution when subsequently reading off the quantity used. All being ready, the test bottle is placed under the tap of the burette and the solution of thiosulphate run in gently, the bottle being shaken from time to time, until the yellow colour nearly disappears. Now add a few drops of the starch solution, when the colour will be changed to a deep blue, by reason of the reaction of the iodine on the starch, forming the well-known iodide of starch. Continue to add the thiosulphate as before, but stop immediately the blue colour disappears. Note the quantity of solution used by reading the burette scale in c.c's and tenths. It will now be necessary to ascertain the relative value of the thiosulphate solution in terms of permanganate, or rather oxygen, as indicated by that substance. This is done by putting 10 c.c. of the standard permanganate solution into a clean 10 oz. bottle; adding 10 c.c. of the 10 per cent. sulphuric acid solution, and making this mixture up to 70 c.c. with the permanganated water; then add a crystal of iodide of potassium, thus imitating the former procedure, with the exception that a water is used which does not absorb the permanganate, and it is not allowed to stand for four hours at 80 deg. Fahr. Fill up the burette to the zero mark again with thiosulphate solution, and repeat the process of "titration," as it is called, adding the starch just before the colour of the iodine disappears. The object of the starch addition is to afford a more distinct "end reaction," and thus obtain a sharper reading. The number of c.c.'s of thiosulphate solution used to neutralise the iodine set free by the 10 milligrammes of oxygen is to be noted, when it will be an easy matter to ascertain the oxygen *un*used by the matter in the 70 c.c. of water taken for the trial. Thus, if the standard 10 c.c. of permanganate solution (= 10 milligrammes of oxygen) required 25 c.c. of the standard thiosulphate solution, and the 70 c.c. of water after standing at 80 deg. Fahr. for four hours with the 10 c.c. of standard permanganate solution, took up only 4 c.c. of thiosulphate, we know that the available oxygen left in the unused permanganate must be $\frac{4}{25}$ of that of the original quantity put in, and as $\frac{4}{25}$ of 10 is 1·6, the unused oxygen is equal to 1·6 milligrammes, and therefore the *used* oxygen is the difference = 8·4; and the water must have taken up, or "absorbed," as it is technically termed, 8·4 grains of oxygen per gallon.

If the colour given to the 70 c.c. of water by 10 c.c. of the standard solution of permanganate is destroyed in less than four hours, it means that the whole of the 10 grains per gallon has been absorbed, and therefore we must add more standard solution of permanganate in order to satisfy the oxidisable matters present. In this case we add another 10 c.c., both of the permanganate and 10 per cent. sulphuric acid solutions, and let the bottle continue to digest in the constant temperature chamber, until the four hours have passed as before, and then proceed as above, remembering that we must add 10 grains per gallon to our result for each additional 10 c.c. of standard permanganate employed. In some cases of strong sewage, gas liquor, &c., it will be advisable to take only 7 c.c. of the sample to be tested, and to make up to 70 c.c. with the "permanganated water for analysis," and multiply the result found by ten. In the case of manufacturing refuse containing the lower metallic oxides which rapidly absorb oxygen, it is advisable to ascertain the quantity of oxygen absorbed *at once* and to deduct this from that required in four hours, the difference presumably being due to organic matter, but the inference is by no means to be relied upon, as many organic bodies in certain conditions rapidly absorb considerable quantities of oxygen from permanganate. Therefore, it is always better to state the result as "oxygen absorbed" simply. From these considerations it will be readily understood that this factor is not to be confounded with the "albuminoid ammonia," which is an approximate measure of the complex *nitrogenous* organic matters.

MATTERS IN SUSPENSION.

The apparatus required for estimating the quantity of matters held in suspension may be very much simplified by adopting a method which I have recently described, viz., the micro-filter method. This does not give the results in terms of grains per gallon, but in that of volume instead. This difference, however, is not a matter of practical importance, as all that is required is the fact that such or such a sample contains a more or less quantity of solid particles. If the actual weight is required the water to be tested should be filtered through filter-paper, the weight of which is ascertained before use after drying at 212 deg. Fahr. for an hour or more until the weight is constant, and then weighed again with the suspended matters which have been collected on it, after a second drying in the same way, when the increase in weight found will indicate the weight of the matters originally in the sample—a simple calculation indicating the quantity in terms of grains per gallon—thus, if 700 c.c. of water are filtered, each 0·010 gramme will indicate 1 grain per gallon. Care must be taken to ascertain the increase in the weight of the dried filter-paper by the absorption of solid matters dissolved in the water, which would otherwise be counted as due to suspended matters.

The details of the micro-filter process are as follows: If a drinking water, or one containing but minute quantities of suspended matter, the neck of the bottle containing the sample is first carefully cleansed to remove extraneous dust; and then one litre of the water, or proportionately less when the quantity of sediment is evidently large, is decanted into a clean litre flask, which should have a narrow neck, such as those used in the well-known Bischoff's bird fountain, which I have found to be specially suited for the purpose. A clean filter-paper, about 3 in. in diameter, is placed in position in a glass funnel resting in the neck of a flask or bottle of at least a litre in capacity. Then the flask containing the water is inverted, so that its mouth is just below the level of the top of the filter-paper. The water will at once fill the filter-paper, and so close the mouth of the flask, which thus acts in the ordinary way of the bird fountain, feeding the supply in the filter until the whole of the water has passed through. During this operation, which will take an hour for a good clean drinking water, great care must be



PRELIMINARY FILTRATION OF THE WATER THROUGH HARD FILTER-PAPER.

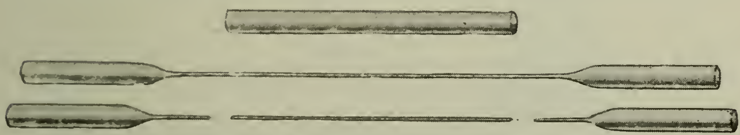
taken to exclude dust by placing a perforated card, through which the neck of the inverted flask passes, over the funnel. When the water is thus filtered, the deposit obtained on the

MICRO-FILTER.
Washing the deposit from filter-paper into micro-filter.

paper, to which it lightly adheres, is washed by a fine jet of water from a laboratory wash-bottle into the micro-filter.

The micro-filter is prepared by selecting a length of glass

A
B
C

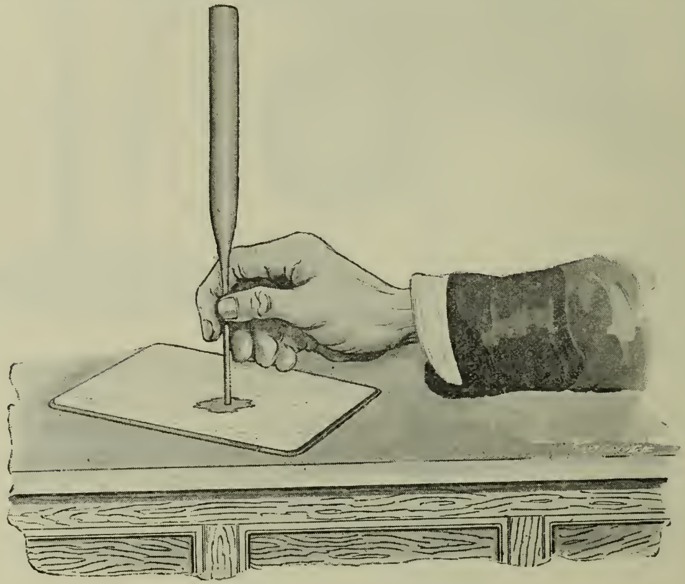


CONSTRUCTION OF MICRO-FILTER.

A Plain combustion tube.
B Same drawn out.
C Divided so as to form two micro-filters.

combustion tubing, from 8 in. to 10 in. in length, which after thorough cleansing by drawing a wet plug of cotton wool through it, is heated to redness over a blowpipe flame in the middle portion of its length, and pulled out when soft to a capillary tube.

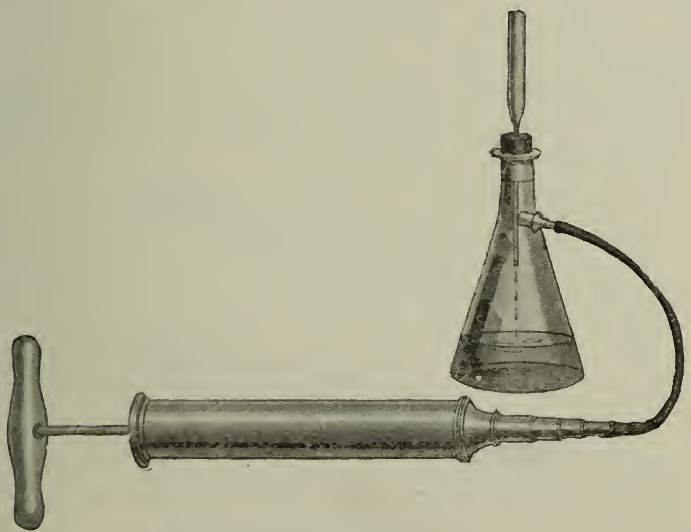
The diameter in the thinnest part should be something less than two millimetres. It is then cut with a sharp file at the two points at which the capillary tube is exactly two millimetres in diameter, and neatly broken. By this means two micro-filter tubes will be prepared. They are then



MICRO-FILTER.
Forming the porous filter-plug.

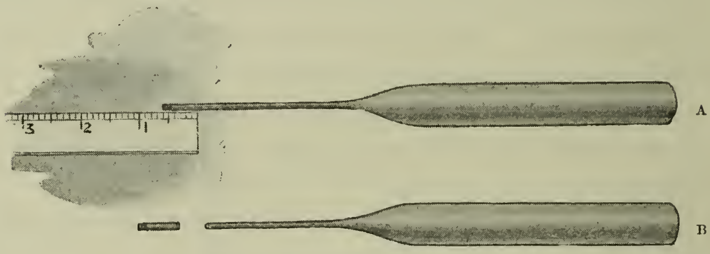
converted into filters by charging the small ends with a suitable porous diaphragm prepared by mixing about one part of powdered air-dried clay with three parts of Kieselguhr. This mixture is moistened and worked up by rolling between the palms of the hands into a smooth putty, which must be spread out to a depth of two millimetres on a clean plate of glass or glazed earthenware. The filter tube being held upright in the manner of a pencil, with the small end downwards, is pressed steadily on to the mass of clay and Kieselguhr, and then worked round to free the enclosed portion on the tube from the surrounding mass. This separation will be facilitated by moistening the glass tube with water just before pressing it on the clay, &c. By this method the capillary tube will be neatly charged with a plug of the mixture. This is next warmed in the flame of a lamp and gradually heated to redness, when the burnt clay will set hard and keep the Kieselguhr in position, and so form a porous diaphragm admirably suited for the purpose of a minute filter. If a little air is sucked through the tube while the plug is red hot, the organic matter always present with the Kieselguhr will be completely destroyed and the filter made more porous.

As the fine sediment from the water will often choke the pores of this small plug, the filtration may be conveniently



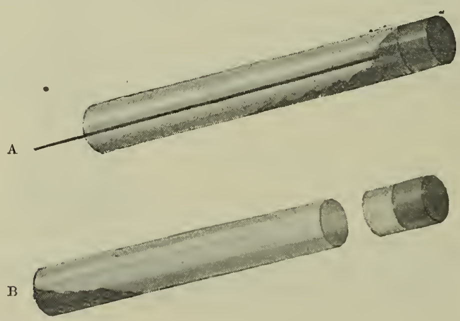
MICRO-FILTER SUBJECTED TO VACUUM.

accelerated by putting the small end of the tube through an aperture perforated in an india-rubber stopper fitting into a convenient bottle, a second glass tube from which leads by means of india-rubber pressure tubing to an exhaust pump, which when worked creates a vacuum in the bottle, and so pulls the water through the filter drop by drop. When only about half-an-inch of water remains in the micro-filter, the



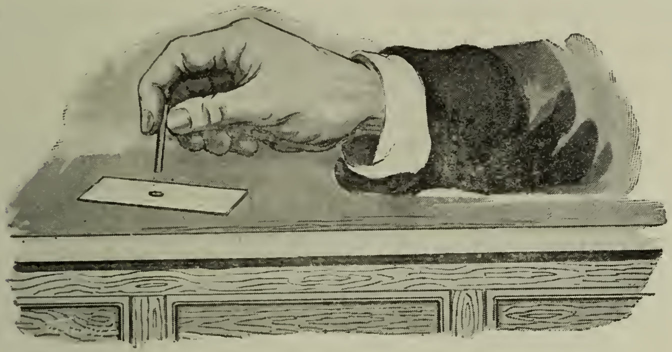
MICRO-FILTER.
A Measuring depth of deposit.
B End of filter-tube containing deposit cut off.

latter is removed, and the depth of deposit which will now be collected on the filter-plug is measured, and the results expressed in terms of millimetres of deposit in a two-millimetre diameter tube per litre of water. Thus, a numerical factor is obtained to express the actual quantity



MICRO-FILTER.
A Loosening deposit with wire from filter-plug.
B Deposit collected at open end, and plug cut off.

of suspended matter present in a water. Of course, in the case of dirty water, effluent, or sewage, when the deposit from a litre would be too great to be contained in that part of the micro-filter tube having a diameter of about two millimetres, half or a quarter of that quantity may be taken, or even less, say, 5 or 10 c.c., when it may be placed in the filter-tube direct without the preliminary filtration through paper, and the depth of deposit actually found should be



MICRO-FILTER.
Shaking the drop of water with deposit on to microscope slide.

multiplied accordingly, so that the result, in all cases, even the most foul water, where only a few c.c.'s can be used, may be expressed in the same terms of "millimetres per litre." In some cases it is difficult to induce all the water to pass the plug, but where only the depth of deposit is required, the solid matters may be made to collect rapidly at the end of the fine tube by holding the stout end in the fingers, and with a long sharp sweep at arm's length, inducing them to fall to the thin end by centrifugal action. So delicate is this method, that I have been able to demonstrate the presence of most objectionable matters in a single tumblerful of ordinary so-called good drinking water.

ESTIMATION OF NITRITES.

The estimation of the nitrogen which has been oxidised into nitrous and nitric compounds, and in that condition forming, in combination with alkaline bases such as lime, soda, potash, &c., the corresponding salts, known as nitrites and nitrates, must be divided into two operations, one for each condition in which the nitrogen may so exist. We will consider the nitrites first, as being the first in order of formation by nitrifying bacteria, and then the nitrates.

The best method for the estimation of small quantities of nitrites is that suggested by Griess, and is known by his name. The reagents required are:—

(1) A solution of five grammes of meta-phenylene-diamine in one litre of water, made acid with sulphuric acid.

(2) Sulphuric acid (pure) in the proportion of one volume of acid to two volumes of water.

(3) A solution of pure potassic nitrite containing 0·01 milligramme of nitrous acid in every c.c. This is best made by dissolving 0·406 gramme of silver nitrite in hot water, decomposing it with a slight excess of potassic chloride, allowing the silver chloride thus formed to settle, making up to a litre, and then diluting each 100 c.c. of the clear fluid again to a litre.

The actual operation is performed by putting 100 c.c. of the water to be tested into a narrow glass cylinder (Nessler glass), and adding first 1 c.c. of the sulphuric acid solution, and then 1 c.c. of the meta-phenylene-diamine. If a red colour is immediately developed, less of the water must be taken, and it is to be diluted until the colour just shows itself at the end of one or two minutes. The colour thus obtained is imitated exactly as possible by running from a burette a small quantity of the standard nitrite solution into a similar cylinder charged with distilled water, adding a small quantity of sulphuric acid and the meta-phenylene-diamine. It will be noted that the nitrite solutions thus treated are continually getting darker, so that the final determination must be started simultaneously, and the final shade observed in both at the end of the same interval of time, which, as the reaction is somewhat slow, may be at the end of from twenty to twenty-five minutes.

The quantity of nitrous acid present in the sample under examination will then be easily calculated from the quantity of nitrite solution used.

ESTIMATION OF NITRATES.

For the determination of the combined nitrites and nitrates there are several approved processes, and it may be as well to give three of these, if only for the purpose of indicating to the student various methods by which he may check his results from time to time, as it is only by constantly calling oneself to order that we can avoid those errors into which the best intentioned must otherwise occasionally fall.

Aluminium foil method:—This is one which I have largely used with great confidence. In this process the nitrites and nitrates in water are determined by reducing the nitric acid with aluminium foil in presence of much caustic alkali, and thereby converting it into ammonia, which, if it be little, is measured by the Nessler test; and if it be much, is measured by alkalimetry.

The details of the operation are as follows:—

First, caustic soda is prepared quite free from nitrates, &c. This is done by dissolving metallic sodium in water in the proportion of two grammes of sodium to 100 c.c. of good distilled water. Nitrate-free sodium hydrate can, if desired, be purchased pure, and thus is saved the troublesome and at times startling process of dissolving the metal, which has an unhappy knack of exploding with great violence, especially if pieces of sodium larger than a pea are placed in the water, and at times the dish containing the water may be broken by the violence of the concussion, and the whole batch, which most probably is just being finished, will be lost.

Seventy c.c. of the water to be tested are first boiled to expel all free ammonia, and then mixed with an equal volume of the pure alkali solution, and a piece of aluminium foil, larger than is capable of dissolving, say six square inches, is placed in it and left for several hours, preferably overnight. At the end of the time the liquid is distilled in a small retort and the distillate "Nesslerised."

The following chemicals and apparatus in addition to those already given are required for the performance of this operation,* which is in itself very simple and expeditious:—

Nessler reagent.
Dilute standard solution of ammonia.
Distilled water.
20 oz. stoppered retort.
Liebig's condenser.
Lamp and retort holder.
Glass cylinders, or "Nessler" glasses.
Pipette for Nessler reagent.

The *Nessler Reagent* consists of a solution of iodide of potassium saturated with periodide of mercury, and rendered powerfully alkaline with potash or soda. It is prepared by taking 35 grammes of iodide of potassium and 13 grammes of corrosive sublimate, and about 800 c.c. of water. The materials are then heated to boiling, and stirred up until the salts dissolve. That having been accomplished, a cold saturated solution of corrosive sublimate in water is cautiously added until the red periodide of mercury, which is produced as each drop falls into the liquid, just begins to be permanent.

* "Water Analyses." Wanklyn, 4th edition, page 25.

In this manner we obtain the solution of iodide of potassium saturated with periodide of mercury, and it remains to render it sufficiently alkaline, to render it sensitive. This is accomplished by adding 160 grammes of solid caustic potash, or 120 grammes of caustic soda, to the liquid, which is afterwards to be diluted with water, so that the whole volume of the solution may equal one litre. In order to render the Nessler reagent sensitive, it is mixed finally with a little more cold saturated solution of corrosive sublimate, and allowed to settle.

When properly prepared, the Nessler reagent has a slightly yellowish tint. If it be perfectly white, it is sure not to be sensitive, and requires a further addition of solution of corrosive sublimate to render it so. Before being employed it should be tested to ascertain its condition. For this purpose about 2 c.c. of the Nessler reagent are dropped into a very weak solution of ammonia (strength about 0·05 milligramme of NH_3 in 50 c.c. of water), and if it be in proper condition it will *at once* strike a yellowish-brown tint with the solution.

The stock of Nessler reagent should be kept in a well-stoppered bottle, from which a little is poured out from time to time into a smaller bottle for daily use.

I have made many gallons of Nessler test according to these directions, and as I have never had a failure, I can safely recommend the student to closely follow the above method.

Dilute standard solution of ammonia.—It will be found convenient to keep two solutions—a stronger solution and a weaker one. The stronger solution is made by dissolving 3·15 grammes of chloride of ammonium in one litre of distilled water. (The commercial sal-ammoniac, in dry fibrous crystals, answers very well for the purpose.) If the solution be thus prepared it will contain one milligramme of ammonia in one cubic centimetre of solution. The weaker solution is prepared by diluting the stronger one with 99 times its volume of distilled water. The weaker solution, which, therefore, contains ·01 milligramme of ammonia per cubic centimetre, is generally used.

We are now prepared to "Nesslerise" the distillate from the aluminium and caustic soda solution, and thus, by finding out the quantity of nitrogen now existing in the form of ammonia, we shall know how much primarily existed in the water in the form of nitric acid, or *nitrates*.

Nesslering is the operation of finding the strength of dilute solutions of ammonia by help of the Nessler test—a test discovered by a chemist named Nessler. We now require to ascertain how much ammonia is present in our distillate. For this purpose the distillate, which will be about 50 c.c. or rather more, is collected in a "Nessler" glass as it falls from the lip of the Liebig's condenser, to which the retort has been connected for the purpose of the distillation.

Into this Nessler glass is then dropped from a pipette 2 c.c. of the Nessler solution or "test," the pipette being used as a convenient stirrer. If the distillate contains any ammonia it will at once—or very soon after the addition of the Nessler, as above described—assume a rich brown colour, or pale straw tint, according to the quantity of ammonia present; the more ammonia the deeper the colour.

If the mixture of Nessler test and distillate becomes muddy in appearance, precipitation will have taken place, in consequence of more ammonium compounds being present than can be retained in solution, and when such is suspected, from the known conditions, to be the case, it will be as well to take only a small quantity of the distillate and to dilute it with pure distilled water, and to submit this diluted quantity to the test—the necessary calculations being made to arrive at the total present in the distillate.

The next step is to imitate the depth of colour given by the distillate. For this purpose a second clean Nessler glass is taken, and a measured quantity of distilled water, free from ammonia, placed in it equal in volume to that in the glass containing the distillate. Into this a few c.c. of the weak ammonia solution is dropped from a graduated burette, scaled so as to indicate c.c.'s and tenths; and then two c.c. of the Nessler reagent, as in the first case, and the whole stirred. The two cylinders are stood upon a white porcelain tile, or a white piece of paper, taking care that the bottoms of the Nessler glasses are dry, and then carefully looked through, when if they be of equal tint the process is completed, as it will be at once apparent that the quantity of ammonia in the distillate is equal to that introduced into the second cylinder from the burette for comparison. If they be not of equal depth, the trial cylinder is emptied out, and a second test made with either smaller or larger quantities of standard ammonia solution as may be required to match the trial of the distillate. It is not necessary to empty the comparison cylinder if the ammonia therein is insufficient, as more may be added as judged requisite, until equality is established.

Having now ascertained that the distillate from the quantity of water under trial for the presence of nitrates contained so much ammonia, the quantity of nitrogen is found by the simple fact that every 17 of ammonia represents 14 of nitrogen, so that if 17 c.c. of the weak ammonia solution were used in the Nesslerising to match the colour of the distillate, there must have been nitrogen equal to 0·14 milligramme in the 70 c.c. of water taken for the trial; and consequently that water contained nitrogen, as nitrates, equal to 0·14 grain per gallon, because, as already shown in connection with the "oxygen absorbed" determination, the milligramme has the same ratio to 70 c.c. as the grain has to the gallon.

I have set out this method of Nesslerising somewhat at length, as the process, which is also employed in the "copper-zinc couple" method next described, is one which lies at the base of a large number of methods of analysis, known as "volumetric," and when once mastered (it is very simple) will be of the greatest possible value to the student.

Copper-zinc couple method for combined nitrites and nitrates.—This very elegant method was introduced by Mr. W. Williams. The details of the process are precisely the same as those in the foregoing aluminium and sodic hydrate method, with the exception that instead of the water being mixed with pure caustic soda and aluminium, it is placed in a suitable wide-mouthed bottle, and a strip of zinc foil coated with copper is placed in it, so that the foil is completely covered by the water, the stopper placed in position, and the whole allowed to stand, all night by preference, when the water may be either decanted from the foil into a retort and distilled and Nesslerised, or a portion of the clear liquid may be carefully withdrawn by a pipette and introduced into the Nessler glass, a sufficient quantity of pure ammonia-free distilled water added to make up the quantity to 50 c.c. and Nesslerised direct, thus saving the generally unnecessary process of distillation, which, indeed, may often be neglected with advantage in the case of the aluminium foil process.

The copper-zinc couple is made by taking a strip of zinc foil, about 6 in. or 8 in. long, curling it round so that it will readily enter the wide-mouthed bottle to be used for the operation, and placing it in a 2 per cent. solution of cupric sulphate, when a deposit of brownish-black spongy copper will loosely adhere to the foil. In a few moments the whole of the foil will be coated, when it is withdrawn and washed under the tap, care being taken to avoid removing the loosely-adhering copper. It is then placed in the bottle of water and the process completed as described.

I have used this method with very satisfactory results, but it is not difficult to find differences of opinion respecting its merits; and Dr. Dupré, who has had considerable experience in this class of work, prefers the indigo titration method, which will next be described.

Indigo method for combined nitrites and nitrates.—This process was originally devised by Marx, but it has been modified and improved. The principle is that of liberating free nitric and nitrous acids from their combinations by the aid of strong sulphuric acid, and measuring the quantity so liberated by the decoloration of a solution of indigo. Sutton, whose work on "Volumetric Analyses" should be obtained by the student, describes the process as follows:—"Experience has shown that the only method by which it can be made serviceable in the case of waters is to have a solution of indigo carmine of good quality, which is standardised upon a very weak solution of potassic nitrate. A definite volume of indigo must be used invariably, and the water to be examined varied in quantity according to its contents of nitric acid. In this manner very excellent results may be obtained, but it must always be remembered that the process is only accurate with moderate proportions of nitrates."

The solutions required are:—

Standard potassic nitrate made by dissolving 0·1011 gramme of potassic nitrate in a litre of water free from nitrates and nitrites. 1 c.c. = 0·015 milligramme of nitrogen.

Indigo carmine.—A good quality of this substance should be selected, and about a gramme dissolved in half a litre of dilute sulphuric acid (1 in 20). This solution keeps in the dark for months without diminution of strength.

Pure sulphuric acid.—This must be free from nitric and nitrous compounds, and of not less sp. gr. than 1·843.

Standardising the indigo.—About 10 c.c. of the standard nitrate are run into a thin flask holding about 150 c.c., then

10 c.c. of indigo ; 20 c.c. of sulphuric acid are then quickly added from a graduated measure, and a rotary motion given to the flask to mix the liquids; the flask is then quickly held over a spirit lamp or small rose gas burner to maintain the heat.

If the indigo is at once decolorised, more is run in with constant heating, until, after heating for about thirty seconds, a persistent greenish colour is noted. From the number of c.c. of indigo decolorised the necessary degree of dilution is calculated, and must always be made with the 5 per cent. sulphuric acid, and not with plain water. Fresh trials are made in the same manner until the strength of the indigo is accurately determined.

Process for nitrates in water.—A trial titration is first made by taking 10 c.c. of the water, adding indigo, then strong sulphuric acid in volume equal to the united volumes of indigo and water, and heating exactly as in standardising the indigo. This first titration will show how much the water under examination must be diluted, so that it may contain nitric acid approximately equal to the standard potassic nitrate. After the water has been diluted with distilled water free from nitrates and nitrites, fresh titrations are made as before described, until the exact number of c.c. of indigo decolorised by 10 c.c. of the diluted water is known. In all cases it is important to work to the same shade of greenish colour, after heating for thirty seconds, as was obtained in the original standardising of the indigo. The colour of the oxidised indigo by itself should be a clear yellow.

Dr. Dupré is of opinion that when only very small quantities of nitrates are present, it is advisable to add a little nitrate solution in known quantity to the sample to be tested, and then to deduct the amount so added from that found, as by this means he obtains more accurate results.

CHAPTER VIII.

INTERPRETATION OF THE RESULTS OF ANALYSES.

Considering, in the same relative order, the three points dealt with in the last chapter, viz., oxygen required to oxidise the organic matters, or "oxygen absorbed," as it is shortly called; the suspended matter; and the quantity of nitrates, we may now study them in relation to the work of sewage purification.

Oxygen absorbed.—The quantity of the oxygen absorbed by the organic matter in solution in crude sewage will vary from an average of about three to four grains per gallon, according to the character of the sewage. It must be noted in passing, that the word "average" is here used as denoting the average quality of the daily flow, and not merely a mixture of samples taken at odd times. If this is done, the strength of the sewage will be found to vary very considerably according to the time of day, rainfall, &c. We may, therefore, take 3·5 grains as a fair average factor for crude London sewage throughout the year as a standard of comparison. The effect of treating sewage chemically by putting precipitating agents into it will be to remove a certain proportion of the matters in solution, in addition to all, or nearly all, the matters held in suspension. The extent to which the matters in solution are affected was shown in the tables in Chapter III. On turning to these we see very clearly that the strength of the solution of organic matter is very considerable in certain cases, and in these no less than from 90 to 91 per cent. of the dissolved organic matter is thrown down by suitable precipitating reagents; but as the strength of the solution declines the quantity removed by the same means falls to only about

50 per cent., thus clearly showing that the dilution of the sewage is an objection from the point of view of its suitability for treatment. As will be noted, these experiments were made upon a specially prepared solution of meat extract, in order that we might have a fairly definite extractive substance as a standard. In order to ascertain the effect of similar treatment on ordinary sewage, the further trials given in that chapter were made upon simple raw sewage collected throughout the twenty-four hours, so as to show the influence of the varying character of the sewage upon the treatment, and to throw light upon the many discrepant statements made by one set of experimentalists, and so loudly contradicted by others; each vaunting the infallible process of the patent rights of which he was the happy possessor. In this table the same characteristic is shown. The stronger the sewage the greater the percentage removal of the organic matters in solution, as determined by the quantity of oxygen absorbed by those remaining in solution.

As showing how the monthly average quantity of dissolved impurities, as indicated by the oxygen absorbed, may vary during the year, apart from the daily variation, the following table will be of interest. Each factor is the average of daily analyses of samples collected day and night at intervals of two hours, so as to ensure accurate results:—

1894.	Northern outfall, Barking Creek.	Southern outfall, Crossness.
January	3·396	3·418
February	3·415	3·474
March	3·283	4·050
April	3·172	3·658
May	3·269	3·614
June	2·924	3·952
July	3·013	3·721
August	2·814	3·554
September	2·856	3·799
October	3·221	3·951
November	2·942	3·420
December	3·186	3·892
Average	3·124	3·709

At certain times the effect of the large quantities of blood let into the sewers from the cattle market, Deptford, and which formerly used to flow direct into the river at that point on the southern side of the Thames, is very noticeable, the quantity of oxygen absorbed rising to abnormal figures, and contributing greatly to the usual amount of impurity. As I have already shown, the greater the impurity the better the effect of the treatment, and thus the process adopted at these works has been able to cope effectually with the increased amount.

For comparison with the above samples of sewage from the Sutton (Surrey) Works, which are on the "separate system," were found to absorb an average quantity of oxygen equal to 4·29 grains per gallon, so that the effect of this system is to keep the sewage a little stronger—a result which I fail to see is sufficiently commensurate with the increased cost of the necessary double set of sewers, one for sewage and another for rain water; and, as will be seen later on, there is no advantage in this respect when the sewage has to be dealt with by bacteriological means, instead of by farming or chemical processes, which I now look upon as rapidly passing into the things of the past, as in the light of our present knowledge they are efficient in only very few cases; for as I have shown, the effect of simple chemical treatment upon the oxidisable matters is to reduce their amount by only a small proportion. In the case of the southern outfall, where the process is working fairly well, the average quantity of oxygen absorbed for the year 1894 was 3·115 grains per gallon, thus showing a reduction of 16 per cent., and in the case of the stronger sewage at Sutton the reduction was 32 per cent. But on turning to the effect of biological filtration the result of the experiments made at the Northern Outfall Works at Barking Creek, we find that the average reduction was nearly 80 per cent., and in the case of the Sutton experiments almost as much, and in some cases the combined effect of precipitation and filtration gave 95 per cent.

In the case of river water, such as that of the Thames during the period from July, 1893, to March, 1894, the oxygen absorbed varied according to the following table. The figures are the results of daily analysis during that period, which includes phenomenally dry and wet seasons:—

Oxygen Absorbed.

	Grains per gallon. High water.	Grains per gallon. Low water.
Teddington, above Lock	0·162	—
Kew Bridge	0·179	0·161
Hammersmith	0·197	0·173
Battersea Bridge	0·231	0·185
London Bridge	0·273	0·198
Greenwich	0·361	0·252
Blackwall	0·375	0·270
Woolwich	0·377	0·307
Barking Creek	0·381	0·349
Crossness	0·353	0·387
Erith	0·294	0·400
Greenhithe	0·198	0·302
Gravesend	0·164	0·213
The Mucking	0·101	0·126
The Nore	0·052	0·068

Carrying the comparison one step farther, we may now look at the average results of the daily analysis made under my direction of the London water supplied by the various companies. It will be interesting to remember that the water in the Thames at Sunbury is that practically taken by all the respective companies drawing their supplies from that river, the different positions of their intakes having but little effect. These will complete the sequence of comparisons for ascertaining the degree of impurity in any given sample that the student may be called upon to examine.

Average Daily Quantity of Oxygen Absorbed (by the Dissolved Matters) from Permanganate in four hours at 80 *deg. Fahr., during the twelve months ending December,* 1895.

Description of water.	Grains per gallon.
River Thames at the intakes at Sunbury	0·128
Kent Company	0·018
New River..................................	0·041
West Middlesex	0·072
Chelsea	0·064
Grand Junction	0·069
East London	0·060
Lambeth	0·071
Southwark and Vauxhall	0·078

Summarising these results in their order, we have the following very interesting and instructive table:—

Description of water.	"Oxygen absorbed" in four hours. Grains per gallon.
Kent Company's deep well in chalk	0·018
New River, partly spring, well, and river................	0·041
Lee River, filtered supply	0·060
Thames Company's average filtered supply	0·071
Thames, unfiltered, the Nore..........................	0 060
,, ,, the Mucking	0·113
,, ,, Sunbury (companies' intakes)..........	0·128
,, ,, Teddington (above lock)	0·162
,, ,, Kew...............................	0·170
,, ,, Hammersmith	0·185
,, ,, Gravesend	0·188
,, ,, Battersea Bridge	0·208
,, ,, London Bridge	0·235
,, ,, Greenhithe	0·250
,, ,, Greenwich	0·306
,, ,, Blackwall	0·325
,, ,, Woolwich	0·342
,, ,, Erith	0·347
,, ,, Barking	0·365
,, ,, Crossness	0·370
Average water-carried sewage, London, North	3·124
,, ,, ,, ,, South............	3·709
,, ,, ,, separate system, Sutton....	4·290

If the quality of the water of the river at Southend is taken as being equal to that represented by the mean of that at the Nore and the Mucking, then we have the somewhat startling but satisfactory result that the water of the estuary at that favourite watering-place is to all intents and organically as pure as that supplied after filtration to the consumers of London by those companies drawing from the Thames at Hampton and Sunbury, and the quality of which has been described by Sir Edward Frankland as equal to the finest drinking water supplied to any community in the world.

Suspended Matters.—In the same way as that in which we have considered the quantity of oxygen absorbed by the dissolved matters, we may look at the quantity of solid matters held in suspension.

The following table, showing the quantity of suspended matters in average London sewage during the year 1894, and that in the effluent after treatment with lime and iron, will serve as a starting-point for comparison so far as water-carried sewage is concerned. It will be remembered that in this instance all storm water is included, and as the process has been converted from the original design of quiescent precipitation to one involving continuous flow, the settlement is not so perfect as it would otherwise be :—

Suspended Matters.

	Grains per gallon.	
	Sewage.	Effluent.
January	38·1	8·9
February	30·2	6·1
March	29·5	7·8
April	30·2	7·2
May	33·5	7·1
June	30·6	6·3

	Grains per gallon.	
	Sewage.	Effluent.
July	36·1	6·6
August	36·1	6·1
September	26·6	5·7
October	35·3	5·0
November	22·5	3·2
December	29·1	5·0

In the filtrate from a properly-worked coke-breeze filter, or "bacteria bed," the suspended matters are reduced to a mere trace, which can be best determined by the micro-filter.

The following are the results of a series of daily determinations of the quantity of suspended matters in the water of the river Thames from Teddington to the Nore during 1893-4, as above mentioned, in connection with the "oxygen absorbed." It must be noted, however, that in most of these cases the suspended matter consisted largely of loam and sand.

No. 5.—Total Matters in Suspension—Monthly Averages.

Locality.	HIGH WATER.								
	1893						1894.		
	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Teddington	·03	traces	traces	traces	traces	3·11	2·28	1·17	1·28
Kew Bridge....	5·22	4·67	6·66	5·58	5 59	3·56	2·86	2·65	1·90
H'smith Bridge..	3·59	2·64	3·32	7·04	6·35	9·52	6·00	4·84	2·88
Battersea Bridge	3·61	2·49	4·01	3·92	6·76	8·29	10·55	11·71	9·38
London Bridge..	9·50	24·62	19·21	26·21	18·59	16·80	24·46	23·53	16·55
Greenwich	5·79	10·91	8·46	9 88	11·56	5·79	13·30	16·27	5·79
Blackwall......	5·68	6·08	5·27	4·25	5·56	5·54	9·54	9·34	4·46
Woolwich	3·68	5·08	4·30	4·33	6·05	7·58	9·79	16·99	6·91
Barking........	2·07	2·67	2·86	2·17	2·65	2·23	5·42	7·30	5·46
Crossness	2·25	2·37	2·90	2·42	2·38	3·86	4·37	3·65	2·97
Erith	2·23	2·41	2·92	2·56	3·30	3·74	5·61	5·99	5·20
Greenhithe	3·88	2·27	3·31	3·09	6·46	7·40	9·19	7·23	8·70
Gravesend	5·98	6·75	9·84	9·53	15·16	24·71	24·71	18·73	10·43
Mucking Light..	3·54	2·15	2·10	2·68	3·79	6·28	7·01	7·02	4·80
Nore Lightship..	3·09	2·02	1·98	3·61	6 10	6·25	5·80	5·18	3·05

Quantities are expressed in grains per gallon.

Locality.	LOW WATER. 1893. July.	Aug.	Sept.	Oct.	Nov.	Dec.	1894. Jan.	Feb.	Mar.
Teddington						—	—	—	—
Kew Bridge	1·20	1·11	1·38	·96	·60	1·99	3·42	3·26	2·04
H'smith Bridge..	2·97	3·37	3·70	2·60	1·92	2·13	3·10	2·85	2·26
Battersea Bridge	6·85	7·25	12·59	10·21	7·64	2·95	4·41	3·81	4·24
London Bridge..	13·59	14·66	22·74	27·75	27·65	12·07	6·92	5·67	3·09
Greenwich	7·89	25·94	35·12	21·74	27·22	22·43	17·47	14·79	11·83
Blackwall	4·86	9·78	13·79	7·18	10·50	12·19	11·79	10·73	8·01
Woolwich	4·68	6·56	7·21	10·05	5·48	5·28	9·43	11·66	5·54
Barking........	3·44	7·60	7·25	8·59	5·65	3·94	8·39	16·57	12·02
Crossness	7·89	8·88	14·42	6·88	10·10	8·35	17·81	18·44	6·96
Erith	3·29	4·00	4·18	3·75	4·99	3·36	4·09	6·57	3·83
Greenhithe	5·19	3·27	5·22	2·69	5·42	7·73	7·93	5·95	9·53
Gravesend	4·91	5·28	7·41	6·27	9·87	9·53	18·98	12·89	8·08
Mucking Light..	7·89	18·57	9·27	10·80	18·73	31·75	11·23	15·62	8·25
Nore Lightship..	3·15	2·49	3·71	4·40	10·93	8·29	4·81	5·33	5·20

Quantities are expressed in grains per gallon.

For comparison with the above, the following results of the filtered water supplied to London will be interesting :—

Average Quantity of Suspended Matter during 1895.

Source of Water.	Grains per Gallon. Mineral.		Organic.		Total.
Intake water, river Thames, Sunbury....	0·4181	..	0·1179	..	0·5360
Kent Company's supply	0·0007	..	0·0004	..	0·0011
New River Company's supply	0·0006	..	0·0005	..	0·0011
East London Company's supply	0·0015	..	0·0012	..	0·0027
West Middlesex Company's supply	0·0005	..	0·0005	..	0·0010
Grand Junction Company's supply......	0·0010	..	0·0013	..	0·0023
Chelsea Company's supply	0·0014	..	0·0013	..	0·0027
Lambeth Company's supply............	0·0018	..	0·0015	..	0·0033
Southwark Company's supply	0·0031	..	0·0025	..	0·0056

The following table shows the comparison of the results of the determinations of the quantity of suspended matters in the above waters, during the latter six months of that year, by the micro-filter method and the gravimetric process :—

Company.	JUNE.		JULY.		AUGUST.		SEPTEMBER.		OCTOBER.		NOVEMBER.		Average.
	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. grains. Mm. grains.
Kent	0·0	0·0006	0·2	0·0006	0·1	—	0·8	—	0·4	0·0008	0·3	0·0007	0·3 =0·0007, or 1=0·0023
New River	0·0	0·0010	0·2	0·0012	0·2	0·0011	0·8	0·0013	0·4	0·0009	0·3	0·0010	0·3 =0·0010, or 1=0·0033
West Middlesex	0·1	0·0012	0·2	0·0014	0·2	0·0008	0·7	0·0007	0·4	0·0007	0·4	0·0009	0·4 =0·0009, or 1=0·0022
Chelsea	0·4	0·0038	0·5	0·0020	0·3	0·0013	0·4	0·0024	0·4	0·0016	0·4	0·0013	0·4 =0·0021, or 1=0·0052
East London	0·4	0·0019	0·3	0·0030	0·2	0·0020	1·1	0·0027	1·1	0·0040	0·5	0·0015	0·6 =0·0025, or 1=0·0042
Grand Junction	0·4	—	0·2	0·0037	0·3	0·0031	0·7	0·0018	0·4	0·0013	0·3	0·0016	0·4 =0·0023, or 1=0·0057
Lambeth...........	0·3	0·0026	0·2	0·0020	0·1	0·0018	0·8	0·0023	0·4	0·0026	0·4	0·0015	0·4 =0·0021, or 1=0·0052
Southwark	0·7	0·0098	0·7	0·0057	0·4	0·0031	1·1	0·0022	0·9	0·0013	0·6	0·0011	0·7 =0·0039, or 1=0·0056
Average	0·3	0·0010	0·3	0·0024	0·2	0·0019	0·8	0·0019	0·6	0·0016	0·4	0·0011	0·44=0·0019, or 1=0·0042

—	SEPTEMBER.		OCTOBER.		NOVEMBER.		DECEMBER.		Average.
	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. in micro-filter per litre of water.	Grains per gallon.	Mm. grains. Mm. grains.
River Thames at Sunbury.............	1·8	0·1718	4·8	0·2020	33·7	1·1775	7·8	1·4870	12·0=0·7569, or 1=0·0633

Nitrates.—Generally speaking, sewage contains no nitrates, but this is a case by no means without an exception, although the quantity present in a given volume of water must always be less than that present in the originally clean water supplied to the town. As must be obvious, the presence or otherwise of nitrates entirely depends upon the time the sewage matters have been in contact with the water used for flushing. If a sufficient interval has not elapsed, the nitrates originally present in the water supplied will not be reduced by the action of the de-nitrifying organisms, and therefore they will be found in the sewage if looked for at once.

In the course of the experiments at Barking the following results were obtained :—

1894.	Effluent from precipitating tanks.	Filtrate.
	Grains per gallon.	
April 7th to June 9th	0·128	0·238
August 3rd to Nov. 9th ..	0·022	0·141
Nov. 16th to March 2nd ..	0·396	0·699
April 8th to April 20th	0·143	0·770

In a very large number of cases there were no nitrates at all in the raw sewage. The excess in the effluent shows the satisfactory processes of the work of the bacteria in the filter bed in oxidising the nitrogen organic matter.

I do not here propose to further discuss the work of Warington and others regarding the action of minute organisms upon organic matter, as that has been so well and often done in different works by various authors. It is well known that we owe a large share of gratitude to Warington for his classical work in this direction, and the student is advised most strongly to read up the subject as far as he is able. Shortly, it may be desirable to state, as already pointed out, that the oxidation of organic matter is brought about by the agency of living organisms; but in order that putrefaction should be avoided, they must be supplied with fresh air, in which case the carbon is converted into carbonic acid, the hydrogen into water, and the nitrogen into nitrates. Consequently the measure of the quantity of nitrates in the effluent, whether from the tank, field, or filter bed, must be a measure of the degree of wholesome purification which has taken place. From this it follows that even when a water is perfectly pure so far as organic matter is concerned, the presence of large quantities of nitrates is indicative of the former presence of nitrogenous organic matter, and therefore of "previous contamination."

For comparison, as before, the following tables of nitrates in various waters, in addition to those already given, will be useful. The great point, however, to be observed in connection with sewage treatment is that if the filtrate or effluent is well charged with nitrates, there is not much fear of the process coming to a sudden stop. But should these decrease and disappear, there is danger of putrefaction; and in the case of a filter, rest must be at once given.

River Thames.

	Nitrates and Nitrites. Grains per Gallon.
Sunbury. Average—Summer	0·206
,, ,, Winter	0·258

London Water Supply.

Kent Company	0·401
Filtered River Supplies. Average—Summer	0·128
,, ,, ,, ,, Winter	0·258

Various Waters.

Welsh Rivers	0·022
Chalk well	0·370
Deep well	0·540
Well, 60 ft. deep	1·010
Spring	0·028
Polluted well	1·880
Ditto	4·360
Shallow well, 14 ft. deep	1·150

By comparing the results of his examinations with these various tables the student will easily be able to gauge the quality of the sample under examination, and thus arrive at a reliable conclusion. Many more instances might readily be given, but these will be ample for our present purpose. The question of the degree of aëration of a sample of water will be dealt with in the succeeding chapter.

CHAPTER IX.

THE ABSORPTION OF ATMOSPHERIC OXYGEN BY WATER.

It being established that the friendly or non-putrefactive organisms which bring about the destruction of the effete matters in foul waters cannot continue their beneficent work unless there is a plentiful supply of oxygen dissolved in the water, it becomes necessary to ascertain the rates at which water will renew the oxygen abstracted from it by the life processes of the microbes. This rate, it will be seen, is a measure of the degree of the rapidity with which they can multiply and work; and beyond that point it will be useless to expect results without incurring the risk of putrefaction by the agency of the anærobic organisms. Of course, if it be desired to bring about the destruction of the organic matter by their means instead of by the oxidising microbes, the oxygen dissolved in the water is a matter of no importance. Of late, a suggestion has been made to allow the putrefaction to proceed in a closed chamber in a manner similar to that of a cesspool. This scheme has been put into operation at Exeter under the direction of the city surveyor, Mr. Cameron, and the process will doubtless come more to the front as, worked as it is in combination with the coke breeze filter beds, it is strictly on biological lines; and it will be for the future to determine whether the work is best accomplished by the one set of organisms or the other. In the present connection, however, we need not delay to further consider it, especially as the process has already received full attention.

Water dissolves very unequal quantities of the different gases, and very unequal quantities of the same gas at different temperatures. One volume of water absorbs, at the temperature stated in the following table—which is given in "Fowne's Chemistry," edited by Watts, twelfth edition, page 148—and under the pressure of 30 in. mercury, the following volumes of different gases measured at 0 deg. Cent. and 30 in. pressure :—

Deg. Cent.	Oxygen.	Nitrogen.	Hydrogen.	Nitrogen. monoxide.	Carbon dioxide.
0	0·041	0·020	0·019	1·31	1·80
10	0·033	0·016	0·019	0·92	1·18
20	0·028	0·014	0·019	0·67	0·90

Deg. Cent.	Chlorine.	Hydrogen Sulphide.	Sulphurous Oxide.	Hydrochloric Acid.	Ammonia.
0	—	4·37	53·9	505	1180
10	2·59	3·59	36·4	472	898
20	2·16	2·91	27·3	441	680
30	1·75	2·33	20·4	412	536
40	1·37	1·86	15·6	387	444

When the pressure increases a larger quantity of the gas is absorbed. Gases moderately soluble in water follow in their solubility the law of Henry and Dalton, according to which the quantity of gas dissolved is proportional to the pressure. At 10 deg. Cent. one volume of water absorbs under a pressure of one atmosphere 1·18 volume of carbon dioxide, measured at 0 deg. and under a pressure of 30 in. mercury. The quantity of carbon dioxide dissolved under a pressure of two atmospheres, and measured under conditions precisely similar to those of the previous experiment, equals 2·36 vols. Gases which are exceedingly soluble in water do not obey this law, except at higher temperatures, when the solubility has been already considerably diminished.

It deserves, however, to be noticed that the pressure which determines the rate of absorption of a gas is by no means the general pressure to which the absorbing liquid is exposed, but that pressure which the gas under consideration would exert if it were alone present in the space with which the absorbing liquid is in contact. Thus, supposing water to be in contact with a mixture of one volume of carbon dioxide and three volumes of nitrogen, under a pressure of four atmospheres, the amount of carbon dioxide dissolved by the water will be by no means equal to that which the water would have absorbed, if it had been at the same pressure of four atmospheres in contract with pure carbon dioxide. In a mixture of carbon dioxide and nitrogen in the stated proportions, the carbon dioxide exercises only one-fourth, the nitrogen only three-fourths, of the total pressure of the gaseous mixture = four atmospheres; the partial pressure due to the carbon dioxide is in this case one atmosphere, that due to the nitrogen three atmospheres; and water, though exposed to a pressure of four atmospheres, cannot under these circumstances absorb more carbon dioxide than it would if it were in contact with pure carbon dioxide under a pressure of one atmosphere.

It is necessary to bear this in mind in order to understand why the air which is absorbed by water out of the atmosphere differs in composition from atmospheric air. The latter consists very nearly of twenty-one volumes of oxygen and seventy-nine volumes of nitrogen. In atmospheric air which acts under a pressure of one atmosphere, the oxygen exerts a partial pressure of $\frac{21}{100}$, the nitrogen a partial pressure of $\frac{79}{100}$ atmosphere. At 10 deg. Cent., one volume of water (see the above table) absorbs 0·033 volume of oxygen and 0·016 volume nitrogen, supposing these gases to act in the pure state under a pressure of one atmosphere. But under the partial pressures just indicated, water of 10 deg. Cent. cannot absorb more than $\frac{21}{100} \times 0{\cdot}033 = 0{\cdot}007$ of oxygen, and $\frac{79}{100} \times 0{\cdot}016 = 0{\cdot}13$ volume of nitrogen. In

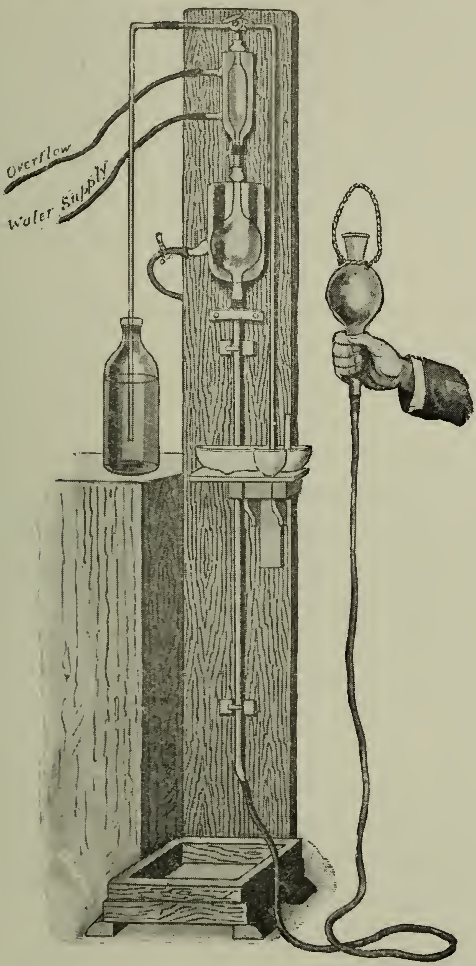
0·007 × 0·13 = 0·020 volume of the gaseous mixture absorbed by water there are consequently 0·007 volume of oxygen, and 0·013 volume of nitrogen, or in one hundred volumes of the gaseous mixture, thirty-five volumes of oxygen and sixty-five volumes of nitrogen. The air contained at the common temperature in water is thus seen to be very much richer in oxygen than ordinary atmospheric air. This property of water to absorb oxygen from the air more readily than nitrogen has been applied to the preparation of oxygen for industrial use.

Air is pressed into water by means of a force pump, and the gases which escape on diminishing the pressure are subjected to the same treatment eight times in succession, by which time nearly pure oxygen is obtained. The following table shows the composition of the gaseous mixture at each successive stage :—

Atmospheric air.	Composition after Successive pressures. 1	2	3	4	5	6	7	8
Nitrogen 79	66·7	52·5	37·5	25·0	15·0	9·0	5·0	2·7
Oxygen 21	33·3	47·5	62·5	75·0	85·0	91·0	95·0	97·3

In the course of a series of experiments on the condition of the water in the river Thames I instituted some tests for the purpose of ascertaining the rapidity with which water will take up oxygen from the atmosphere. In these experiments the conditions actually occurring in the river could not necessarily be reproduced; the agitation, influence of wind, and varying ratio of surface to the depth being impossible to gauge with any degree of certainty. By the method adopted, however, a fairly accurate series of results was obtained, applicable to absolutely still water, in which the ratio of surface to depth was practically unity. By this means it was rendered certain that the results could not exceed those which would have been found had the whole of the actual circumstances been brought under control, since any agitation by traffic or wind, or any increase in the ratio of surface to depth, must necessarily have increased the normal rate.

The actual *modus operandi* was as follows:—A quantity of



MERCURY EXHAUST PUMP FOR ESTIMATING DISSOLVED GASES IN WATER.

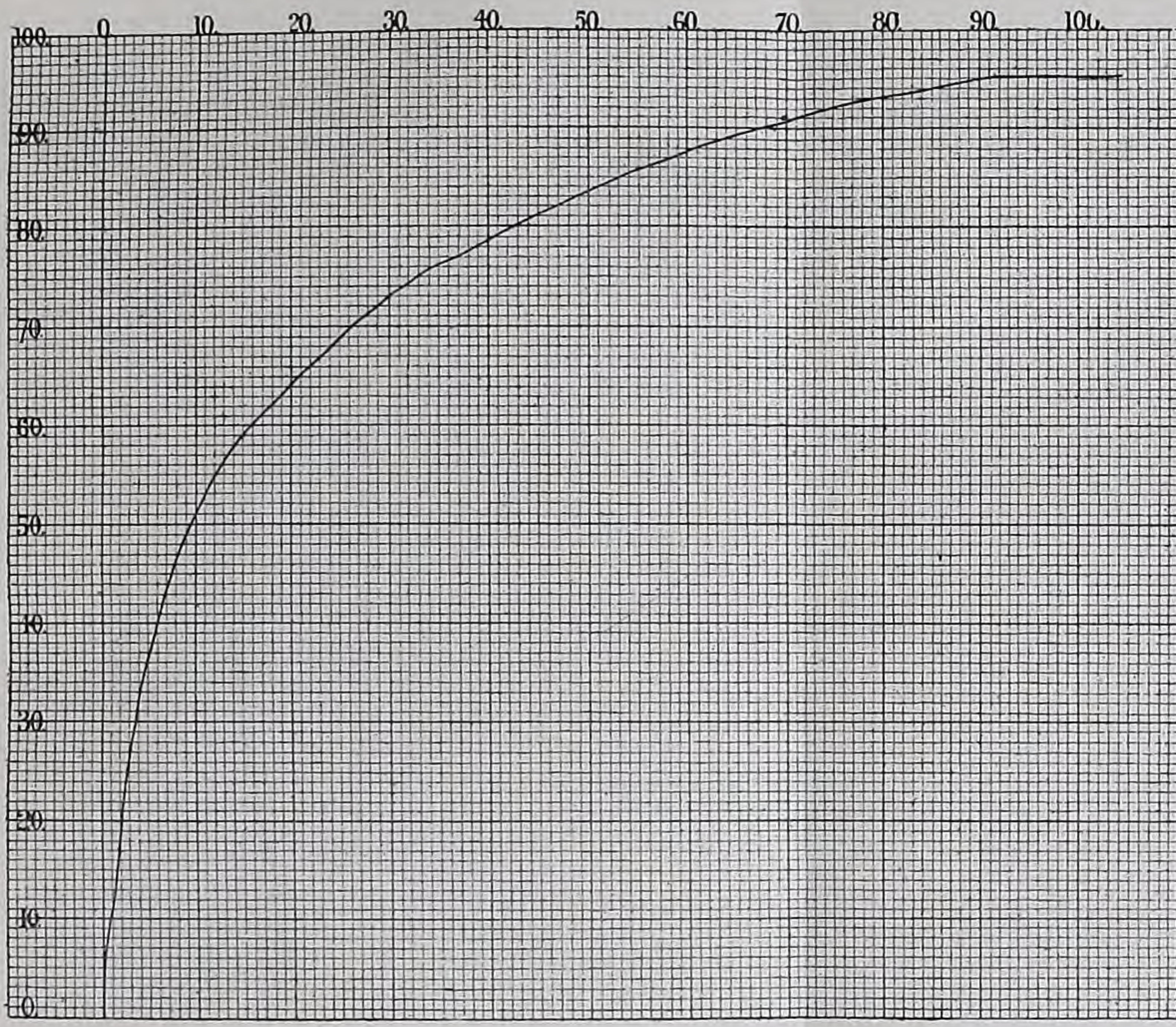
water was boiled in a flask until all the air was expelled. The flask was then sealed and allowed to cool. When cool the seal was removed and the contents transferred without agitation to open vessels, in which the water was exposed to the atmosphere for periods of time varying from one to ninety-six hours. The quantity of dissolved oxygen was then determined by the usual gasometric method, in which the air is boiled out of the water in a vacuum, and collected over mercury and analysed in the usual way by either exploding the oxygen with an excess of hydrogen, or by absorbing it with pyrogallic acid in the presence of alkali; both methods being used as a check on each other. The special form of air pump employed for withdrawing the gases from the water, was designed by myself on the lines of Macleod's apparatus, and has been found to be most efficient for its purpose, many thousands of determinations having been made in the three laboratories under my charge by its use.

Those who desire to use a method based on volumetric processes cannot do better than to employ that designed by Dr. Thresh, which I have used very largely in those cases in which it was desirable to make tests on the spot, and before the samples could undergo change. The following woodcut shows the apparatus employed, with the exception that where coal gas is available the hydrogen generator may be displaced. The process is described at length in the Appendix.

Upwards of 150 estimations were made, and from the figures thus obtained a curve was constructed, showing the rate of absorption for each percentage degree of aëration. These results are shown in the diagram.

From this it will be seen that a water absolutely free from oxygen dissolved therein will absorb in one hour 10 per cent. of the total possible quantity which it can take at ordinary temperature and pressure, viz., about 1·8 cubic inches per gallon. In two hours it will have taken up 20 per cent. In

RATES OF ABSORPTION OF ATMOSPHERIC OXYGEN BY STILL WATER.



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three hours the quantity of oxygen dissolved will have increased to 26 per cent. ; in four hours to 32 per cent.; in five hours to 36 per cent.; in six hours to 40 per cent.; in

THRESH APPARATUS FOR ESTIMATING THE DISSOLVED OXYGEN IN WATER.

seven hours to 43 per cent., and so on, until ten hours are required for it to absorb only one-half its total quantity, viz., 50 per cent., the rate decreasing as the degree of saturation increases, until, as it approaches saturation, it takes only a few tenths of a per cent. per hour.

As showing the practical bearing of these results upon the water of the river Thames, we may consider their effect on the tidal portion of the river from Teddington to the Nore. The following table of the average quantity of dissolved oxygen at fifteen different points at and between these places, shows the average percentage quantity of oxygen dissolved in the water from July, 1893, to March, 1894 :—

Average percentage Quantity of Oxygen (saturation = 100) *Dissolved in the Water of the River Thames at*

Locality.	High Water.	Low Water.
Teddington (above lock)	85·0	
Kew	70·3	85·5
Hammersmith	55·7	78·8
Battersea	42·6	67·6
London Bridge	34·5	51·8
Greenwich	24·6	37·4
Blackwall	22·5	34·3
Woolwich	22·2	30·8
Barking Creek	24·2	30·8
Crossness	43·0	41·6
Erith	39·4	29·1
Greenhithe	38·4	25·1
Gravesend	50·7	39·5
The Mucking	83·6	72·0
The Nore	90·1	89·1

From this table it will be seen that the average aëration at high and low water, between Teddington and Chiswick, is a trifle under 80 per cent. of the total possible quantity.

This decreases rapidly, reaching at its lowest point at or about Woolwich, where it is only 26 per cent. From that point it rises again, until between Gravesend and Southend it is about 75 per cent., and at the Nore 90 per cent. In other words, the water as it flows over Teddington weir is well aërated, and is able to deal with all polluting matters contained in it without suffering any material reduction in aëration, *i.e.*, the rate of absorption from the atmosphere (actual aëration being 85 per cent.) is equal to the rate of consumption by the microbes in eating up the organic impurities. As we proceed downwards it is found that this process abstracts more oxygen than can be supplied at the former slow rate, at the higher degree of aëration; and, accordingly, the degree of aëration falls, which fall is accompanied by a corresponding increase in the rate of absorption from the atmosphere, as shown by the foregoing experiments. When the rate is equal to the necessities of the organic impurities, the balance is once more established, and the aëration remains constant at the lower rate. Further down again, the organic impurities becoming less, both by previous oxidation and by dilution, the quantity of oxygen dissolved in the water gradually increases, accompanied by a diminution in the rate of absorption from the atmosphere until the two factors are once more equal and equilibrium is regained.

From these observations it is evident that at Teddington, where the degree of aëration is 80 per cent., the rate of absorption of atmospheric oxygen will be 3·6 tons per hundred million cubic feet per day, and as the sectional volume of the river between that point and Chiswick at high water may be taken at 250·8 million cubic feet, according to Professor Unwin, it follows that this reach of water will absorb nine tons of oxygen in twenty-four hours.

In like manner each section of the river is tabulated as follows:—

Section.	Volume of water in million cubic feet.	Rate of absorption tons per 100 million cubic feet per day.	Tons of oxygen dissolved by the water in section per 24 hours.
Teddington to Chiswick	250·8	3·6	9
Chiswick to St. Paul's Pier	678·6	12·7	86
St. Paul's Pier to Deptford	643·2	21·4	138
Deptford to Woolwich	1099·0	43·8	481
Woolwich to Barking	480·3	43·8	210
Barking to Crossness	898·7	29·2	262
Crossness to Erith	1155·0	21·9	253
Erith to Gravesend	6543·0	21·9	1432
Gravesend to Southend	34695·0	5·5	1898

These considerations show the enormous forces at work in purifying our streams and rivers, and constitute the real secret of Nature's method in effecting the destruction of effete matters wherever they may be. It must be obvious on the face of it to the meanest capacity that without some such operation the whole world would soon be covered to a considerable depth with rubbish, and life would be insupportable. But by these constant processes of give and take, Nature restores the balance, and man, in common with all animal and vegetable life, continues his way, and except where he wilfully or ignorantly spoils his surroundings, the world is kept clean and wholesome.

We have seen in the past chapters how this oxygen is brought into actual combination with the organic matters by the action of living organisms, and thus by careful consideration of that action, combined with that of the mighty sponge-like power of the water, the whole mystery of Nature's method of purification is made plain. In this we see but one more instance of the power of science to clear up mystery after mystery, and to lead us to stand in awe of the wonderful order and arrangement which has been ordained to the establishment of a world so altogether admirably adapted not merely to maintain man, but to correct the errors and faults of his own blindness. A few years ago it was stoutly denied that rivers had the power of purifying themselves! Then we knew practically nothing of Nature's method. Now that this has been so far revealed to us, it is declared with equal force that not only are effete matters rendered innocuous, but even disease-producing microbes are themselves voraciously devoured by others of like kind, and the formerly much-dreaded bacteria are—and properly so—considered amongst the best friends of man.

CHAPTER X.

SUGGESTIONS FOR SEWAGE WORKS CONDUCTED ON BIOLOGICAL PRINCIPLES.

Presuming that we have one million gallons per day to dispose of, the following suggestions may be mapped out as being worth trial, both as to economy and efficiency, as well as durability. It will be understood that these suggestions are to be considered in the light of a "general idea," to use a military expression, and must be modified to suit local conditions. In the system of continuous work with the open-sided filter hereafter described, it is necessary to have a fall of from 8 ft. to 10 ft., and therefore if that fall cannot be obtained naturally, pumping will have to be resorted to. In such cases, however, the original Sutton No. 1 bacteria tank, as it is termed, permits of the practice of biological treatment being brought into play where only a few feet—or even on emergency a few inches of fall is available, and thus the first difficulty—pumping—is avoided by the original method.

We will suppose that we have the sewage brought to a point on the site of the works where there is a gentle slope of ground, so as to give a suitable fall by means of which the water may be turned on to a set of filters without pumping, and that the volume is about one million gallons per day.

Let us begin by looking at the problem a little closely in detail. The crude sewage consists, first, of solid particles held in suspension, some of these being coarse and others graduating in size to extremely minute fragments. As a preliminary it will be advisable to remove as many of the particles as possible by mechanical separation, by passing the sewage through a screen having as fine a mesh as possible. Although much has been done in this direction—and doubtless the subject presents no difficulty in many works where the necessary labour for cleaning the screens can be conveniently provided—the best and most economical method has yet to be worked out.

What is really required is straining through a self-cleansing mesh sufficiently fine to collect the fibres of paper, &c. Various suggestions have been made, and doubtless the difficulty will soon be solved. For our present purpose I will assume that the sewage has been sufficiently strained, the more perfectly this being accomplished the nearer perfection we shall attain in our subsequent work, as the bacteria can more rapidly dispose of minute particles than of those of larger size, their action being mainly on the outside, or surface, of the particle, which is necessarily greater for a given quantity of matter as the division is finer.

Having removed by straining the grosser solids, which may be disposed of either by burning or burying, we have the remainder in various grades of fineness; and these, if placed upon a filter constructed in the ordinary manner with a stratum of fine material upon the surface, will at once form a layer of slimy mud, impeding the progress of the water into the pores of the filter, and preventing the entrance of air so necessary for the healthy life processes of the bacteria, with the result that in a short time the whole mass becomes putrid, and the "filter" is a failure.

The first set of bacteria beds should, to be on the safe side, have a collective capacity of 160,000 cubic feet, divided into, say, nine partitions. These beds should be filled with either coke, burnt ballast, or other suitable substance which has been rejected by a half-inch mesh in order to exclude dust and small stuff, and thus lessen the chance of clogging from the accumulation of sludge and the zooglea form of bacteria, which, by its gelatinous character, under favourable conditions might develop to a sufficient extent to assist materially in rendering the filter water-logged.

The best method of distributing the raw sewage over these beds is, in the light of our present knowledge, by means of cast iron troughs of square section, laid about 1 ft. apart, and regulated by screws at the end, in order to secure the water flowing over their sides, through file notches, regularly throughout their length. In order to secure each trough having an equal rate of feed, a method of regulating the flow of sewage into them should be employed, otherwise some of the troughs will be passing more sewage than others. Wooden troughs have been tried at Sutton, but the warping action under the rays of the sun is so considerable as to largely diminish their usefulness. In the original "bacteria tank," however, no such precautions were used, the sewage being run straight on to the top of the burnt ballast.

In addition to this set of beds filled with coarse stuff, a second series of the same capacity should be constructed at such a level that they can be filled without pumping from the first. These should be filled with the fine coke or ballast passed by the sifting in the first instance, but the fine dust should be rejected.

If it should be desired to obtain a still more perfect effluent, and thus to realise the ideal of perfection, namely, an approach to drinking water, another set of filter beds of the same area as the foregoing may be provided in those cases where the levels permit, and filled with very fine breeze or fine sand, such as that used by the water companies.

It will be understood that I am not proposing to give engineering instructions as to the most suitable manner of constructing these tanks. That is not my province; but it is quite open to me to indicate the simplest method, where local circumstances permit, as on a clay soil, in which case all that is necessary for the construction of such a bed, or set of beds, is to dig into the clay to a sufficient depth, burn it, and return it to the pit, which, after being suitably provided with drainage pipes, penstocks, &c., will be fully equal in working capacity to a similar area enclosed with the most ornate descriptions of masonry. In fact, as already described elsewhere, this method has been most usefully and economically followed at Sutton at my suggestion, and under the direction of Mr. Greatorex, C.E., and Mr. Chambers Smith, C.E., at a cost of about 1,000*l.* per acre, whereas the old plan of building brick and concrete tanks, &c., involved a far larger cost, the excess being absolutely unnecessary. The latest bed constructed on this principle at Sutton cost, according to Mr. Chambers Smith, only 3*d.* per foot super.

The filter beds, or rather "bacteria beds," as I prefer to call them, having been provided, should be charged with the crude sewage, which should be strained as already described in the first part of the chapter. The method of this charging may be somewhat in the following manner:—First, the sewage is passed on to No. 1 bacteria bed filled with the coarse burnt ballast or coke. For convenience, these separate beds may be described as the "coarse grain beds;" and the second series, filled with the finer material, as the "fine grain beds." After No. 1 is filled, No. 2 is charged, and so on until No. 8 bed is filled, by which time No. 1 should be ready for a second charge. Let it be presumed that it takes an average of one hour to fill a bed, two hours to rest full, one hour to empty, and three hours to rest empty, we shall have a cycle of eight hours before the bed is ready for work again, so that it can thus receive three charges per day, if necessary, without interrupting the continuity of work. These eight beds filled three times per day will answer for the daily period of twenty-four hours, the ninth division being reserved for rest when it is necessary to place one out of action. In fact, it would be a useful arrangement to systematically throw one tank out of action each day, thus giving them all a day's rest once in nine days.

It will of course be understood that this cycle of work will in most cases be subjected to considerable modification according to circumstances, night, flow, &c.

Each day, or as frequently as necessary, the surface of the beds should be raked over to break up any deposit which might otherwise accumulate, and tend to diminish the access of the air to the interior of the bed, and so prevent the perfectly free drainage of the water from the porous material of which the filter is composed.

The effluent water, or "filtrate," from the coarse grain beds, should then be sent on to the second set, or "fine grain beds," which should be treated in precisely the same way, and so on to the third set, or "sand beds," if they are provided, when the resulting filtrate will be such as to far more than answer every possible requirement, and be ready for discharge into either ornamental waters or cleanly brook.

It will be understood that, with proper screening and care in working the beds, these might be one half the area given, and capital results might be safely predicted. Again, if the depth of the tanks be doubled, the area will be reduced to one-half. In short, as I have repeatedly stated, each case must be dealt with according to local conditions.

As a modification of this, the original unprotected method adopted at Sutton, the following protected system has recently been put forward in competition with that and the Exeter "septic tank" process. In this new departure, that is, new in detail but not in principle, the material of which the filter is composed is laid in stratified layers, commencing with the finest at the bottom, and progressing upward in layers of less and less degree of fineness until the topmost are composed of rough material, such as that rejected by a one-inch mesh, for the reason that when the sewage is distributed over the surface of the filter in as fine a state of division as possible, the coarse particles will be arrested by the coarse grain of the filter at the top, and, in succession, those next in size by the various layers, until the bottom finest-grained layer will keep back the finest particles in the sewage liquid, and thus each section of the filter will have its own section of work to accomplish.

A further advantage claimed for this system is that in the event of road drift or mineral matter of like nature finding its way on to the filter, the various sized particles will work their way through the filter until they meet that particular stratum to which, by reason of their size, they belong, and there being arrested, simply serve to increase the granular layer of their particular size, and so assist in the process of filtration. Even let it be assumed that no means are adopted for keeping out the sand, how long would it be before such an accumulation would take place as to render it necessary to re-sift the whole of the filtering material, and thus restore to a working condition either this filter or the original "bacteria tank" at Sutton? Obviously, years, and even then the expense would be but trifling. As will be seen presently, however, the means most suitable for distributing the sewage over the surface of the filter will also enable the sand to be kept out most effectually, and therefore no trouble need be anticipated in this respect.

The ordinary way to construct a filter is to build a tank with solid walls and a solid bottom, and the only air which can gain admittance is that which finds its way in through the top. Suggestions have been made to aërate a filter by blowing air from time to time into the bottom of the filter, and thus forcing it up through the bed. Such are the schemes of Lowcock in England, and Waring in America. Instead of thus using force, the inventor lets the air find its way into the filter in all directions, top, bottom, and sides.

In a filter constructed with coarse material at the top, graduating to fine at the bottom, a slow stream of sewage amounting almost to drop by drop, allowed to fall on any particular portion of the surface will slowly wend its way downwards until, if there be no obstruction, it will arrive at the bottom and flow away. In passing slowly from fragment to fragment of the filtering medium, the suspended particles will be left behind, and also a large proportion of the foul matters carried in solution, the extent depending upon the fineness of the medium, and the rate of travel of the water. The organic matter so taken up by the filter, if worked continuously, under ordinary conditions, will accumulate and choke the pores; and, becoming putrescent, render the whole process a failure. To overcome this difficulty, it has been proposed to ensure a constant supply of fresh air which will support the life process of the bacteria, and if the rate at which the sewage is supplied be properly regulated, the inventors hope that the process of purification will continue indefinitely.

In order that the air should be thus introduced, the filter is built with perforated walls, and from some of these perforations air inlets are carried into the whole substance of the filter in all directions and at all depths. Such a filter may be described as answering the same object as a lung in the animal economy, the air being taken up by a multiplicity of chambers, and thus utilised to oxidise the waste organic matter as it passes through the thin-walled vessels which are pervious to the oxygen of the air as well as to the carbonic acid formed and expired in our breath. In this idea we have a wonderfully close copy of Nature's action. If successful in continuous working such a filter will be indeed self-cleansing, because thoroughly self-aërating. When once properly adjusted to take the maximum flow of sewage arriving at the works, no further attention will be required beyond occasionally sweeping the feeding troughs to prevent blockage, and perhaps now and then the surface of the filter might be raked to disturb the fibrous deposit.

The walls of the filter are constructed of ordinary agricultural drain pipes instead of bricks, and thus the wind blows direct into the bed, having free access to the interior by the system of drain pipes at various depths.

It is claimed that the rate at which the sewage can be treated by such a filter may be put at the present time at not less than one million gallons per day per acre.

The index of efficiency will be in all cases the presence of nitrates in the filtrate. The presence of nitric acid should be occasionally looked for, and as long as its presence is clearly indicated in undiminished quantity (apart from the fluctuations due to seasons) in the filtrate from any particular filter bed, that bed may be continued at work. As soon, however, as there is a perceptible diminution in the quantity of this product of oxidation of the organic nitrogen in the sewage, the bed should be given a rest. As soon as it is found that the substance of the bed is clean and sweet it may be put to work again. By thus carefully watching the progress of the work no fear need be entertained of the results of the process, which must infallibly continue to work indefinitely. That this is so will be seen by reflecting upon the manner in which the manure in a garden continues to disappear year after year, so long as it is not put on the ground in excess. For how many generations has manure been placed on our borders and vegetable beds, and in our market gardens, without the slightest indication of its presence after a very short time? The manner of its disappearance is precisely the same as that which takes place in the case of sewage in a bacteriological "filter" bed when it is eaten up by the organisms; and so long as the supply of food and air is regulated to their necessities, so long will they continue to effect its destruction without the slightest nuisance or evil effects of any kind.

The following question has often been asked me by persons interested in the subject, but who have not had the opportunity of studying it:—"How is it that the sewage matters are destroyed in the bacteria bed?" and, in reply, I have often given the above instance of a simple example, which, putting the matter in the form of common knowledge, needs no further explanation to show that the process is founded upon Nature's laws, which are immutable.

CHAPTER XI.

THE PURIFICATION OF THE THAMES.—Part I.

There are many persons still living who remember the condition of the river Thames before 1855, when the Metropolitan Board of Works was constituted for the express purpose of putting an end to the state of things that prevailed at that time. The history of the work which has resulted in effecting the great improvement which has taken place in the river has never yet been written in its entirety, the story being wrapped up in numerous official reports, and in papers which have been read from time to time before various societies. A complete work upon the subject would involve such numerous extracts from these as to make the present chapter so voluminous as to be tiresome to the reader, and I therefore propose to indicate only in outline the chief points, naturally giving prominence to the method of treating the sewage at the two outfalls as being of more immediate interest to my readers.

Of all the evils from which London suffered, the most manifest and the most detrimental to the health and well-being of the inhabitants was the extremely defective sewerage system, and with this the accompanying evil that all the filth of the vast metropolitan population was poured into the river in the very midst of the most populous quarters. The sewers were under the control of Commissioners appointed for the purpose by the Crown. They were originally intended to carry off only rain water from the streets, the open ground, and the roofs of houses. But upon the compulsory abolition of cesspools, which was effected by the Metropolitan Commissioners of Sewers under the provisions of the Act of the year 1848, the sewers became the vehicle for carrying into the river all the excreta and waste water of the population. Most of the sewers, having to pass under the low grounds on the margin of the river, discharged their contents at, or about, the low-water level, and at the time of low water only. As the tide rose it closed the outlets, and thus the sewage flowing from the high grounds accumulated in the low-lying portions of the sewers, where it remained stagnant in many cases for eighteen out of the twenty-four hours. During this stagnation the heavier ingredients fell to the bottom, and from day to day accumulated in the sewers, besides which, in times of heavy and long-continued rain, and more particularly when much rain fell at the time of high water in the river, the closed sewers were unable to store the increased volume of sewage water, which thus rose through the house drains and flooded the basements of the houses.

The mischief caused by emptying the sewers into the Thames in the middle of London was of course intensified by the circumstance of the discharge taking place at the time of low water only. The sewage was carried by the receding tide up the river to be brought back to London by the falling ebb tide, there to mix with each day's additional supply, the progress of many days' accumulation towards the sea being almost imperceptible except in periods of heavy flood. Moreover, the small volume of water in the river at low water was quite incapable of effectually diluting and neutralising the offensiveness of the vast quantity of sewage poured into it. Thus were the Thames and its tributaries turned into veritable sewers, and the broader reaches of the river as it then was, such as that between Westminster and Waterloo Bridges, had their banks covered with accumulations of offensive mud, which was exposed at low water, and in warm weather, under the influence of the sun, gave forth exhalations of a most objectionable character.

In consequence of this state of things, a Royal Commission, appointed in 1853 to inquire into the state of the Corporation of the City of London, recommended the division of the metropolis into municipal districts, and the creation of the Metropolitan Board of Works as the central body, the members of which should be elected by the Boards or Councils of the several districts, including the City. This central body they thought should be entrusted with the management of public works in which all parts of the metropolis had a common interest. It will be understood that there were many functions entrusted to this body which need not here be mentioned, as our express subject is that of the purification of the Thames, and we need not dwell on questions of purely political aspect.

The Metropolitan Board of Works thus created, as soon as possible after its formation, applied itself to the consideration of what was undoubtedly the most important question with which it had to deal, namely, the improvement of the sewerage system and the diversion of the sewage from the Thames as it flowed through London. The main objects to be attained were the interception (so far as practicable by gravitation) of the sewage, and of so much of the rainfall with it as could be reasonably dealt with, and its conveyance to points of discharge at some distance down the river below London; the substitution of constant instead of intermittent flow in the sewers; the abolition of stagnant and tide-locked sewers, with their consequent accumulation of deposited matters; and the substitution of deeper and better sewers, with improved outfalls.

After the usual debates amongst various authorities, which are now of only historical interest, the Board proceeded with the construction of the present main drainage system. For this purpose three main intercepting sewers were constructed on each side of the river, and termed respectively the high-level, the middle-level, and the low-level sewers. The high and middle-level sewers on the north side of the Thames discharged by gravitation, but the low-level sewers discharged only by the aid of pumps. The three intercepting sewers were made to converge and unite at Abbey Mills, West Ham, where the contents of the low-level sewers are pumped up to a higher level, and the aggregate stream of sewage flows through the northern outfall sewer to Barking Creek, and then into the river by gravitation.

On the southern side of the Thames the three intercepting sewers were made to unite at Deptford Creek, where the sewage from the low level is pumped to the higher level, and the united stream flows in one channel through Woolwich to Crossness, where it is pumped into reservoirs, and thence flows into the river. The greater part of these works was completed by the year 1864, in which year sewage began to flow into the river at Barking Creek, and in 1865 the works on the south side of the river at Crossness were opened by H.R.H. the Prince of Wales.

The following short statistics will convey some idea of the magnitude of these main drainage works:—

North Side of the Thames.

Sewer.	Length. Miles.	Diameter.
Northern high-level sewer	$7\frac{1}{2}$	from 4 ft. to $9\frac{1}{2}$ ft. by 12 ft.
Northern middle-level sewer	$9\frac{1}{2}$	from $4\frac{1}{2}$ ft. by 3 ft. to $10\frac{1}{2}$ ft.
Piccadilly branches	$2\frac{3}{4}$	
Northern low-level sewer	$8\frac{1}{4}$	from $6\frac{3}{4}$ ft. to $10\frac{1}{4}$ ft.
Hackney branch	$2\frac{1}{2}$	
Isle of Dogs branch	$1\frac{7}{8}$	
Western sewers, main line	$5\frac{1}{8}$	from 4 ft. by 2 ft. to 5 ft.
Fulham branch	$1\frac{1}{3}$	
Acton line	$1\frac{3}{8}$	
Northern outfall sewer	$5\frac{1}{2}$	three culverts each 9 ft. in diameter.

South Side of the Thames.

Sewer.	Length. Miles.	Diameter.
Southern high-level sewer	$5\frac{3}{8}$	from $4\frac{1}{2}$ ft. by 3 ft. to $10\frac{1}{2}$ ft.
Effra branches	$7\frac{1}{4}$	from 7 ft. to $10\frac{1}{2}$ ft.
Southern low-level sewer	$9\frac{1}{2}$	from 4 ft. to two culverts each of 7 ft.
Bermondsey branch	$2\frac{3}{4}$	from 5 ft. to $5\frac{1}{2}$ ft.
Southern outfall sewer..........	$7\frac{1}{2}$	$11\frac{1}{2}$ ft.

Pumping stations :—Abbey Mills, eight engines, Crossness four engines, Deptford four engines, Pimlico four engines.

The total length of the main intercepting sewers was thus about 82 miles, they are capable of intercepting daily 63 million cubic feet, or nearly 400 million gallons of sewage, and the total cost of the works was about 4,600,000*l.* The average daily quantity of sewage discharged is about 200 million gallons.

So far all went well for a time, the river as it flowed through London no longer showed signs of pollution, where before it was a mass of stagnant corruption, and it appeared for a time that the alteration in the discharge by sending it into the river twelve miles below London Bridge, at Crossness and Barking Creek at high water, instead of in London itself at low water, would effectually prevent all further cause of nuisance. Ten years after the opening of these works, however, it appeared that certain signs were not wanting that the river was being over-taxed, and it was seen that instead of the discharge being confined to the first part of the ebb-tide, as originally intended, it was extended over several hours in consequence of the increased volume of water which had to be dealt with, and which could not be retained in the storage reservoirs for a sufficient length of time, and therefore overflowed into the river before the time of high water. The result was to repeat to a large extent the experience of years before when the sewage ran into the river at low water, as part of the sewage was thus carried by the tide to the upper reaches instead of being carried down into the larger volume of water in the lower reaches, and in hot and dry weather the full purifying power of the river could not be utilised. So marked was the effect which was brought about by the increased number of intercepting sewers constructed from time to time to prevent flooding in many parts of the metropolis in response to the demands of various districts, as the effect of previous work became more and more marked, that in 1882 a Royal Commission, with the late Lord Bramwell as its chairman, was appointed "to inquire into and report upon the system under which the sewage is discharged into the Thames by the Metropolitan Board of Works; whether any evil effects resulted therefrom; and, in that case, what measures could be applied for remedying and preventing the same."

As a result of their inquiries the Commissioners reported that the London sewage ought not to be discharged in its crude state into any part of the Thames; that the solid matters should be separated from the liquid by some process of deposition or precipitation, and should be applied to the raising of low-lying ground, or burnt, or dug into land, or carried away to sea. That the liquid portion of the sewage remaining after precipitation might, as a temporary measure, be then allowed to pass into the river. *That its discharge should be rigorously limited to the period between high water and half-ebb of each tide.*

In consequence of this decision, which was in accordance with the evidence I had the honour to submit to the Commissioners, as the outcome of the results of a large number of experiments carried out by Sir Joseph Bazalgette, Dr. Dupré, and myself, on the London sewage, for the express purpose of submitting them in evidence before the Commissioners, who were kind enough to listen to my suggestions with the most encouraging attention, the Metropolitan Board pro-

SLUDGE SHIP RETURNING EMPTY.

[*To face p.* 143 (*No.* 2).

ceeded to make further trials for the purpose of obtaining definite information before constructing the works on a sufficiently large scale. As a result of these, in January the Board entered into a contract for the construction of the Northern Outfall Precipitation Works at Barking Creek at a cost of 406,000*l.*; and followed this action by another contract in May, 1888, for similar works for the southern side at Crossness at a cost of 259,816*l.*

As it had been decided to adopt the system of carrying the solid matters precipitated from the sewage to sea, a trial vessel was obtained from the Barrow Shipbuilding Company in 1887 at a cost of 16,353*l.* This vessel was the outcome of competitive plans, and has been found to do its work in a most admirable manner, as also have the five additional vessels constructed on the same pattern, which form the present fleet of six steamers, each having a tonnage of 1,000 tons; the additional five costing, however, from 24,000*l.* to 26,000*l.* each.

In general design these vessels may be described as consisting of four oblong tanks, viz., two aft and two forward, having a floatage space between them and the bottom of the vessel, with engines and twin-screws to drive them. When the vessel is unloaded the bottom of these tanks is 6 in. above the surface of the water, as also is the top of the sludge when the tanks are full. When the outlet valves at the bottom of the tanks are opened by means of screws worked from the deck, the vessel rises until the tanks are empty. When the valves are fully opened the whole cargo of 1,000 tons can be discharged in about seven minutes.

In consequence of numerous inquiries as to the plan which the late Metropolitan Board of Works decided upon adopting, and in response to a request from the Institution of Civil Engineers, I submitted the outlines of the method and the reasons for them to that body in a paper read in January, 1887.

In this paper I drew attention to the following points :—

(1) Detrimental effect of an excess of chemicals.

(2) The limited reduction of the organic matters in solution by chemical treatment.

(3) The use of iron salts as an auxiliary to lime when necessary.

(4) The action of bacteria in completing the process of purification.

(5) The objection to filtration of crude sewage on the lines as then understood.

(6) Final purification of the effluent by proper filtration through land.

(7) Subsidiary treatment of effluent when necessary.

(8) Aëration as an aid to bacterial life.

(9) Disposal of the solids.

CHAPTER XII.

THE PURIFICATION OF THE THAMES.—Part II.

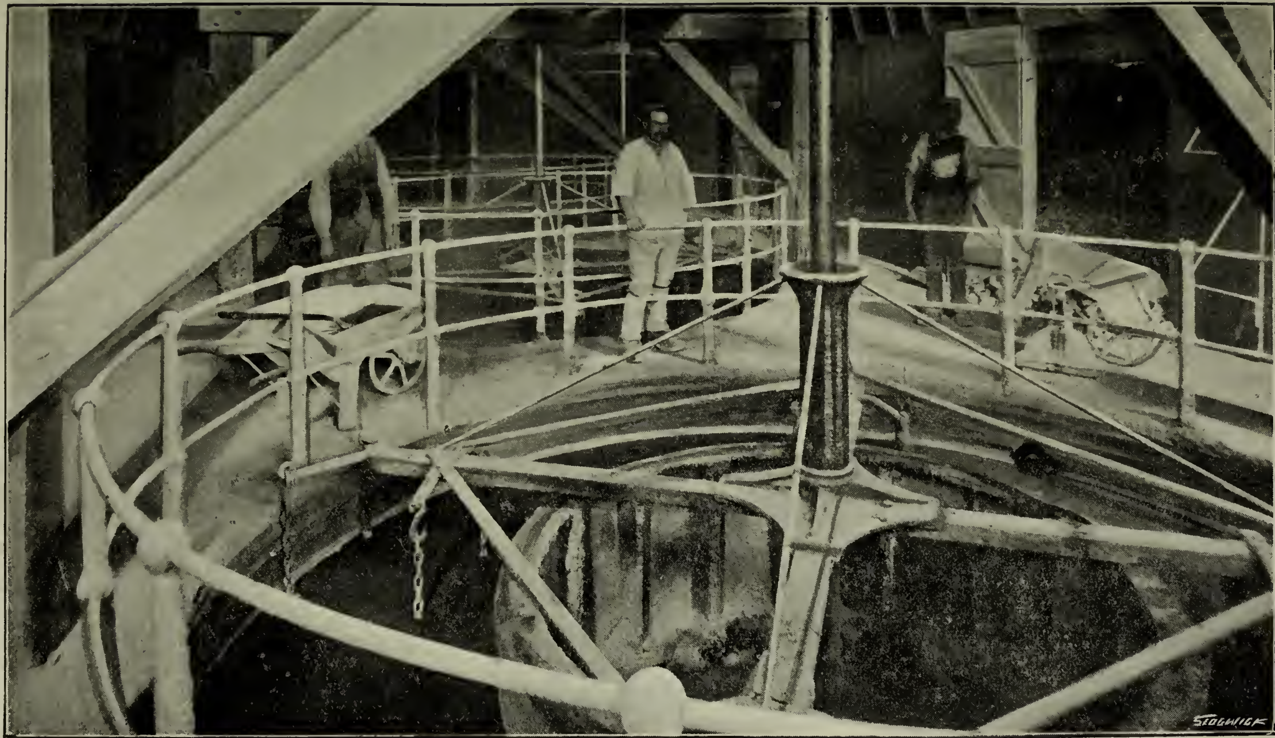
As already mentioned, the method adopted by the Board was first submitted to the Royal Commissioners by myself in 1884, and the following extract from that evidence will clearly indicate the position as it then stood :—

" We found that whatever process might be used which could be applied in practice would have but a very slight effect in removing the dissolved organic matter. Then we came to the conclusion that the only effect which might be expected would be the removal of the suspended matters, and that we might neglect for this purpose the whole of the dissolved matters. Proceeding with our experiments we found that the use of four grains of lime and one grain of proto-sulphate of iron was sufficient practically to remove the whole of the suspended matter and the grosser part of the offensive odours. In fact, we were satisfied that it would do all that was required to be done with the London sewage at Barking and Crossness, and that the effluent, if discharged into the Thames there, would certainly be hardly noticeable; and by the time it was thoroughly diluted with river water it would be to all intents and purposes invisible ; and that all effect of the sewage in the river in point of appearance would be annihilated. The matters in solution in the sewage would still be there; but the matters in solution are those which are more readily oxidised by the action of the river, and so would disappear at a much greater rate than they do at present."

As will be seen from the foregoing summary of the report of the Commissioners, they agreed with these views, but with the following proviso :—" 10. But we believe that the liquid, so separated, would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a *permanent* measure. It would require further purification, and this, according to the present (1884) state of knowledge, can only be done effectually by its application to land."

This safety clause, as it may be called, is now fully met by the results of the experiments described in the previous chapter, and which can be put into practice on the whole of the London sewage whenever it may be deemed to be necessary.

The sewage north of the Thames is delivered at the Northern Outfall by three 9 ft. sewers. After passing the screens it receives its proper quantity of lime, which varies with the strength and rate of flow of the sewage. At the liming station the lime, after being weighed as it is taken from the store, is placed in large mixing trays 15 ft. in diameter, fitted with four revolving arms, to each of which a heavy rake is suspended. Sufficient water is then let into the tray to slake the lime. This being accomplished, more water is added and the mixing-arms are rotated by steam-power, the lime and water being thus stirred into a cream as dilute as possible. Water is continually admitted and the cream of lime flows out into a channel leading to the lime-water tanks, where it meets a large access of water, and is thereby diluted and carried into the tanks, six in number, each having a capacity of about 100,000 gallons. The



LIME STIRRERS, NORTHERN OUTFALL, BARKING CREEK.

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mixture of the lime and water is further facilitated by the fall from the trough into the tank, and thus the whole bulk is kept in agitation until the tank is full. The lime-water so obtained is forced by centrifugal pumps to an overhead tank placed on the top of the boiler-house and lime-store, whence it is drawn off as required. At first, the lime-water was made with crude sewage and the top liquor drawn from the sludge-settling channels, but the extent to which the lime is destroyed by these was so great that they have been replaced at Crossness by river water.

After receiving the lime, which at Crossness is entirely in solution, as originally intended, the sewage passes the iron-water station where the solution of iron sulphate is added. No special mixing arrangement is applied, as the rolling motion of the sewage as it passes along the sewer is found to answer the purpose. The iron salt is dissolved in a tank of water heated by a steam coil, and the concentrated solution thus obtained is sufficiently diluted and passed direct into the sewer containing the already limed sewage. The precipitation effected by the combined action of the lime and iron is completed in thirteen precipitation channels.

The method of discharging the sludge from the precipitation channels to the sludge-settling channels is by sweeping the deposit obtained from the action of precipitation through culverts leading under the main sewer to the receiving-chamber at the engine-house, whence it is pumped into the settling channels. On its way to these, the sludge is again passed through gratings to collect rags, &c., which may have escaped the first filth-gratings. The quantity of solid matter extracted by the combined action of the double set of gratings is between 80 and 100 tons per week. A destructor furnace is built close to the filth hoist, or first set of gratings, and is used for calcination of the refuse.

The following are the results of an analysis of a sample of this refuse:—

Analysis of Filth from Gratings at the Northern Outfall.

		Per cent.
Moisture		77·2
Wood		1·0
Coarse string and fibre		0·7
Coarse rags		0·4
Fine rags, pulp, &c.		16·6
Very fine fibrous matters, sand, earthy matter, &c., containing volatile organic matter, of which one-fiftieth is nitrogen	51·5	
Phosphoric acid	2·6	4·1
Sand, earthy matter, &c.	42·2	
Moisture	3·7	
	100·0	100·0

The amount of nitrogen in the fine fibrous and earthy matter is only 0·041 per cent., and of phosphoric acid 0·11 per cent. of the whole. While, therefore, its manurial value is but slight, it would appear to be well suited, from its fibrous nature, for making coarse paper; and experiments on a working scale are in progress with the view of ascertaining its adaptability for that purpose.

After the sludge has settled and the top water has been drawn off by means of sliding penstocks, the sludge is let into the storage tanks under the settling channels, whence it is forced by direct-acting pumps to the ships. Formerly the water drawn from the settled sludge was pumped to the liming station, but alterations have been made which enable this liquor to be separately treated with lime and iron, and after such treatment to settle in the sewage-precipitation channels.

The sewage of London south of the Thames is carried by an 11 ft. 6 in. sewer to Crossness. As the whole of the sewage was already screened, it was not necessary to erect an additional filth hoist as at the Northern Outfall works, except on a small scale for the sludge. The liming station is admirably suited to the requirements of the works, practically the whole of the lime being in solution before its addition to the sewage. The lime mixers at Crossness are similar to those at the Northern Outfall, and are 12 ft. in diameter. The charge of lime varies between 1 ton and 1½ ton, to meet the flow of sewage. The lime, having been formed into a cream, is discharged from the mixers into a culvert, where it meets with river water pumped for that purpose, and then through a series of tanks, six in number, each of a capacity of about 40,000 gallons. In two of these tanks a pair of Gabbott stirrers, 12 ft. in diameter, are fixed. The lime-water passes first through one of the end tanks and thence over weirs into four others successively, into the lime-water culvert. The quantity of river water pumped for this purpose is between 2,500,000 gallons and 4,000,000 gallons daily. The quantity of commercial lime taken for making the lime-water is about 110 grains per gallon, of which, on an average, about 70 per cent. is in solution. It will be noticed that it is necessary to employ an excess of lime to allow for the hard core, and the neutralisation of a portion of the lime by the carbonic acid in the river water employed for its slaking and solution. The iron water is made at Crossness by the simple agitation of the crystals of iron salt with water in an ordinary mixing mill from which the rollers are removed, stirring arms being substituted in their place, the effect being equally efficacious with that of the steam-coil at the Northern Outfall works. The precipitation-channels at Crossness are not fitted with the telescope weirs for the purpose of emptying the channels, but with the ordinary floating arms, the bulk of the effluent, however, falling over the weirs as at Barking Creek. In other respects these channels are almost identical. In consequence of the more effective arrangements for making lime water at Crossness, the results have been much more satisfactory than those at Barking Creek. The method of collecting the sludge, settling it, and loading the ships is identical with that at the Northern Outfall works.

The fleet of vessels, each capable of carrying about 1,000 tons, employed for the purpose, carried to sea during the year 1894, 2,052 cargoes of sludge, of which quantity 1,380 cargoes, containing 90·7 per cent. of moisture, were conveyed from the Northern Outfall, and 724 cargoes, containing 91·25 per cent. of moisture from the Southern Outfall. The discharge takes place in the Barrow Deep, commencing at a point ten miles east of the Nore, and proceeding thence from five miles to ten miles down that channel, which is unused for traffic, being about half way between the Swin Channel, or route for vessels proceeding north, and the Princes Channel, which is the ordinary route for vessels going south. As the sludge is discharged from the bottom of the vessel, some 10 ft. under water, and is thus agitated with the sea water by the action of the twin-screws, the diffusion of the sludge in the water in the wake of the vessel is very complete, so much so that when there is but a slight ripple, the visible effect of the sludge is lost after a few minutes. The sand and earthy matters soon separate by subsidence, and the animal and vegetable *débris* is rapidly consumed by the organic life in the sea water. This is evidenced by the fact that, although about 10,000,000 tons of sludge have now been deposited in this part of the estuary, the most careful microscopical examination and chemical analysis fail to detect more than the merest trace of the mineral portion of the sludge, either in dredgings from the bottom of the channels or on the surface of the sandbanks, which are now as clean as in 1888, before more than a few trial cargoes had been discharged. The cost of this operation has been found to work out to about 4¼*d.* per ton of sludge.

Character of Sewage and Effluent.—The effect of the general desire to lessen the pollution of the Thames by refuse from manufactories has been largely to increase the quantity of foul matters received at the outfalls, and this has necessitated careful watching. In almost every case, however, it has been satisfactory to find that such increases in the pollutive matters have been fully met by the treatment adopted. The average character of the sewage before and after treatment is set out in Table I., Appendix I., showing the monthly averages of the daily analyses of samples taken every two hours, day and night, at each outfall, during the year 1894. These include storm water, which increases the average amount of suspended matters left in the effluent, as in many instances the quantity found in the dry weather sewage is considerably lower. It will be seen that at Crossness, in consequence of the better solution of the lime water, there is a material reduction of the matters held in solution, the oxygen absorbed from permanganate in four hours being reduced from 3·7 to 3·1 grains per gallon, or 17 per cent., a result which agrees closely with the preliminary laboratory experiments.

At the Northern Outfall, the results are not so good. By analyses it is shown that the average quantity of suspended matters in the sewage at the Southern Outfall was 31·5 grains per gallon, and at the Northern Outfall 29·8 grains per gallon; results which agree very closely with the quantities determined in 1883, and given in evidence before Lord Bramwell's Commission, with the exception that the former is now somewhat stronger than at that date. The average results then found over a period of three months were, Southern 26·26 grains per gallon; Northern 29·1 grains per gallon. Having regard to all the circumstances, it would probably be difficult to obtain a closer agreement, especially when it is considered that the actual quantity of sludge obtained as measured in the sludge stores, after correction for quantity and effect of the chemicals used, moisture and matters left in the effluent, agrees with the above results within a fraction of a grain.

Cost.—In a report to the late Metropolitan Board of Works on the 24th November, 1884, by Sir Joseph Bazalgette and myself, an estimate for the precipitation of 162,500,000 gallons of sewage at the present outfalls was submitted as follows:—

Chemicals	£22,000
Barging to sea	37,200
Labour and pumping	26,300
	£85,500
10 per cent. contingencies	8,500
If effluent is treated with about four tons of manganate per day for three months in the year	6,000
	£100,000

First outlay (estimated) £1,140,000, including £131,000 for barges.

The manganate has not been found essential, as was originally suggested, and was provided for only as a safeguard. The working expenses are thus reduced to 94,000*l.*, which, with interest on capital at 3 per cent., or 34,200*l.*, equals a total of 128,200*l.* per annum.

The following are the figures actually obtained in practice during the year 1894:—

Working expenses (including chemicals, &c.), for precipitation	£71,119
Barging to sea	30,212
	£101,331
Interest on capital	25,400
	£126,731

First outlay (capital), £932,000.

This close approximation to the estimate of 1884, especially considering the difference in the daily volume of sewage then taken into account, viz., 162,500,000 gallons, as against the volume in 1894, viz., 203,000,000 gallons, may be regarded as satisfactory. If the estimated working expenses, viz., 85,500*l.* are increased proportionately to the volume of sewage, the original estimate will be raised to 106,800*l.*, as against the actual cost of 101,331*l.* These figures, coupled with the results obtained, speak for themselves as to the wisdom of the action of the late Board with reference to the question of the treatment of the sewage of London.

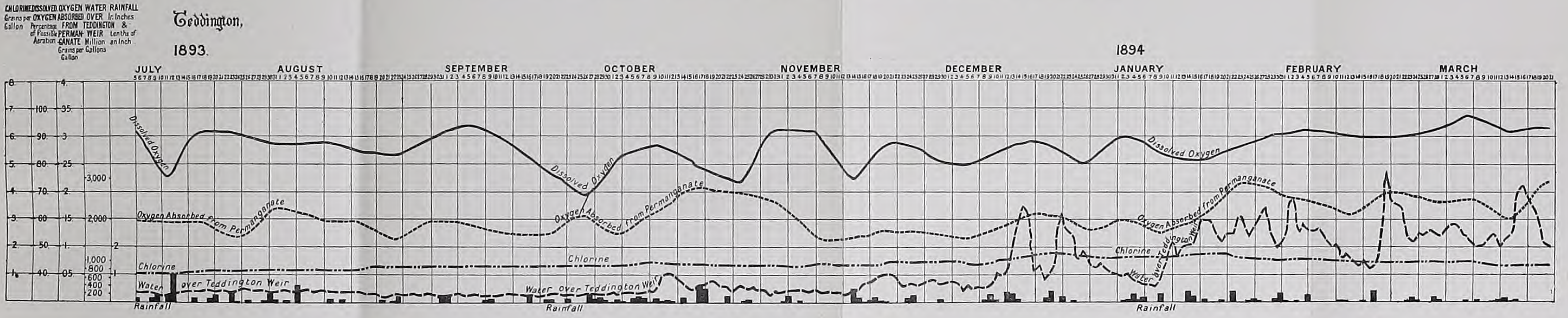
It will be of interest to note that as a rate of $\frac{1}{4}d.$ in the pound produces 35,320*l.* per annum, the cost of working is less than a rate of $\frac{3}{4}d.$ in the pound, or, including the repayment of loan and interest on capital, only a fraction over 1*d.* in the pound. In comparison with this result of a capital expenditure of 932,000*l.*, and a working expense of only 101,331*l.* per annum, it may be of interest to shortly glance at some of the alternative proposals which have been made for dealing with the sewage of London. One proposal was to remove the outfalls to Hole Haven, below Gravesend, at a first cost of 4,000,000*l.* sterling, there to erect the necessary works and precipitate as at present. This, it will be seen, would have involved a first outlay of about 5,000,000*l.* sterling. Another, very strongly and influentially supported, was to expend 12,000,000*l.* sterling and carry the sewage to the Maplin Sands. Again, another authoritative opinion, expressly invited by the present London County Council, was to the effect that in the event of the present scheme proving unsuccessful, the next alternative would involve an outlay of 8,000,000*l.* sterling. Many other proposals for the chemical treatment of the sewage alone, or in combination with extensive farming operations, have been made from time to time, the lowest estimate for which involved an annual cost of double that of the present scheme.

It will thus be seen that on financial grounds alone the adoption of the system which I had the honour of submitting to Lord Bramwell's Commission in 1884 has been of vast benefit to the ratepayers of the metropolis; in addition to which the information on the general question of sewage treatment which that system has been the means of disseminating throughout the country, has enabled alterations to be made on large numbers of sewage works, resulting in greater efficiency and considerable economy, to the advancement of pure sanitation and the relief of the public purse.

The improvement in the state of the river since the opening of the outfalls in 1890-2 has been so great that many observers have evinced surprise that such results could have been achieved by such apparently simple means. The secret, if secret there be, lies solely in the fact that while the addition to the sewage of certain purifying agents was evident to ordinary observation, the invisible but far more potent action of the bacteria already in the sewage and in the river water to destroy the organic matters remaining after chemical treatment, was not so evident; and thus, although I clearly indicated their action in 1887, their work has been overlooked by the majority who largely judge by external appearances.

EXAMINATION OF THE RIVER THAMES FROM TEDDINGTON TO THE NORE, 1893—4.

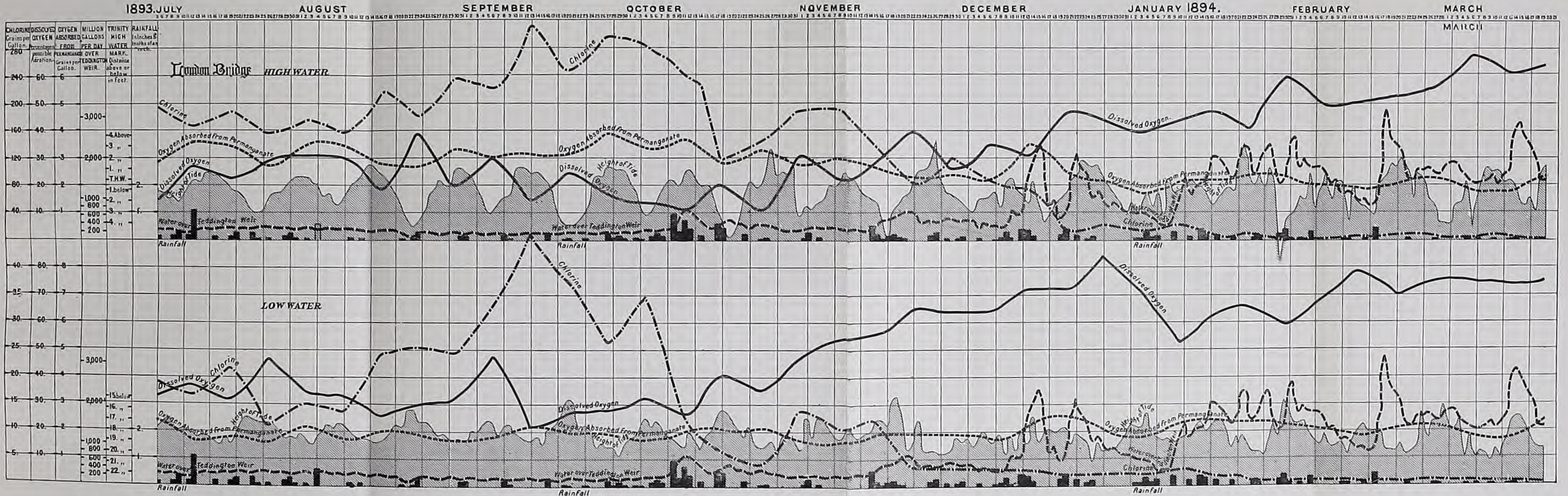
Diagram showing the Results of the Analyses of Water collected at Teddington, above Lock.



To face p. 154 (No. 1).

EXAMINATION OF THE RIVER THAMES FROM TEDDINGTON TO THE NORE, 1893—4.

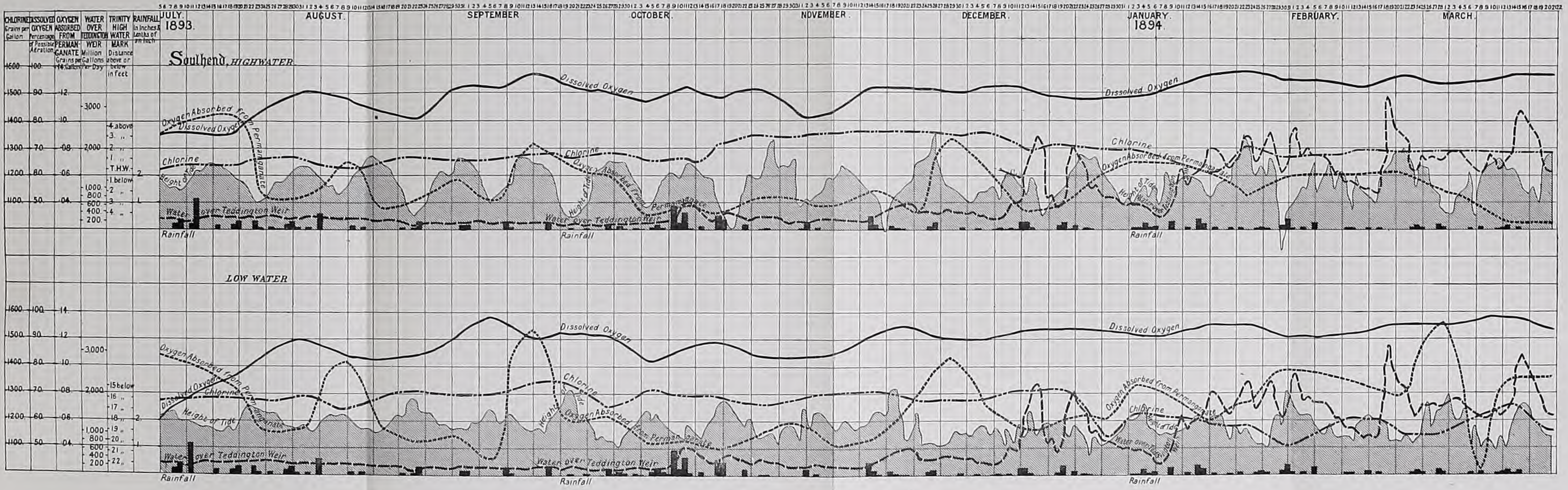
Diagram showing the Results of the Analyses of Samples collected at London Bridge.



To face p. 154 (No. 2).

EXAMINATION OF THE RIVER THAMES FROM TEDDINGTON TO THE NORE, 1893—4.

Diagram showing the Results of the Analyses of Samples collected at Southend.



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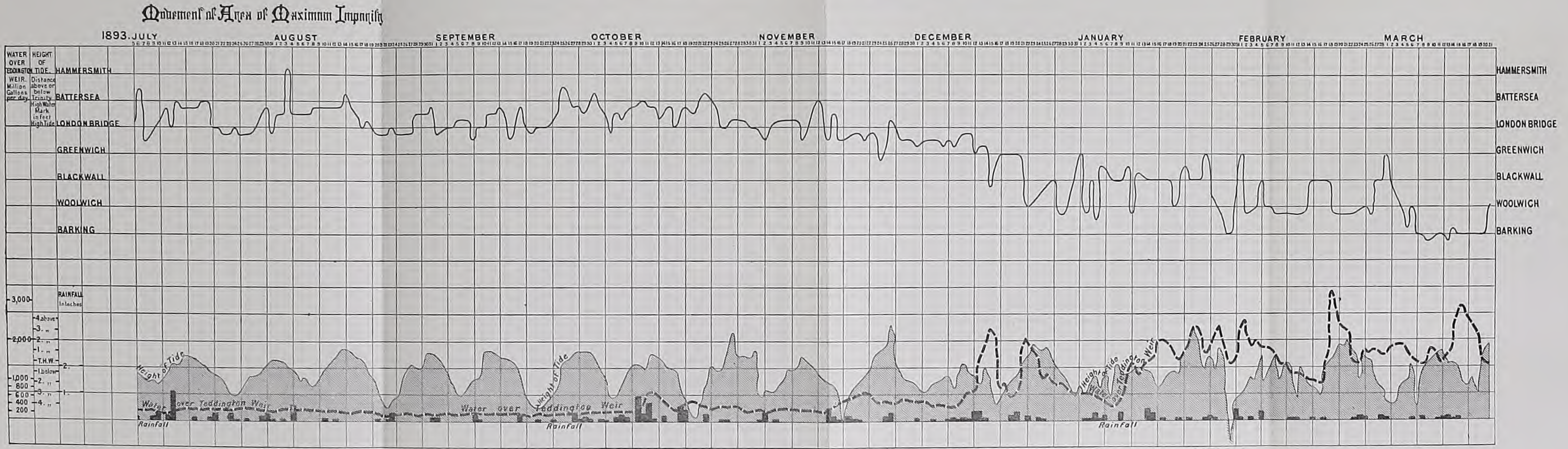
EXAMINATION OF THE RIVER THAMES FROM TEDDINGTON TO THE NORE, 1893—4.

Diagram showing the Movement of the Area of Maximum Impurity.



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CHAPTER XIII.

VENTILATION AND DEODORISATION OF SEWERS.

The various means for preventing as far as possible the formation of offensive gases in sewers, and for disposing of such gases when formed by ventilating the sewers, have received the earnest attention of various authorities for many years, and have necessarily been under the constant investigation of persons interested in the sanitary conditions of towns. The mere enumeration of all the schemes suggested and the experiments tried would occupy too much space to no advantage. Prior to the year 1850 the sewers of London were almost wholly ventilated by means of gully gratings in the gutters at the edge of the foot-pavements. These gratings were at times mediums of great offence to foot passengers and to residents in the houses adjacent, and it became necessary to trap them. In the year 1849, Mr. Henry Austin, the consulting engineer to the Metropolitan Commissioners of Sewers, recommended that the trappings should only be proceeded with as other means of ventilation were provided, otherwise the sewers would be rendered dangerous, and Sir Joseph (then Mr.) Bazalgette was directed by the Commissioners to make a series of experiments as to ventilating sewers by means of shafts leading from the crown of the sewers to gratings in the centre of the road. These experiments showed that a reduction of the nuisance followed from ventilating through shafts and trapping the side gullies, and consequently that method of ventilating the sewers of the metropolis was gradually adopted.

In view of the considerable improvements brought about by this alteration, the system has now become almost universal. The change, however, did not reduce the quantity, or materially affect the nature of the gases rising from the sewers in the streets. In their diluted form the sewer emanations were far less perceptible to pedestrians and residents than formerly, and were less liable to be injurious to health; but as they were still at times a nuisance, it appeared desirable either to dispose of them in some other way or to render them inoffensive before their discharge into the streets. Of the numerous schemes for effecting this object which have been suggested from time to time since 1850, by far the greater number have been found on careful examination to be either wholly impracticable, or quite unsuitable for a large system of sewers.

Sewer gases are evolved during the decomposition of substances passing through or deposited in the sewers; and this decomposition takes place to a greater extent when the contents of the sewer are in a stagnant or nearly stagnant condition. A much less quantity of gas is evolved when the temperature is low and the sewage is diluted and flowing through the sewer freely. It is therefore of the first importance that sewers should be constructed with as good a fall as practicable, and should have a copious flow of water through them. The discharge into the sewers of specially offensive trade refuse or filth also gives rise to offensive gases in the sewers. Although to cause such a discharge is an offence, it is unfortunately done to a great extent, and the difficulty of detecting such practices is considerable. Another source of special nuisance arises from the discharge, from manufactories and other places, of steam or hot water into sewers. In the metropolis this is now a legal offence.

The want of sufficient water carriage is one of the principal causes of nuisance. However offensive sewage may be when stagnant, it gives off little offensive effluvium when it is fresh and largely diluted with water flowing at a fair velocity. The extent to which it is diluted determines the degree of the offensiveness of the sewage itself, and swiftness of flow removes it before material decomposition sets in. Ample flushing is therefore the best remedy. This conclusion raises the question of the efficacy of the "separate system" for sewerage in general, which is now the fashion of the day; but I am by no means certain that by this method we avoid as many evils as we are liable to encounter by its adoption.

The late Sir Joseph Bazalgette reported in 1866 as follows: — "The most efficacious and most universally applicable mode of preventing the escape of noxious gas is so to construct the sewers that a continuous flow shall be kept up in them, and to provide them with a sufficiently copious supply of water, that decomposing matters within them shall be diluted and instantaneously removed, and not allowed to settle or ferment in the sewers. Much improvement has already been effected in the ventilation of the London sewers by the abolition of the tide-locked and stagnant sewers, and much more may yet be accomplished by the introduction of a more copious supply of water."

The practice of flushing varies very considerably, both as to times and methods. In some cases the smaller sewers are usually flushed with water drawn from the stand pipes on the water companies' mains, and discharged into the sewers through hose, or by means of water vans. In some cases, however, the water is not sent at once into the sewers, but is accumulated in the shafts or side entrances, and is then suddenly discharged, the sewers being effectually scoured for some distance. A still larger head of water is sometimes obtained by the use of storage tanks, from which the water is suddenly discharged, either by hand or automatically, and in many cases this is most successful.

The escape of sewer gas is at times very perceptible at the upper end of branch sewers, and it is therefore necessary that provision should be made for flushing from the commencement or "dead ends" of local sewers, as in the absence of such flushing those sewers are in dry seasons specially liable to be sources of nuisance.

In order to prevent the escape of gases from the sewers during flushing, provision must be made for ventilation, otherwise the escaping gases would be forced through the traps into houses at every sudden discharge into the sewers, and the health of the inhabitants of every household imperilled.

The conditions governing the ventilation of sewers have been a matter of considerable debate. Many people are of opinion that temperature is the only factor. On the other hand, Mr. Santo Crimp, who has paid considerable attention to the question, is strongly of opinion that the direction of the wind is the chief controlling factor, and he has given many instances in support of his contention. The advocates of the temperature theory contend that as the temperature of the air of the sewers is lower than that of the external atmosphere, and when no other influence is at work the colder atmosphere of the sewer, being heavier than the external air, remains in the sewers; but when the outer air becomes colder, and consequently heavier than the sewer air, it presses down through some of the openings of the sewer and drives out the warmer and lighter air through other openings.

For instance, in the cool of the evening in hot dry seasons, at which times the nuisance from ventilators is stated to be probably at its worst. During the autumn and winter months the average temperature of the air of sewers is warmer than the external atmosphere by about 7 deg. Fahr. In spring, the temperature is about equal; and in summer, the external day temperature averages over 3 deg. warmer than that in the sewers. At night the temperature of all sewers, at all times of the year, is usually higher than the temperature of the external air. It will therefore be seen that throughout the greater part of the year, the law by which the heavier external air forces out by its greater weight the warmer air of the sewers is in operation; and, if proper facilities are given, that law will ventilate the sewers. The temperature of the air of sewers is, however, affected locally by hot water and other liquids poured into them. Every such discharge at once raises the temperature of the air in its vicinity, and the sudden expansion which follows causes air to escape up the nearest opening.

In like manner, every increase in the quantity of sewage by the discharge from the drain into the sewer expels air from the sewers, and assists ventilation. In fact, every rise or fall in the level of the sewage either expels air from or draws it into the sewer; and as the level of the sewage is constantly changing, this fact operates powerfully for ventilation.

In a system of sewers ventilation should be as constant as possible in its operation; it should effect the greatest possible change in the air of the sewer with the least amount of nuisance to the public; and it should do this automatically and economically. That no system of ventilation has been found which is entirely successful is probably due to the fact that the complexity of the conditions renders a perfect system very difficult of attainment. Of the numerous schemes that have been proposed, by far the greater part deal with one section of the subject only, and do not take into account all the practical considerations affecting sewers.

As an instance of this may be mentioned the proposal frequently made that the principle adopted in the ventilation of mines should be applied to sewers. That system, as applied in mines, has proved very successful indeed, but a practical knowledge of the conditions would show that the system is not applicable to sewers. Fresh air is drawn through one downcast shaft, and travels through the various galleries and cuttings to an upcast shaft, through which it passes from the mine. The force which moves the air is either a fire in the upcast shaft or a fan. Such a method cannot be applied to a system of sewers, because instead of the air entering at one point and being quickly distributed throughout the system, it would be drawn into the sewers only through the drain openings nearest to the fan or exhaust shaft, and the remainder of the sewers would receive no benefit.

The only method of ventilating sewers that experience has shown to be practicable are :—

(*a*) By surface ventilation, that is to say, by shafts leading from the crown of the sewers to the centre of the road, and covered at the road level by open gratings.

(*b*) By large separate shafts, factory chimneys, and smaller shafts; in all of which fire or other heat is a motive power.

(*c*) By pipes or shafts without heat.

The objection to surface ventilators is rather on account of the gases escaping from them being more directly in evidence than to their being more dangerous to health than any other method of ventilation. Although the improvement effected by removing the points at which sewer gas escapes from the side of the footpaths to the centre of the road is very great, both in reducing offence and in minimising danger to health, there can be no doubt that at times the system is, as at present carried out, a serious cause of nuisance.

The question of deodorising sewer gases before their escape through the ventilating shafts or surface gratings has received much attention from drainage authorities and others interested in the subject. If, without materially interfering with the ventilation of the sewers, the gases could be readily, economically, and effectually deodorised before reaching the exterior air, one of the greatest difficulties in connection with the subject would be solved. This object has been attempted in various ways, either by means of fire, by the agency of chemical substances, or, more generally, by means of charcoal. General experience, however, has shown that the charcoal method of filtering the gases through cages containing charcoal is a failure in consequence of the charcoal becoming clogged with wet, and thereby being rendered useless. This system appears to be generally abandoned.

If it be desired to adopt a chemical method of deodorising the sewage and thereby prevent noxious emanations, this can only be done in one way, viz., by adding a solution of permanganate of potash, or soda, directly to the sewage, and so keeping it in a comparatively fresh condition until its arrival at the sewage works. The result of experience has been to show most clearly that the quantity of permanganate required to destroy existing foul odours, and to stay the production of others, is exceedingly small, being only from one to two grains per gallon. To obtain the maximum effect with the minimum expenditure it is advisable that the points of application should be multiplied to the greatest extent practicable; and householders should be urged to systematically use this and similar oxidising disinfectants freely. Various expedients have been suggested for the purpose of accomplishing this object. One very simple arrangement was to fill a porous pot, such as used for electric batteries, with the crystals of permanganate of potash, and suspend this in the special cistern supplying the lavatory, &c., when a slow solvent action took place by osmosis through the pores of the vessel, and the water in the cistern was thus kept charged with dissolved permanganate. Such a system, if universally adopted, would be of the greatest possible benefit.

Some time back Mr. Harris Reeves took up the idea suggested by the use of manganate of soda and sulphuric acid for the temporary deodorisation of the London sewage pending the opening of the outfall precipitation works, and constructed a convenient arrangement of earthenware, by means of which a solution of manganate of soda was constantly prepared, and to this was added, as it flowed over a porcelain capsule, strong sulphuric acid, the action of which not only converted the cheap manganate of soda into the permanganate, but by the heat set up by the action of the acid, evolved *vapours* of permanganic acid, probably one of the most powerful deodorants we have.

This system appears to have been tried at various places with marked success for the purpose of dealing with special ventilators which have been found to be a nuisance. In one case nine manholes were so treated at a first cost of 112*l.*, and an annual working expense for manganate of soda and sulphuric acid of 20*l.*, the labour being performed by the ordinary staff without extra cost. Equally satisfactory results appear to have been obtained elsewhere, but it is evident that the cost of this system is against its general adoption for all manholes, however suitable it may be for special cases.

As the result of most careful inquiry into the whole question of the cleansing and ventilation of sewers by the Special Purposes and Sanitary Committee of the late Metropolitan Board of Works, that Committee reported in January, 1886, the following conclusions and recommendations on the subject:—

(1.) That old, defective, disused, or partially disused sewers should be disconnected from the present sewerage system, cleansed and filled up; and that, where necessary, pipes or other proper sewers should be substituted.

(2.) That stringent measures be taken for preventing road sweepings passing into sewers, and for preventing the discharge into sewers from manufactories and other places of improper substances, such as chemical refuse or trade filth, or of hot water or steam, so as to be the cause of nuisance.

(3.) That the most important requirement for keeping sewers in satisfactory condition is a supply of water sufficient in quantity to carry the sewage in suspension through the sewers.

(4.) That whenever the supply of water is insufficient for cleansing the sewers, effectual provision for cleansing such sewers should be adopted by flushing or other means.

(5.) That one of the most effectual methods of flushing would be by means of water simultaneously discharged into house drains, and such a simultaneous discharge would flush branch sewers, then local sewers, and finally main sewers; that such method of flushing can be effectually carried out by householders flushing their house drains periodically and simultaneously at stated times; that a great number of householders would probably be willing to co-operate with the Authorities in improving the condition of the sewers in their district in this way; and that it is desirable that the several Vestries and District Boards should intimate upon what days and at what hours householders should flush their drains.

(6.) That provision near the heads of branch sewers for flushing such sewers from their commencement is to be desired.

(7.) That the practice of flushing the courts, alleys, small streets, &c., in poor districts in summer is to be highly recommended as a desirable method of flushing sewers and improving the sanitary condition of the districts.

(8.) That next to effectual cleansing one of the most important safeguards against nuisance and danger to health from sewers is the dilution of the gases therein by a constant and plentiful supply of fresh air to the sewers by means of effective ventilation.

(9.) That the ventilation of sewers in the metropolis by means of ventilating shafts leading to gratings in the centre of roadways has been the cause of complaint, owing to the imperfect manner in which the system has been carried out, the ventilators being deficient both in size and numbers.

(10.) That the surface ventilators to the recently-constructed sewers have ordinarily been placed at a distance of from fifty to sixty yards apart, with air openings in the gratings equal to sixty square inches; and that the number and size of many of the ventilators and the sewers in the metropolis should be increased.

(11.) That the amount of ventilation afforded by large special ventilating shafts is in no way commensurate with their cost, and that the adoption of such shafts, with or without fire heat, or the connection of the sewers with factory shafts, can only be adopted in very exceptional circumstances. Where shafts with fire are used, the sewer gases should be allowed to pass into such shafts over as well as through the fires, otherwise the amount of ventilation afforded will be very limited.

(12.) That pipe ventilators of large section, and constructed with bends, and without angles, can be used with great advantage in addition to, and not in substitution for, surface ventilators, wherever the consent of owners and occupiers can be obtained to such ventilators being affixed.

(13.) That your Committee are of opinion that the ventilation of the sewers of the metropolis may be improved by altering the construction of many of the surface ventilators as previously recommended, and by carrying up large pipe ventilators at convenient points wherever practicable.

(14.) That the use of charcoal or of other appliances for deodorising gases in sewer ventilators is undesirable, as such appliances do much harm by obstructing ventilation, are costly and troublesome, and are quite unsuitable for general use over a large sewerage system.

(15.) That during the cold and wet seasons the arrangements suggested in this report for providing ventilation will be sufficient, as putrefaction proceeds slowly at low temperatures; and when the sewage is diluted with large volumes of fresh water, that the foul matters pass from the sewers before material quantities of offensive gases are generated.

(16.) That during dry and hot weather the foregoing recommendations respecting the flushing and cleansing be carried out as far as practicable, especially in sewers having only a small flow of water.

(17.) That in addition to these precautions, a system of deodorisation during the summer be arranged for the main sewers on the plan adopted by the Board during the past summer (by permanganate of soda); and that Local Boards be requested to adopt a similar system with local sewers, and to use all their influence to induce householders to employ in their house-drains suitable deodorising agents during periods of high temperature and drought.

(18.) That manufacturers and others discharging refuse into the sewers be compelled to so treat their waste (by such process as they may deem fit, but to the Board's satisfaction) that it shall have no greater *deoxidising* powers than the average household sewage.

In the course of a series of experiments on the micro-organisms contained in sewer air made for the Main Drainage Committee of the London County Council by Mr. J. Parry Laws, F.I.C., that gentleman came to the conclusion that they were not only less in number than the micro-organisms in fresh air in the vicinity at the same time, but that they were also apparently related to and derived from those of fresh air rather than from the sewage; and further, that no evidence was forthcoming that sewage was able to give off micro-organisms to the air in contact with it. Inasmuch as these conclusions were not in harmony with generally-accepted views—although not published for the first time, as was shown by Drs. Carnelly and Haldane a few years previously—it became of great importance to gain corroborative evidence upon the point by a study of the organisms existing in sewage, and to this end further investigations were carried out at the instance of the Committee by Mr. Parry Laws in conjunction with Dr. F. W. Andrews in 1894.

The conclusions arrived at by these gentlemen, so far as related to the first part of their investigations, were as follows:—

CONCLUSIONS OF MESSRS. LAWS AND ANDREWS.

If we now proceed to contrast the micro-organisms which we have found present in London sewage, as above described, with those found in the air of London sewers, and described in a previous report, certain striking differences become at once apparent. The most striking is the absence of moulds from sewage. Out of the many thousand colonies which arose in the numerous plates which were made, moulds occurred only seven times, and of those seven moulds one, and one only, was allied to the common species existing in sewer air. This result coincides with that obtained by Jordan in the sewage of Lawrence, Mass. "Moulds," he says, "are found rarely in the sewage and effluents." Further, the same striking result was obtained by Mr. Dibdin in a series of experiments he made on the number of micro-organisms in Barking sewage. In sewer air, on the contrary, moulds were found to be a predominating feature, forming on an average no less than 64·33 per cent. of the total colonies. The proportion, however, varies according to season; in winter it may be as low as 13·33 per cent., while in the summer months it may rise as high as 82·6 per cent. of the total. It is right, however, to point out that in our sewage experiments, agar-agar, which is a less favourable medium than gelatine for the growth of moulds, was employed, whereas in the estimation of the organisms present in sewer air gelatine was used. This, however, does not materially affect our results, since most moulds grow well on agar-agar at a temperature of 22 deg. Cent. Jordan and Dibdin, moreover, employed gelatine plates only.

Bacillus coli communis was found, with one exception, in each sample of sewage we examined, and varied in numbers from 20,000 to 200,000 per cubic centimetre. In addition we isolated in every case many bacilli which, although indistinguishable in cultural features from bacillus coli communis, nevertheless gave only one, or at most two, of the three characteristic chemical reactions. These bacilli in most instances far outnumbered the true bacillus coli communis. Nevertheless, neither B. coli communis nor any of its close allies were ever found in sewer air. Furthermore, we have obtained enormous numbers of sarcina, amounting in one case to over 300,000 per cubic centimetre, yet we have not found one single colony of sarcina lutea, which is so common in sewer air and fresh air.

The flora of sewage naturally embraces a very large number of different species of bacteria, but when we consider the enormous number of micro-organisms per cubic centimetre and the extreme degree of dilution that it is necessary to employ in making cultivations, it will be evident that we have probably isolated only those species which are present in comparatively large numbers. The following organisms are those which we have found to be present in numbers varying from 200,000 to 2,500,000 per cubic centimetre—bacillus fluorescens stercoralis, bacillus albus putidus, bacillus fluorescens liquefaciens, bacillus cloacæ fluorescens, bacillus mycoides, proteus cloacinus, proteus Zenkeri, a streptococcus coagulating milk, staphylococcus pyogenes citreus, sarcina flava and its allies, and diplococcus albicans tardissimus. Other bacilli, which rapidly liquefy gelatine and produce a green fluorescence, were found in numbers varying from 10,000 to 200,000 per cubic centimetre.

A further difference between the bacteria of sewer air and those of sewage lies in the relative proportions of micrococci and bacilli. The bacteria of sewer air were found to consist mainly of micrococci, bacilli forming but a small proportion of the total species found. The bacilli found were B. subtilis, B. aureus, B. arborescens, B. helvolus, B. nigrescens, and B. acidi lactici. In sewage itself, however, there can be no doubt that bacilli preponderate over micrococci, probably in actual numbers, certainly in the numbers of species present. The large majority of those species which we have been obliged to pass over were bacilli. This was less noticeable in the fresh sewage taken from St. Bartholomew's Hospital, where the large number of streptococcus colonies materially altered the ratio between the bacilli and micrococci; in the sewage taken from Snow Hill and Barking the bacilli showed a distinct numerical preponderance. This result again is in harmony with that obtained by other observers, indeed the results we have obtained show a somewhat smaller preponderance of bacilli over cocci than has been recorded by others. Jordan states that the comparative absence of micrococci from sewage is a striking and highly remarkable circumstance. In any case, the facts again come out in striking confirmation of the view that the organisms present in sewer air are not derived to any essential extent from the sewage, or they would show to some degree the same relative ratio of micrococci to bacilli. The argument receives also important confirmation from other considerations. A large proportion of the bacteria of sewage have the property of very rapidly liquefying the nutrient gelatine used as a cultural medium—so large a proportion, indeed, as to make gelatine an impossible medium to employ in estimating their numbers. In sewer air, on the contrary, organisms rapidly liquefying gelatine were found to be practically absent, a fact impossible to explain on the assumption that sewer air is able to take up bacteria from sewage.

Again, the number of micro-organisms existing in sewer air appears to be entirely dependent upon the number of micro-organisms existing in the fresh air at the same time and in the same vicinity. With the advance of the colder weather, and consequent rapid decrease in the number of micro-organisms in fresh air, we find a corresponding decrease in the number of the micro-organisms of sewer air, although the temperature of the sewer air and sewage suffer but a comparatively slight variation.

If the organisms existing in sewer air were derived from those existing in sewage, then the flora of sewer air should bear a very close resemblance to the flora of sewage. When, however, we compare the organisms which have hitherto been isolated from sewer air with those species which we have found to be *predominant* in sewage, it is at once evident that they bear no resemblance whatever to one another; indeed, we may go even further, and state that, so far as we are aware, not a single colony of any of those species which we have found predominant in sewage has been isolated from sewer air. We consider, therefore, that the study of the sewage bacteria, on which we have been engaged, fully confirms the conclusion previously arrived at from the study of the micro-organisms of sewer air, viz., that there is no relationship between the organisms of sewer air and sewage.

It is possible that some of the ill effects which have been erroneously ascribed to sewer air may be due to subsoil air derived from soil polluted by constant infiltration of excremental matter through a leaky drain. It is a well-recognised fact that subsoil air does at times gain access to our dwellings, either through the pressure of the wind on the surface of the ground, or from currents induced by wide differences between the exterior and interior temperatures. Under such conditions it is possible that sewage may gradually extend through a permeable soil until its outer margin becomes sufficiently dry to give off micro-organisms to the subsoil air. Whatever the danger arising from this cause may be, it would in all probability be strictly limited in its effect.

Continuing their investigations on the vitality of the typhoid bacillus in sewage, Messrs. Laws and Andrews made, amongst others, the following experiment:—

"*Experiment V.*—A tube of sewage sterilised by heat was inoculated with one drop of a fresh broth culture of B. typhosus, and incubated at 20 deg. Cent. A small quantity was removed on a platinum loop and transferred to gelatine immediately after inoculation to determine the number of colonies originally present, and the process was repeated at stated intervals. The results were as follows :—

Immediately after inoculation	225	colonies arose.
After twenty-four hours	250	,, ,,
,, sixty-eight hours	140	,, ,,
,, five days	48	,, ,,
,, seven days	13	,, ,,
,, thirteen days	0	,, ,,

"It is to be observed that the removal of so small a quantity of fluid as can be conveyed on a platinum loop is no fair test of the total absence of living bacilli from a culture, and it is quite possible that the removal of larger quantities might have shown living bacilli to be present after thirteen days. Similar, or approximately similar, amounts would nevertheless be removed by a platinum loop on each occasion, so that the experiment clearly shows that although an attempt at growth may occur during the first twenty-four hours, the typhoid bacillus gradually but surely dies out in sewage, and is quite incapable of any active growth therein.

"Sewage, therefore, even in the absence of the normal micro-organisms which it contains, is clearly an unfavourable medium for the growth of the typhoid germ, whereas the colon bacillus can grow and multiply freely in it."

After detailing further experiments on the same subject they concluded their valuable and interesting report in the following terms :—

"So far as deductions can be safely drawn from a single series of experiments, the following conclusions seem to be warranted. Bacillus typhosus seems capable of slight multiplication in sterilised sewage during the first twenty-four hours only, thenceforward it becomes gradually extinct. The presence of certain non-pathogenic organisms, commonly present in sewage, appears to affect its extinction. Of the four organisms which we tested, B. fluorescens stercoralis alone seems to have any marked effect upon the vitality of B. typhosus, and this effect is practically absent when other organisms are present at the same time. The mixture of the four non-pathogenic bacteria had no effect in hastening the extinction of B. typhosus; indeed, the reverse appears to have been the case.

"These preliminary experiments are necessarily very incomplete, and afford only an indication of the probable fate of typhoid bacilli which gain access in a living condition to sewage. It seems, however, clear that sewage does not form a medium in which much, if any, growth is possible for them under natural conditions, and their death is probably only a matter of a few days, or at most one or two weeks. But this degree of resistance may, nevertheless, be sufficient to allow of their being carried in sewage to remote distances and of their being able to produce disastrous results should they gain access to any water supply. As our knowledge accumulates, it becomes more and more evident that water supply, and, as an incidental result, our milk supply, constitute the chief channels of infection by which typhoid fever is communicated; and this is true also of cholera, and possibly of other infectious diseases. It is, therefore, of the first importance to determine in an exhaustive manner how far sewage is a possible soil for the growth of these and other disease germs which admittedly gain access to it, and also to determine what precise influence their non-pathogenic companions may exert on them.

"In the conclusions to Part I. of this report we endeavoured to show that sewer air has no power of taking up bacteria from the sewage with which it is in contact. A strong argument in favour of this view is the fact that the very organisms which are most abundant in sewage are precisely those which are absent from sewer air. In the course of previous experiments on sewer air, the nature of the organisms in some

1,200 litres of sewer air was carefully determined. Not once was Bacillus coli communis, or any of the predominant organisms of sewage found, though we have shown above that the former is present in sewage in numbers varying from 20,000 to 200,000 per cubic centimetre. If this be so, how infinitely improbable becomes the existence of the typhoid bacillus in the air of our sewers. That sewage is a common medium for the dissemination of typhoid is certain ; that sewage-polluted soil may give up germs to subsoil air is possible ; but that the air of sewers themselves should play any part in the conveyance of typhoid fever appears to us, as the results of our investigations, in the highest degree unlikely."

CHAPTER XIV.

THE FILTRATION OF POTABLE WATER.

The first water purifier for which protection was obtained in this country is that of William Walcott, who in 1675 obtained a patent for the "art of makeing water corrupted fit for use, and sea water fresh, clear, and wholesome in very large quantities, by such wayes and means as are very cheap and easy, and which may be done and practised with great speed and expedicion." Unfortunately these "wayes and means" are not given in the specification; but doubtless it was a method of distillation.

It is not until the year 1790 that we find mention of any contrivance which can claim to be regarded as a filter, when Johanna Hempel patented a method of making porous vessels which were to be used as filters, the substances used being clay and sand. In the following year upward filtration was patented, the materials employed being "sand, sandy gravel, and broken or pulverised glass." Wood charcoal was introduced in 1802. Ten years later, in 1812, we have the first rudimentary idea of oxidation, when Messrs. Dickinson and Maudsley proposed to oxidise the organic matter by simply forcing a stream or streams of air through the foul or tainted water by means of bellows or pumps. This may be looked upon as the forerunner of the system adopted by Lowcock for the filtration of sewage effluent, and Waring for that of crude sewage.

In 1818, John Bennett proposed to use animal charcoal, in combination with sand, gravel, and "a very fine ground charcoal of Prussian blue, made by potash."

The extraordinary number of organic matters which were used by the earlier filter makers is very curious. Wood, leather, paper, sponge, hair-cloth, horse-hair, wool, skins of animals, cotton, felt, linen, &c., in addition to the usual sand, gravel, shells, &c. The want of elementary knowledge is here curiously illustrated by the early manufacturers overlooking the fact that organic materials decompose and eventually render the water worse after filtration. Again, most of them proposed to clean the filtering materials by forcing the water the reverse way instead of entirely removing them for a good washing, &c. This method is even at the present time recommended as effective. Bad, indeed, must be the water before filtration when such a system can be adopted with advantage. Such filters are little better than sieves. It is well known that where a new supply of filtering material is not obtainable the most efficacious method is to remove the old charcoal, &c., well wash it, and then heat it in a closed vessel to a red heat, when it will be thoroughly renovated.

The now well-known "block" filters were first introduced by Samuel Bagshaw in 1834, who constructed his block by mixing charcoal, stone, and clay, with water into a paste, which was then moulded to shape, dried, and heated in an oven or retort.

In 1838, Matthew Heath proposed to clarify the water by "precipitating the heterogeneous insoluble matter by means of a solution of muriate of zinc." This startling process, however, was disclaimed later on.

The proposition to use canvas bags in order to obtain as large a filtering surface as possible seems to have been a favourite one, and as a strainer the system is largely adopted, but it cannot strictly be called filtration in the ordinary sense.

In 1852, the necessity for radical measures seems to have been urgent, as in that year one gentleman proposed certain improvements in the method of treating water, to wit:—The water was to be first chemically treated, then distilled, again chemically treated, and finally filtered, no particular filter being mentioned. A few years later another inventor was determined that he would be on the safe side, so he constructed a filter as follows:—First, a perforated stage on which was laid a layer of pebbles; then fragments of granite; a piece of hair-cloth; a bed of ground glass; a second piece of hair-cloth, upon which was laid a "terro-metallic" bed, which contained flint, steel filings, oxalate of ammonium, peroxide of manganese, animal charcoal, and boxwood charcoal; above this was laid another covering of hair-cloth, and then a perforated stage. Below this filtering bed, a powder, containing oxalate of ammonium, peroxide of manganese, and charcoal, was placed to soften hard waters.

Amusing as it may be to read such descriptions as these in the light of our present knowledge, one cannot forget that those early pioneers served the useful purpose of indicating a necessity, and at the same time by their stumblings as surely indicating the dangers and difficulties of the road for the guidance of those who follow them.

The first scientific and practical method of treating hard waters especially is that of Dr. Thomas Clark, who in 1841 patented his famous method of softening water by adding lime water to the hard water in sufficient quantity to absorb the carbonic acid which holds the carbonate of lime in solution. As soon as the excess of acid is thus removed, the lime in the water, as well as that put in and now combined with the carbonic acid, settles to the bottom of the containing vessels, and in doing so carries with it practically the whole of the impurities in the water.

The process is one of the most simple and beautiful methods of treating water which has been brought before the public;

and, although it has been adopted at certain waterworks, as well as in very numerous factories, the marvel is that the inhabitants of the great metropolis are deprived of its advantages by the failure of the water companies to carry out the process, which is easy, simple, safe, and inexpensive. When it is considered that eightpennyworth of lime will soften as much water as forty-seven pounds' worth of soap, in addition to the advantage to be derived by preventing the corrosion and stopping up of hot-water pipes, boilers, &c., it becomes astonishing that the public should have been so patient.

It is often claimed for filters that they will remove living organisms as well as the ordinary impurities. Up to a certain extent this is true, but by no means entirely so, more especially in relation to the bacteria. When we consider the conditions of the case, we shall understand better how a filter will, under suitable circumstances, allow organisms of various sizes to pass through, and in fact to live and multiply in it, with the result that after a time such a filter may become a perfect aquarium in itself.

All filters are made of porous substance, whether compressed into blocks or not, the medium being in small granular pieces having interstices between them. These act very well when they deal with inert matter, but when the particle to be arrested is alive and swimming freely the case is altered. It is probably drawn into the filter by the rush of water, or swims in and finds itself wandering about in what are comparatively large caverns. It swims on and on, turning and twisting about until it emerges at the outlet of the filter, and is at large in the filtered water. This is more specially so in the case of those filters constructed of coarse granular substances, and it is obvious that the finer the material the smaller will be the organism that can pass. But this is supposing the case of a free swimming organism. Let us consider what will happen with a bacterium growing in chains, &c. The pores of the filter may be too small even for this minute body to pass freely. Very well, the bacterium will quietly settle against the side of the filter or on its exposed part, wherever that may be, and begin to grow. As it grows by thrusting out shoot after shoot, some of these will penetrate the infinitely minute pores of the filter, like the roots of ivy on a brick wall; and in time it will actually penetrate the filter, and the descendants of the original parent who was blocked, will take possession of the filter, "fore and aft," as a sailor would say. This considera-tion points out the fallacy of the supposition that such a filter can be cleaned by running the water backward.

So far our remarks apply to ordinary household filtration. It will now be of interest to turn to the filtration of water on a large scale, for public supplies. The following table indicates the character of the filter beds employed by the London water companies, for filtering the water taken from the rivers Thames and Lea.

Maximum Depth of Sand and other Materials Used in the Filters of the London Water Companies. Extracted from the Report of the Water Examiner, General A. de C. Scott, for the Month of November, 1896.

Chelsea.

Sand, &c.	ft.	in.
Thames sand	4	6
Shells, &c.	0	3
Gravel	3	3
Total	8	0

East London.

Sand	2	0
Hoggin	0	6
Coarse gravel	1	0
Total	3	6

Lambeth.

Thames sand	3	0
Shells, &c.	1	0
Coarse gravel	3	0
Total	7	0

Grand Junction.

Old pattern—

	ft.	in.
Harwich sand	2	6
Hoggin	0	6
Fine gravel	0	9
Coarse gravel	0	9
Boulders	1	0
Total	5	6

New pattern—

	ft.	in.
Sand	2	0
Gravel	0	6
Drains	0	3
Total	2	9

New River.

	ft.	in.
Sand	2	3
Gravel Increasing in coarseness towards bottom.	3	4
Total	5	7

Southwark and Vauxhall.

	ft.	in.
Harwich sand	3	0
Hoggin	1	0
Fine gravel	0	9
Coarse gravel	0	9
Total	5	6

West Middlesex.

	ft.	in.
Harwich sand	1	9
Barnes sand	1	0
Gravel Screened to different sizes and arranged in layers.	1	0
Total	3	9

Subsiding and Storage Reservoirs for Unfiltered Water; Available Capacity in Gallons per Million Gallons Supplied.

Chelsea	12,200,000
East London	21,600,000
Grand Junction	3,500,000
Lambeth	6,180,000
New River	5,120,000
Southwark and Vauxhall	4,300,000
West Middlesex	5,960,000

Filtering Area in Acres, per Million Gallons of the Average Daily Supply.

Chelsea	0·58
East London	0·64
Grand Junction	1·13
Lambeth	0·50
New River	0·43
Southwark and Vauxhall	0·61
West Middlesex	0·72

Average Rate of Filtration per Square Foot per Hour, Gallons.

Chelsea	1·75
East London	1·33
Grand Junction	1·63
Lambeth	1·80
New River	2·25
Southwark and Vauxhall	1·50
West Middlesex	1·25

From this table it will be seen that there is a considerable divergence in the system adopted, the total depth of filtering material varying from 8 ft. in the case of the Chelsea Company, to 2 ft. 9 in. in that of the Grand Junction Company. In conjunction with this factor, the available capacity, in gallons per million supplied, of the subsiding and storage reservoirs for unfiltered water must be considered, as natural sedimentation plays no inconsiderable part in relieving the work to be done by a filter. The filtering area per million gallons, and the average rate of filtration, are also matters of the first moment. In considering this table, it must be pointed out that the New River Company avails itself largely of well water; and the river Lea, above its intake, is less fouled by floods than it is lower down the valley. The Southwark and Vauxhall, and the Grand Junction Companies, have the means, during floods, of pumping from the gravel beds adjoining the Thames, and this is practically equivalent, says General Scott, the water examiner, to an addition to their storage resources. Any comparison between the methods of the respective companies is thus rendered extremely difficult, and for our present purpose unnecessary, it being desired to point out, from a general standpoint, the character of the operations adopted under most skilful advice and direction, for freeing the water derived from a more or less polluted source from impurities, whether held in solution or in suspension.

The following represents the composition, according to Professor Mason, of some filter beds on the Continent and in America :—

	Berlin.		Warsaw.		Zürich.		Hague.		Hudson, N.Y.		Pough-keepsie, N.Y.	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Fine sand	1	10	2	0	2	8	1	0	0	6	2	0
Coarse sand	0	2	—		0	6	0	10	1	6	—	
Fine gravel	0	6	0	2	0	4	—		0	6	—	
Medium gravel....	0	5	—		—		—		0	6	1	6
Coarse gravel	0	3	0	3	0	6	0	10 (sea shells)	0	6	—	
Small stones	0	4	1	0	—		—		0	6	0	6
Large stones......	1	0	0	11	—		0	6	2	0	2	0
Total	4	6	4	4	4	0	3	2	6	0	6	0

In order to remove the grosser particles held in suspension in the water, the system of storing it in large reservoirs affords a most valuable and in many cases essential auxiliary to the filtration plant.

The process of sedimentation, as it is termed, in such reservoirs, not only assists in producing a clear and bright water by the settlement of the suspended matters, but under favourable circumstances conduces to a diminution of the impurities actually dissolved in the water. Dr. Percy Frankland has shown that, in a certain case, the number of bacteria present in a water before passing into a storage reservoir was 1,437 per cubic centimetre; after storage, these were reduced to 318; and after storage in a second reservoir, to 177 per cubic centimetre. This fact is only what might be expected from the settlement of the suspended matters, as in the course of my own experience the number of bacteria almost always followed the ratio of suspended particles, as will be seen from the following table:—

Description of Water.	Suspended particles. Grains per gallon.	Bacteria, per c.c.
Kent Company's supply, 1895	0·0011	90
New River ,, ,, ,, ...	0·0011	130
West Middlesex ,, ,, ...	0·0010	130
Chelsea ,, ,, ...	0·0027	139
Grand Junction ,, ,, ...	0·0023	170
East London ,, ,, ...	0·0023	277
Lambeth ,, ,, ...	0·0033	294
Southwark and Vauxhall ,, ...	0·0056	352
River Thames at Sunbury	0·5360	16,061
Sewage	30·0000	2,000,000

The results in the case of the companies' waters and that of the Thames at Sunbury are the averages of daily examinations during twelve months, while that of the sewage is the mean of very numerous determinations on the London sewage.

The following tabular statement by Dr. Percy Frankland, shows the character of the sands used in various places for water filtration.

Analyses of Sands used in Water Filtration.

Source.	Effective size; 10 per cent. finer than Millimetres.	Uniformity coefficient.	Remarks.
London—			
East London Co.........	0·44	1·8	New sand never used or [washed
,, ,, ...	0·39	2·1	Dirty sand, very old
,, ,, ...	0·37	2·0	Same, washed by hand
Grand Junction	0·26	1·9	Sand from rough filter
,, ,, ...	0·40	3·5	Old sand in final filter
,, ,, ...	0·41	3·7	Freshly washed old sand
Southwark and Vauxhall	0·38	3·5	,, ,, ,,
,, ,,	0·30	1·8	,, ,, new ,,
Lambeth	0·36	2·3	,, ,, old ,,
,, ...	0·36	2·4	New unused sand, washed
,, ...	0·25	1·7	New extremely fine sand
Chelsea................	0·36	2 4	Freshly washed old sand
Middlesbrough	0·42	1·6	Dirty sand, ordinary scraping
,, ...	0·43	1·6	Same, after washing

Source.	Effective size; 10 per cent. finer than Millimetres.	Uniformity coefficient.	Remarks.
Birmingham	0·29	1·9	Dirty sand
,,	0·29	1·9	Sand below surface of filter
Reading	0·30	2·5	Dirty sand
,,	0·22	2·0	Same, after washing
Antwerp	0·38	1·6	Dirty sand
,,	0·39	1·6	Same, after washing
Hamburg	0·28	2·5	Dirty sand
,,	0·31	2·3	Same, after washing
,,	0·34	2·2	Dirty sand, another sample
,,	0·30	2·0	Same, after washing drums
,,	0·34	2·3	Same, after washing ejectors
Altona	0·32	2·0	Dirty sand, old filters
,,	0·37	2·0	Same, after washing
,,	0·33	2·8	Washed sand for new filters
Berlin—			
Stralau	0·33	1·9	Dirty sand pile
,,	0·35	1·7	Filter No. 6, 3in. below surface
,,	0·34	1·7	Filter No. 7, 3in. below surface
,,	0·35	1·7	Filter No. 10, 3in. below surface
Tegel	0·38	1·6	Dirty sand, old filters
,,	0·38	1·5	Same, after washing, old filters
,,	0·35	1·6	,, ,, new filters
Müggel	0·35	1·8	Sand from filters below surface
,,	0·33	2·0	Dirty sand, ordinary scraping
,,	0·34	2·0	Dirty sand, another sample
Charlottenburg	0·40	2·3	Dirty sand
Chemnitz	0·35	2·6	New sand not yet used
Magdeburg	0·39	2·0	Dirty sand
,,	0·40	2·0	Same, after washing
Breslau	0·39	1·8	Normal new sand
Budapest	0·20	2·0	New washed Danube sand
Zürich	0·28	3·2	Dirty sand
,,	0·30	3·1	Same, after washing
Hague	0·19	1·6	Dune sand used for filtration
Schiedam	0·18	1·6	Dune sand used for filtration; dirty
,,	0·31	1·5	River sand; dirty
Amsterdam	0·17	1·6	Dune sand
Rotterdam	0·34	1·5	River sand; new
Liverpool—			
Rivington	0·43	2·0	Sand from bottom of filter
,,	0·32	2·5	New sand unwashed and unscreened
,,	0·43	2·7	Washed sand which has been in use thirty to forty years
Oswestry	0·30	2·6	Dirty sand
,,	0·31	4·7	Same, after washing

The exceptionally fine sand employed at some of the Dutch waterworks is particularly noteworthy.

As indicating the methods recommended for the guidance of water companies in Germany the following regulations, issued by the German Government, and which, it is understood, have been drawn up under the supervision of Dr. Koch, will be of interest and value:—

(1.) In judging the quality of a filtered surface water, the following points should be specially observed:—(*a*) The operation of a filter is to be regarded as satisfactory when the filtrate contains the smallest possible number of bacteria, not exceeding the number which practical experience has shown to be attainable with good filtration at the works in question. In those cases where there are no previous records showing the possibilities of the works and the influence of the local conditions, especially the character of the raw water, and until such information is obtained it is to be taken as the rule that a satisfactory filtration shall never yield an effluent with more than about 100 bacteria per cubic centimetre. (*b*) The filtrate must be as clear as possible, and in regard to colour, taste, temperature, and chemical composition, must be no worse than the raw water.

(2.) To allow of a complete and constant control of the bacterial efficiency of filtration, the filtrate from each single filter must be examined daily. Any sudden increase in the number of bacteria should cause a suspicion of some unusual disturbance in the filter, and should make the superintendent more attentive to the possible causes of it.

(3.) Filters must be so constructed that samples of the effluent from any one of them can be taken at any desired time for bacteriological examination.

(4.) In order to secure uniformity of method, the following is recommended as the standard method for bacterial examination:—The nutrient medium consists of 10 per cent. meat extract gelatine with peptone, 10 cubic centimetres of which is used for each experiment. Two samples of the water under examination are to be taken, one of 1 cubic centimetre and one of $\frac{1}{2}$ cubic centimetre. The gelatine is melted at a temperature of 30 deg. Cent. to 35 deg. Cent., and mixed with the water as thoroughly as possible in the test-tube by tipping backwards and forwards, and is then poured upon a sterile glass plate. The plates are put under a bell-jar which stands upon a piece of blotting paper saturated with water, and in a room in which the temperature is about 20 deg. Cent. The resulting colonies are counted after forty-eight hours, and with the aid of a lens. If the temperature of the room in which the plates are kept is lower than the above, the development of the colonies is slower, and the counting must be correspondingly postponed. If the number of colonies in 1 cubic centimetre of the water is greater than about 100, the counting must be done with the help of the Wolffhügel's apparatus.

(5.) The person entrusted with the carrying out of the bacterial examinations must present a certificate that he possesses the necessary qualifications, and wherever possible he shall be a regular employé of the waterworks.

(6.) When the effluent from a filter does not correspond with the hygienic requirements it must not be used, unless the cause of the unsatisfactory working has already been removed during the period covered by the bacterial examinations. In case a filter, for more than a very short time, yields a poor effluent, it is not to be used until the cause of the trouble is found and corrected. It is, however, recognised from past experience that sometimes unavoidable conditions (high water, &c.) render it impossible, from an engineering standpoint, to secure an effluent of the standard quality. In such cases it will be necessary to use a poorer quality of water; but, at the same time, if such conditions arise as outbreaks of epidemics, suitable notice should be given of the condition of the water.

(7.) Every single filter must be so built that, when an inferior effluent results which does not conform to the standard, it can be disconnected from the pure water pipes, and the filtrate allowed to run to waste. This wasting should as a rule take place, so far as the arrangement of the works will permit,—(1) immediately after scraping a filter; and (2) after replacing the sand to the original depth. The superintendent must himself judge, from previous experience acquired by the continual bacterial examinations, whether it is necessary to waste the water after these operations, and if so, how long a time will probably elapse before the water reaches the standard purity.

(8.) The best sand filtration requires a liberal area of filter surface, allowing plenty of reserve, to secure, under all local conditions, a moderate rate of filtration adapted to the character of the raw water.

(9.) Every single filter shall be independently regulated, and the rate of filtration, loss of head, and character of the effluent shall be known. Also each filter shall, by itself, be capable of being completely emptied, and, after scraping, of having filtered water introduced from below until the sand is filled to the surface.

(10.) The velocity of filtration in each single filter shall be capable of being arranged to give the most favourable results, and shall be as regular as possible, quite free from sudden changes or interruptions. On this account reservoirs must be provided large enough to balance the hourly fluctuation in the consumption of water.

(11.) The filters shall be so arranged that their working shall not be influenced by the fluctuating level of the water in the filtered-water reservoir or pump-well.

(12.) The loss of head shall not be allowed to become so great as to cause a breaking through of the upper layer on the surface of the filter. The limit to which the loss of head can be allowed to go without damage is to be determined for each works by bacterial examinations.

(13.) Filters shall be constructed throughout in such a way as to insure the equal action of every part of their area.

(14.) The sides and bottoms of filters must be made water-tight, and special pains must be taken to avoid the danger of passages or loose places through which the unfiltered water on the filter might find its way to the filtered-water channels. To this end special pains should be taken to make and keep the ventilators for the filtered-water channels absolutely tight.

(15.) The thickness of the sand-layer shall be so great that under no circumstances shall it be reduced by scraping to less than 30 centimetres (= 12 in.), and it is desirable, so far as local conditions allow, to increase this minimum limit. Special attention must be given to the upper layer of sand, which must be arranged and continually kept in the condition most favourable for filtration. For this reason it is desirable that, after a filter has been reduced in thickness by scraping, and is about to be refilled, the sand below the surface, as far as it is discoloured, should be removed before bringing on the new sand.

(16.) Every city in the German Empire using sand-filtered water is required to make a quarterly report of its working results, especially of the bacterial character of the water before and after filtration, to the Imperial Board of Health.

(17.) The question as to the establishment of a permanent inspection of public waterworks, and if so, under what conditions, will be best decided after such quarterly reports have been furnished over some period of time.

It appears, from the report of the Water Examiner for the metropolis, General A. de C. Scott, R.E., for the month of November, 1896, that in August, 1892, the Local Government Board, in view of the prevalence of cholera on the Continent, its possible introduction into this country, and the importance of the efficient filtration of the Metropolitan water supply, requested the particular attention of the directors of the water companies to the following points, viz.:—

(1.) That every effort should be made to maintain the layer of sand in each filter at the greatest practicable thickness.

(2.) That the rate of filtration should be as slow as possible, consistently with the supply of the required quantity of water.

(3.) That the sand removed from the surface of the filters, with the deposit, should, if it was to be replaced in the filter, be completely freed from all taint of organic matter.

It is an opinion generally held by bacteriologists who have studied water filtration from their own point of view that the longer a filter has been in use the more bacterially effective it becomes, and that the cleansing of the surface should be performed as seldom as possible. This opinion is grounded on the results of experiments.

It is necessary to guard against the conclusion which might follow, that the return to the filter of dirty and imperfectly washed sand is a course which is necessarily safe and even expedient.

The sand removed from the surface of the fields, together with the mud and impurities, mostly of vegetable, but to some extent of animal origin, is deposited in heaps, where it remains for some months, so that processes of decay and putrefaction are set up. The net bacterial result of these processes is undetermined, and may be totally different from that which obtains on the surface of the sand under water.

This consideration, independently of those which may be called sentimental, indicates the desirability of the thorough washing of the included sand, before its replacement on the filters.

It appears from this report that instructions, drawn up three years ago by Professors Frankland and Dewar, with reference to the manner in which filtration should be carried out, prescribe, amongst other things, that after a filter has been re-charged with water an interval of rest should follow, during which sedimentation may take place, causing the formation of a skin or layer of slime or mud, which apparently constitutes the most effective portion of the filter from the point of view of bacterial interception.

In the course of a paper read before the Institution of Civil Engineers on November 24th, 1896, Dr. Percy Frankland observed in reference to a former paper read by him in 1886, as follows:—

"The principles then enumerated were as follows:—

"(1.) To give the maximum period of storage for the unfiltered water.

"(2.) To filter at a minimum rate.

"(3.) To filter through a maximum depth of fine sand.

"(4.) To frequently renew the filtering materials.

"In reviewing the numerous investigations which have since been carried out on this subject, it will be shown that the only one of these principles which requires any modification, by the light of more recent research, is the last. Further researches appear to show that the power of arresting bacteria possessed by a filter-bed suffers no diminution with age, so that frequent scraping is not necessary for the maintenance of the efficiency of the individual bed. It is, however, quite possible that it may be of advantage for the efficiency of the filtration plant taken as a whole. Thus, by running a filter-bed over a long period of time without cleaning, its yield becomes diminished, and as a certain volume of water must be supplied daily, this may necessitate filtering through other beds at a disadvantageously high rate, and so obtaining a filtrate from the entire works inferior in bacterial quality to that which would result if scraping were practised more frequently and a more uniform rate of filtration employed with all the beds."

In the case of the filtration of sewage waters it has been definitely shown that the continuous passage of the water through a filter has the effect of rapidly choking the pores of the bed, and in consequence of the absence of an ample supply of air, putrefaction will soon set in, but when the water is applied intermittently, the filter being thoroughly drained and allowed a period of rest, the whole of the organic matter in the water undergoes a process similar in its ultimate effect to that produced by burning. The argument follows that if this is the case with one class of organic matter, why not equally so in the case of a water charged with practically similar organic matter, but considerably less in quantity? It is just at this point that further experiments are required. The Massachusetts experiments, although resulting in most valuable information, have not yet been sufficient to demonstrate the point in all its bearings. In the observations of the Massachusetts State Board of Health, 1890, Part II., page 601, it is stated that:—"It is evident that the impurities removed from the water during those two months (November and December, 1887) must have been in large part retained by the sand. There was no indication of any burning process, by which the organic matter could be changed to mineral matter." This result, however, was changed, as on page 610 of the same volume it is observed:—"Without knowing all of the conditions that are essential to nitrification, we find in several of the tanks what appear to be striking parallels to the conditions that would exist if the organic material were burned by fire. There must first be an accumulation of combustible material. When started, the rapidity and completeness of combustion is greatest where most material has been accumulated. In filter No. 8 the greatest rapidity of burning was in May and June, 1888, after four months of accumulation, with no nitrification. This was followed by two months of slow burning, growing more feeble, until extinguished in September. Some accumulation of material occurred in the next three months, and the burning again started in December, and continued feebly through the cold months, and, becoming more active in April and May, burned with greatest intensity in June, though with less intensity and shorter duration than in the previous year, apparently for the reason that there was less to burn, until—the stored material being nearly exhausted—it burned feebly but continuously the organic matter daily supplied through the following months."

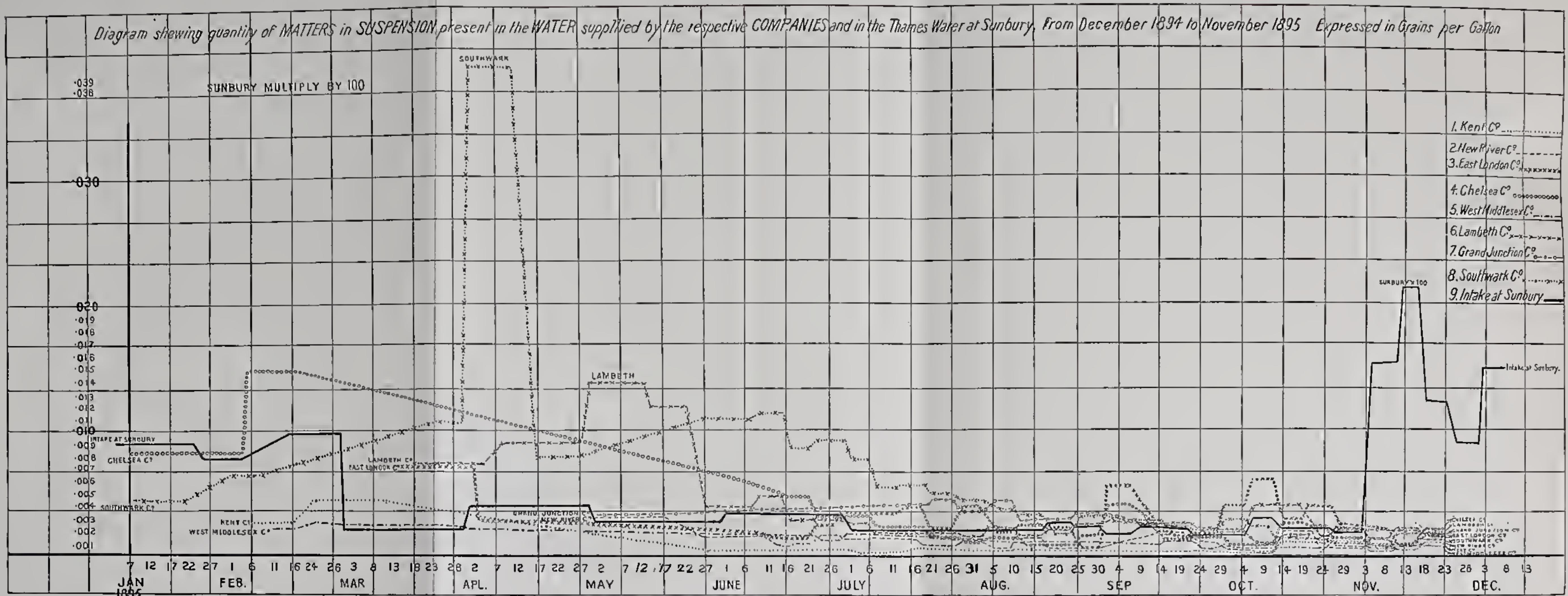
In view of the light which has been thrown upon the question of the action of filters by modern bacteriology, it yet remains to be seen whether water filters can be so managed as to give a maximum of efficiency, both as regards quantity and quality of the water filtered, without it being necessary to throw them out of work for a time while the surface layer of accumulated dirt is removed. If intermittent working would, by increasing the supply of oxygen, enable the bacterial action to completely dispose of this matter as it is formed, it cannot be doubted but that both efficiency and economy would be secured. This point, however, is one which requires no small amount of work and patience for its thorough investigation.

It cannot be overlooked that even when the greatest possible care is exercised, there yet remains a danger from the accidental breakdown of the system of filtering water on a large scale, and as the strength of a chain is but that of its weakest link, it is useless to point to the satisfactory results obtainable when the system is working at its best.

In order to provide against such contingencies, when a water is drawn from a polluted source, there can be but few, if any, better systems than that of Dr. Clark's system of softening the water wherever possible. As will be seen in the next chapter, the effect of this system is to remove practically all but the last minute traces of impurity, and thus to constitute a second line of defence in case of the breakdown of the filters, or one of them, in addition to yielding a supply of water of far greater commercial value by reason of its better adaptability for use in steam boilers, hot-water systems, and the reduced consumption of the domestic soap, which item alone would effect an economy more than equal to the cost of the system.

The failure to introduce this system in the case of the London water companies is one of the many puzzles of the day. Had they done so years ago we should have heard but little of the necessity for schemes for obtaining water from distant places, as the quality supplied would have been entirely unobjectionable from every point of view. It is not yet too late, and it is to be hoped that the day is not far distant when this question will be finally settled by the respective companies adopting a system so earnestly longed for by the majority of those who have studied the subject.

LONDON WATER SUPPLY.



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CHAPTER XV.

THE CHARACTER OF THE LONDON WATER SUPPLY.

In the course of a series of analyses which I have recently been called upon to make, certain new features have come to light which tend to throw into prominence a point of interest which has hitherto been to a great extent overlooked; this is, that the various matters held in suspension, in presumably pure waters, although small in quantity, are yet often of such a kind as to throw considerable light upon a sample of water, even after the old methods of analysis fail to distinguish the difference between one sample and another.

For the purpose of a recent inquiry into the quality of the water supplied to London I have had the opportunity of making daily analyses of the water of the river Thames at the companies' intakes, and of the filtered water supplied by the respective companies drawing therefrom; also the water supplied by the Kent Company, and by the two companies drawing their supplies from the river Lea and New River.

At first these suspended matters were examined only qualitatively, but it soon became apparent, as the work proceeded, that the quantity was sufficient, if properly collected, to admit of exact determinations, and thus more particularly identify them with the unfiltered river water. The collection was therefore conducted on a much larger scale by subsidence in special glass vessels; but, as already described, it was found that the recently-introduced hard filter papers formed an admirable medium by means of which the solid particles could be collected each day and treated with a dilute solution of bichloride of mercury to prevent decomposition, until their microscopical examination, as well as chemical analysis. By this means not only the quality, but the exact quantity was estimated, and thus further light was thrown upon the much-vexed question of the analytical examination of water. A modification of this method, in which a specially-constructed micro-filter is employed, has enabled determinations of the relative quantity, in terms of volume instead of weight, of the suspended matters to be made on quantities of water too small even for an ordinary analysis. The results of this method are embodied in the table of analyses under the head of "millimetres of suspended matter in micro-filter from one litre of water."

This process was a development of that adopted for collecting the floating particles for the purposes of microscopical examination, and by this means ensuring the inclusion of the total number of such particles under one cover glass, thus securing greater rapidity as well as accuracy.

Previous to this inquiry it does not appear that any such quantitative methods had been employed. It is clear that either vegetable or animal substances may be quantitatively indicated in terms of carbon, nitrogen, ammonia, and so forth; but such methods of expression, though valuable under certain circumstances, convey but little idea of their relative character, or whether they are in a fresh and wholesome condition or in a state of putrefaction.

The average results of daily analyses during nearly twelve months ending December, 1895, are given in the table on page 113.

It will be noticed that the average quantities of suspended matters present in the Kent, West Middlesex, and New River supplies were practically identical, namely, 0·0011, 0·0010, and 0·0011 grain per gallon respectively, so that the West Middlesex Company found it possible to so purify and store the water, that in this respect it bears comparison with waters which are generally accepted, in view of their source, as beyond suspicion. This quantity may therefore be looked upon as that unavoidably due to rust and dust, and forms a standard whereby to judge the quality of the remaining supplies. Taking the average quantity of suspended matter found during this inquiry in the water supplied by the Southwark, Lambeth, Chelsea, Grand Junction, and East London Companies as 0·0033 grain per gallon, and deducting therefrom the 0·0011 unavoidable or rust and dust matters, found as above, we have 0·0022 chemically dry grain per gallon as obviously avoidable suspended matters present in the filtered water supplied to consumers.

How far this factor would have been increased had such estimation of the suspended matters been made during the bad season of November and December, 1891, it is difficult to judge; but from the improvement effected in the colour of the water, as well as in its analytical character, it is open to the assumption that the suspended matters largely exceeded those present during 1895.

The table on page 113 shows the relative quantity of suspended matters present in the various supplies when determined gravimetrically and by the micro-filter.

From this table it will be seen that there is roughly an indication of the quality of the suspended matter from the ratio of mm. in micro-filter per litre of water to grains of actual suspended matter per gallon; thus the average of the Kent Company's water for the six months ending November, 1895, gave a ratio of 0·0023 grain per gallon per mm. in the micro-filter; in like manner the New River Company showed a ratio of 0·0033; the West Middlesex, 0·0022; the Chelsea, 0·0052; the East London, 0·0042; the Grand Junction, 0·0057; the Lambeth, 0·0052; and the Southwark and Vauxhall, 0·0056. From this it is seen that when the water is purer the weight of suspended matter per unit volume is least—a fact which is evident on microscopical examination; as in the purer waters only a few fibres with a little *débris* were generally present, in contrast with numbers of particles of *débris* and decaying organic matter, with numerous diatoms, &c., in the case of those waters which bear the least resemblance to the Kent.

In the course of twelve months' determinations of the quantity of suspended matters present in the Kent Company's supply during 1895, I found that the average was 0·0011 grain per gallon. This quantity I have ascribed to unavoidable rust and dust, and it may be safely concluded that any suspended matter less in quantity than this amount may be neglected as of no importance.

My own experience with many waters leads me to think that no serious notice need be taken of any quantity less than 1 mm. per litre, equal to 0·004 grain per gallon, as shown above, or even a larger quantity, unless it is observed there is definite microscopical evidence of objectionable contamination and the chemical analysis shows a questionable state of things.

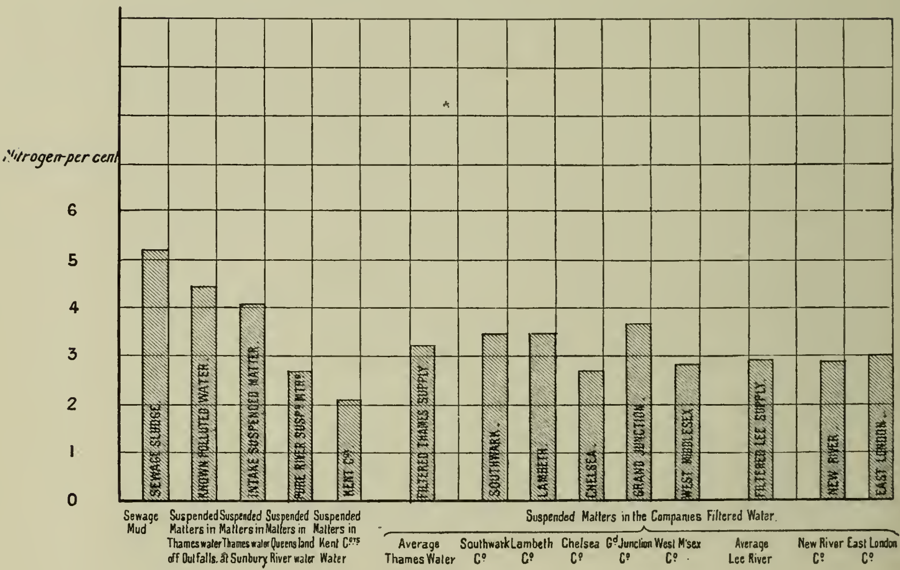
The chemical examination of the character of the suspended matter gave very remarkable results. For the purpose of this comparison the dry matters obtained from the water, either by natural subsidence or filtration, were examined for the nitrogen present in combination with the organic matter. The average percentage quantity found is set out in the following table:—

Nitrogen per cent. on Volatile Organic Matter.

Chalk	Kent		2·12
Thames	Southwark	3·44	3·27
	Lambeth	3·42	
	Chelsea	2·97	
	Grand Junction	3·66	
	West Middlesex	2·86	
New River	New River		2·86
Lea	East London		2·97
Thames Intakes	Sunbury		4·06

LONDON WATER SUPPLY.

Diagram showing Percentage of Nitrogen in Volatile (Organic) Matters held in Suspension in Various Waters, &c.



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For comparison, the following results of the estimation of the quantity of nitrogen present in known samples of polluted mud are given :—

Sewage mud	5·20
Known polluted river mud	4·40
Suspended matter in Thames at Sunbury..............	4·06
Pure river mud from the Fitzroy River, Queensland....	2·70

These results clearly point to the conclusion that, apart from the question of quantity, the suspended matters present in three of the companies' filtered supplies approximated more or less nearly in character to those in the unfiltered river waters at the companies' intakes.

MICROSCOPICAL CHARACTER OF THE SUSPENDED MATTERS.

The conclusion drawn from the consideration of the relative chemical character of the suspended matters in the unfiltered river water, compared with those in the filtered supplies, is borne out by the results of the daily microscopical examination of all samples collected, the average results of which are set out in the condensed table below.

*Percentage Number of Samples returned as "Objectionable" * by the Microscopic Examination.*

———	Samples examined.	Returned as objectionable.
		Per cent.
Kent	284	18
Southwark	286	47
Lambeth	284	34
Chelsea	282	22
Grand Junction	285	25
West Middlesex	285	24
Average	..	30
New River	286	21
East London	285	30

* "Objectionable" samples are those which contained a comparatively large quantity of *débris*, microscopic eels (anguillulæ), &c., decaying *débris* infested with bacteria, the larger infusoria, such as paramecium, rotifera, &c., epithelium scales, &c.

These percentages were then calculated into total quantities of objectionable matter present on the actual estimation of the weights of suspended matters found, and are thus set out in column 4 of the following table:—

Company.	Average suspended matter.	Microscopical examination of objectionable matters.		Organic nitrogen in suspended matters.			Average number of microbes per c.c.	Average oxygen absorbed by the dissolved matters from permanganate in four hours. Grains per gallon.
	Grains per gallon.	Percentage in samples.	Grains per million gallons.	Per cent.	Grains per million gallons.	Equal to organic matter containing 4·1 per cent. of nitrogen, as in Thames at Sunbury. Grains per million gals.		
Kent	0·0011	18	198	0·84	9	220	90	0·018
New River........	0·0011	21	231	1·44	16	390	130	0·041
West Middlesex ..	0·0010	24	240	1·43	14	341	130	0·072
Chelsea	0·0027	22	594	1·87	52	1,268	139	0·064
Grand Junction....	0·0023	25	575	2·06	47	1,146	170	0·069
East London	0·0023	30	810	1·35	36	878	277	0·060
Lambeth..........	0·0033	34	1,122	1·86	61	1,488	294	0·071
Southwark........	0·0056	47	2,632	1·68	94	2,293	352	0·078
Intake at Sunbury	0·5360	81	434,160*	1·01	5,414	132,049	16,061	0·128

* NOTE.—The microscopical examination includes, with the organic, the mineral matter, which is proportionately larger in the case of the intake waters than in the filtered supplies; hence the objectionable matters appear to be greater by the microscopical examination than those estimated by the nitrogen, which relates solely to organic matter.

The practically complete coincidence between the various methods of examination—namely, the physical, as the estimation of the weight of the suspended matters may be called; the chemical and microscopical examination of their character; the biological examination as to the actual number of bacteria present in a given sample of water; and the strictly chemical examination as to the quantity of oxidisable organic matters dissolved in the water—is very striking.

The unfiltered river water contained a mass of matters of generally indefinite character included under the head of *débris;* but, in addition to these, certain noticeable features were distinct, amongst which the diatomaceæ were predominant; entozoic worms, various dyed and undyed textile fibres, such as wool, cotton, silk, &c., were not infrequent, together with numerous infusoria and bacteria.

The results of the examination of the filtered supplies indicated the frequent presence of all these substances, and in the majority of cases it would have been difficult for a careful observer to conclude from the examination of the preparation under the microscope whether it was drawn from the unfiltered river water or from one of the filtered supplies (it being understood that the actual quantity of *débris* taken for examination was equal in each case). Diatoms were always present, and not infrequently anguillula also; but the most noticeable and objectionable feature was the frequent presence of fragments of matter in a state of decomposition and swarming with bacteria. The presence of such particles cannot be accepted as inevitable in the case of a pure water supply, as, if the filter-beds are properly worked, it should be impossible for such matters to pass them, whilst if their presence be due to dust getting into the pure-water reservoirs, evidently greater care should be taken to keep them clean. That a particle of dust might be so introduced is not to be doubted, in view of the fact that on a few occasions the Kent supply was found to contain such matters in small quantities, but evidently accidentally so, as compared with their more frequent presence in larger quantities in the filtered river waters.

From the results of this work, it is clear that much more may be learnt from the proper collection and examination of the suspended matters, however small, in a sample of water than has hitherto been supposed, and I venture to suggest that in future all samples of water should be so examined.

A great point has been made in recent years of the number of bacteria present in a water, but from the experience now obtained it would seem as if the number of bacteria depended more upon the quantity of suspended matter than on any other factor.

Considerable differences have been obtained in the estimation of the number of bacteria by different observers. It would now seem possible that these differences are occasionally due to the fact that in one sample certain particles of decaying matters may have been present, although absent in another—a result which would account for many hundreds, if not thousands, of colonies being obtained by one experiment and but few by another, quite apart from the known differences due to varying methods of procedure, temperature, &c.

BACTERIOLOGICAL EXAMINATION.

The examination of the daily samples of water for the number of bacteria, as determined by the number of colonies developed on gelatine plates, has yielded interesting results, and affords further evidence of the improvement effected in the various filtered supplies.

The following is a condensed tabular statement of the average number of microbes present in the water collected from standpipes in various parts of the respective companies' districts :—

Month.	Kent.	Southwark.	Lambeth.	Chelsea.	Grand Junction.	West Middlesex.	New River.	East London.	Sunbury.
January	89	838	793	127	111	128	274	395	15,135
February	90	545	131	161	201	92	194	318	29,308
March	122	818	238	165	135	294	251	556	29,844
April	135	325	286	188	253	135	114	151	7,080
May	73	170	88	339	284	142	145	78	5,664
June	92	199	204	158	181	231	83	602	16,013
July	79	142	102	95	263	113	83	163	10,774
August	112	164	838	108	119	96	98	123	4,813
September	31	164	124	71	113	80	44	88	2,884
October	40	78	59	61	43	54	56	76	9,900
November	139	427	366	55	169	65	92	494	45,263
Average	90	352	294	139	170	130	130	277	16,061

In 1891-92 the following average results were obtained :—Kent, 4,795; Southwark, 4,594; Lambeth, 4,626; Chelsea, 3,091; Grand Junction, 2,612; West Middlesex, 2,534; New River, 2,299; East London, 3,387; Sunbury, 179,601.

LONDON WATER SUPPLY.

Diagram showing the Relative Quantities of Organic Matters present in the Water Supplied by the respective Companies from October, 1891, to December, 1892, as determined by the Quantity of total Organic Elements (Carbon + Nitrogen).

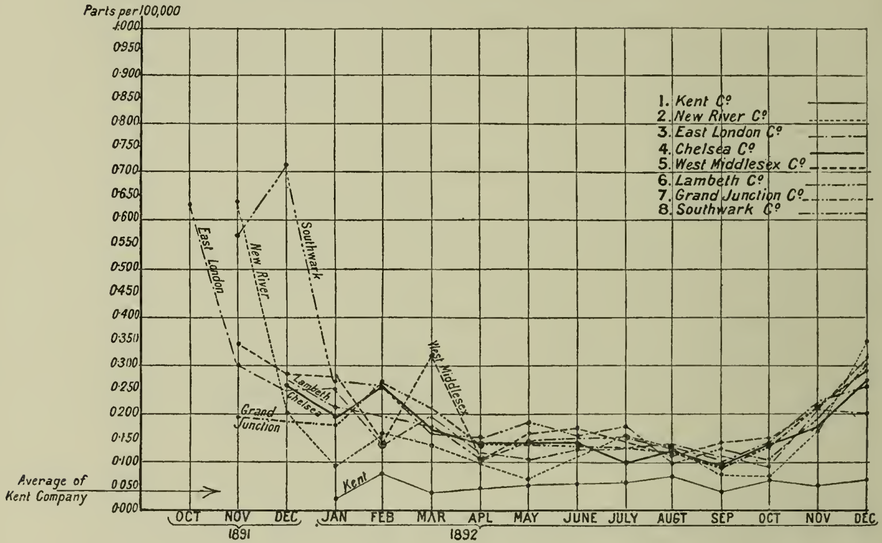
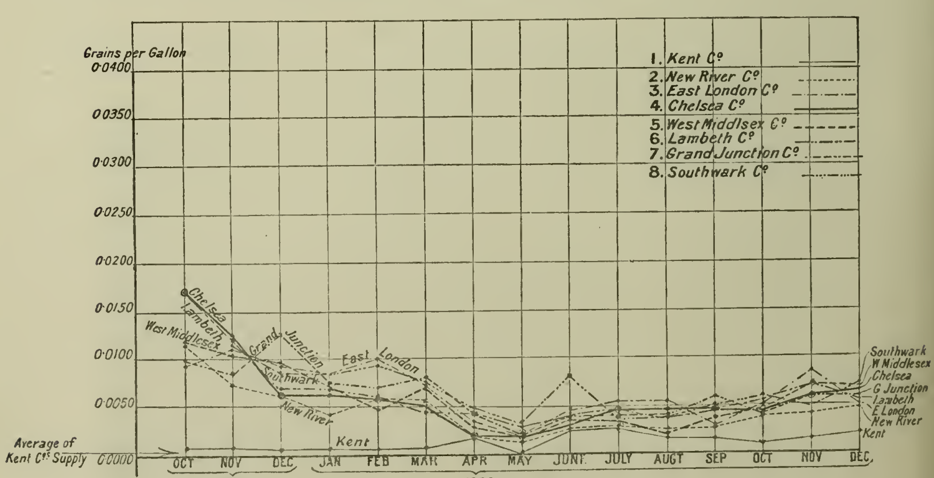
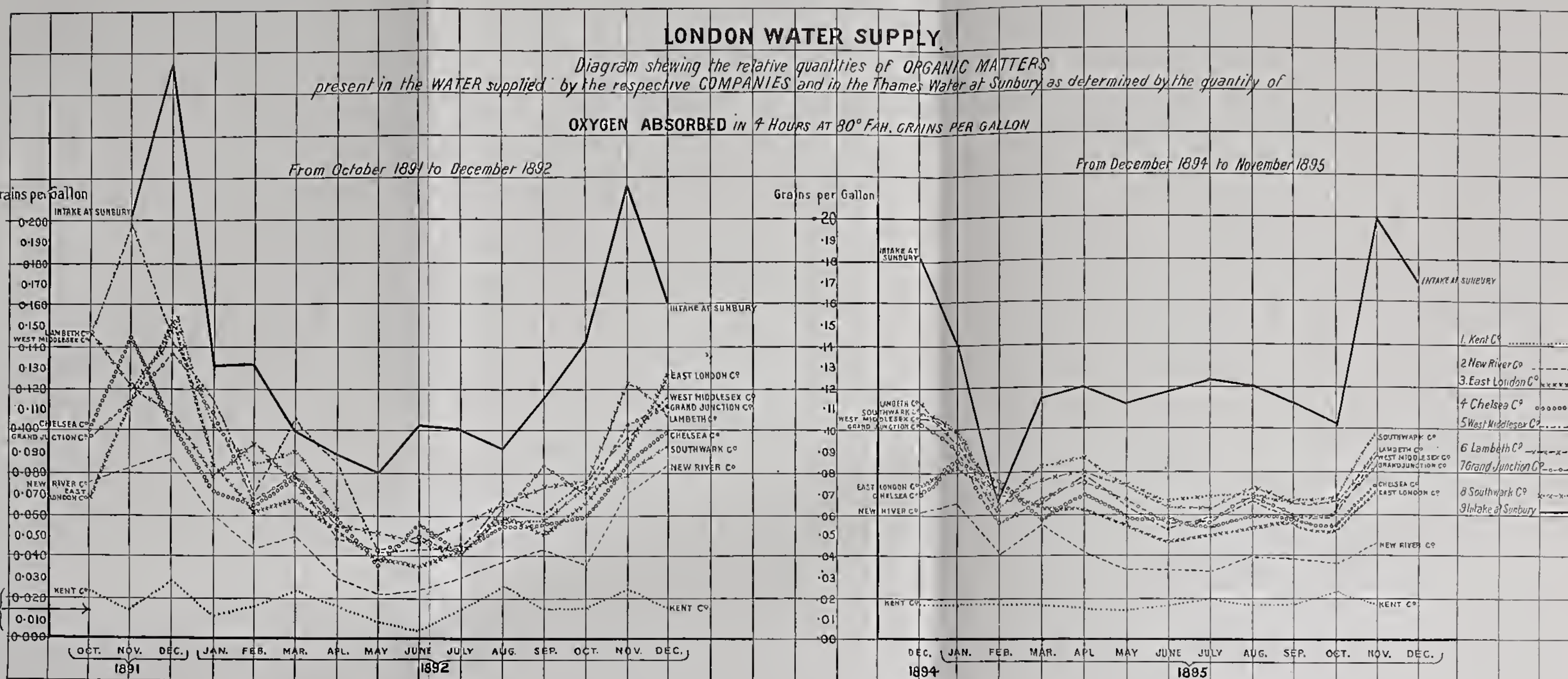


Diagram showing the Relative Quantities of Organic Matter present in the Water Supplied by the respective Companies from October, 1891, to December, 1892, as determined by the Quantity of "Albuminoid Ammonia."





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Having thus reliable data for comparison as to the bacteriological improvement which has taken place in the quality of the water between the years 1892 and 1895, it will be interesting to glance at the still further improvement which took place during the course of the latter year, and of the relation which exists between the quality of the intake waters and the filtered supply.

It will be noticed that the company which supplied water containing the largest quantity of suspended matters—viz., the Southwark and Vauxhall—supplied an average of 352 microbes per cubic centimetre of water throughout the year, this being the largest number of any of the companies. In January the monthly average was 838, which gradually decreased during the year to 78 in October, but, unfortunately, rose again to 427 in November, corresponding to the rise of microbes in the Sunbury river water of from 9,900 in October to 45,263 per cubic centimetre in November.

The relative value of the various methods of estimating the organic matter in water—viz., the organic carbon and nitrogen or "organic elements," the albuminoid ammonia, and the oxygen absorbed—has been noted in connection with the series of analyses under discussion. The results of twelve monthly averages of daily analyses made during 1892 (which period is selected in preference to 1895, when there was a break in the continuity of the analyses as regards organic elements and albuminoid ammonia) has shown that the oxygen-absorbed method, as used by the Society of Public Analysts, has been found to give the most concordant factor all through.

COMPARISON OF THE PRESENT LONDON SUPPLY WITH THE PROPOSED SUPPLY FROM WALES.

In order that the exact position of the present supply may be clearly understood, so far as regards the question of relative

Average Results of Analyses of Welsh and London Waters.

—	Welsh water, unfiltered.	London supply. Filtered river water. Summer. May to October.	London supply. Filtered river water. Winter. November to April.	Kent Company.
Appearance (on examination in 2-ft. tube)	Generally clear and bright.	Generally clear and bright.	Occasionally turbid	Clear and bright
Colour by Lovibond's tintometer scale :—				
Units of red	0·4	0·3	0·3	0·0
,, yellow	0·1	0·7	0·9	0·0
Odour at 100 deg. Fahr.	None	None	None	None
Phosphoric acid	Very slight trace	Very slight trace	Very slight trace	Very slight trace
Free ammonia	0·0003	0·0002	0·0004	0·0000
Albuminoid ammonia	0·0033	0·0045	0·0055	0·0012
Chlorine	0·68	1·34	1·32	1·64
Oxygen absorbed in fifteen minutes	0·018	0·035	0·044	0·010
,, ,, four hours	0·048	0·057	0·079	0·018
Nitrogen as nitrates, &c.	0·022	0·128	0·258	0·401
Organic carbon (parts per 100,000)	0·091	0·090	0·163	0·057
,, nitrogen ,, ,,	0·032	0·038	0·056	0·017
Total organic elements (carbon + nitrogen)	0·123	0·128	0·199	0·74
,, solids	4·3	19·3	23·9	28·6
,, hardness	3·1	12·5	17·0	19·5
Permanent hardness	1·6	4·2	4·2	5·4
Cultivation tests by gelatine plates, number of colonies per cubic centimetre	26	167	298	90
Microscopical examination of matters in suspension	Vegetable débris, diatoms, organisms.	Vegetable débris, diatoms, organisms, &c., in comparatively large quantities.	Vegetable débris, diatoms, organisms, &c., in comparatively large quantities.	Few fibres and occasional organisms.

quality and the extent to which an improvement might be anticipated in the event of the Welsh water being brought to London, the following considerations arising from the comparison of the analyses of the water at present supplied to London with those of the Welsh waters collected by myself in May, 1894, will be of interest.

In the preceding table the analytical factors in each case are placed side by side, so that the specific differences may be seen at a glance. The figures representing the Welsh waters are averages of the samples drawn from the rivers Usk, Ebw, Arfon, Wye, Towy, Ithon, and Clywedog, which were, of course, unfiltered. Those representing the present filtered river water supplied to London are averages of the Southwark, Lambeth, Chelsea, Grand Junction, West Middlesex, and East London. These, however, are given in two columns, one for average summer quality and the second showing average winter quality. For comparison as a standard, the Kent Company's average supply is added.

On carefully examining the results, it will be found that the filtered river water supplied during the six summer months to London contains practically identically the same amount of organic carbon and nitrogen as that present in the unfiltered Welsh waters, viz., 0·128 part per 100,000 against 0·123, whilst during the six winter months it is only half as much again, viz., 0·199.

The oxygen absorbed from permanganate is a little more, viz., 0·057 instead of 0·048 during the summer, but only a little more than half as much again, viz., 0·079 grain per gallon during the winter. In like manner the "albuminoid ammonia" in the Welsh water averages 0·033 against 0·0045 and 0·0055 in the respective summer and winter London supplies, excluding the Kent. The colour of the water when viewed through a 2-ft. tube was on an average even more in the case of the Welsh water, viz., 1·4 against 1·0 and 1·2 in the case of the London supplies.

From this comparison of the average results of nearly 3,000 analyses, it is evident that the organic impurity of the unfiltered Welsh water is a little less than that in the average filtered London water, and the inquiry naturally follows as to the specific differences which exist. This is undoubtedly due to two things: First, the quantity of the solid matter in solution, principally salts of lime, giving the London water its great hardening properties; and, secondly, the comparatively large quantity of floating particles, on which, as has been shown, the number of microbes present to a great extent depends.

The unfiltered Welsh water examined on the spot contained twenty-six microbes per cubic centimetre, whilst the average London filtered waters contained in summer 167 and in winter 298, the Kent supply containing ninety. Of course, it will be noted that these figures refer solely to the number and not to the character of the microbes.

THE EFFECT OF SOFTENING THE PRESENT SUPPLY.

The suggestion has been repeatedly made that the excessive quantity of lime in the London water should be removed by the adoption of the well-known Clarke's process, and it is only natural to inquire as to what would be its effect upon the present filtered river water, not only in removing the excess of carbonate of lime, and thus effecting an enormous improvement in the commercial value of the London water, but also in assisting in the process of purification. With the view of testing this question, certain experiments have been made on one of the best London waters, viz., that of the New River Company, in order that the percentage reduction, if any, which might be brought about in the quantity of dissolved as well as undissolved impurity might be ascertained.

The results of these, which are stated in the table given opposite, are perfectly definite, and show that even in the case

Experiments to Ascertain the Effect Produced on the Impurities of the New River Supply by the Process of Softening.

Date.	Description.	Examination in a 2 ft. tube. Appearance.	Colour by Lovibond's tintometer scale. Red.	Yellow.	Blue.	Odour at 100 deg. Fahr.	Phosphoric acid.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Oxygen absorbed in 15 minutes.	Oxygen absorbed in 4 hours.	Total solids.	Appearance on ignition.	Hardness. Total.	Hardness. Permanent.	Cultivation tests by gelatine plates. Number of colonies.	Microscopical examination of matters in suspension.
1895. Dec. 16	Untreated water ..	Clear	0·1	0·5	—	None	V.S.T.	0·0003	0·0059	1·30	0·029	0·045	23·4	S.B.	17·4	4·2	96	0·3 mm. Tangled mass of fibres, diatoms, bacteria, &c.
	Treated with 9·4 per cent. of saturated lime water.	,,	—	0·3	—	,,	,,	0·0003	0·0047	1·30	0·024	0·037	10·6	,,	5·4	4·0	12	Trace. Few vegetable fibres, organic *débris*.
,, 18	Untreated water ..	,,	0·1	0·6	—	,,	None	0·0003	0·0082	1·30	0·038	0·051	25·2	,,	17·4	3·8	110	Slight trace. Few cotton and other fibres.
	Treated with 9·4 per cent. of saturated lime water.	,,	0·0	0·4	—	,,	,,	0·0003	0·0069	1·30	0·025	0·049	11·0	,,	5·0	4·2	6	Very slight trace. One or two fibres.
,, 20	Untreated water ..	,,	0·1	0·6	—	,,	,,	0·0002	0·0102	1·25	0·030	0·064	24·4	,,	17·2	4·5	60	Very slight trace. Few fibres and little *débris*.
	Treated with 9·4 per cent. of saturated lime water.	,,	0·0	0·4	—	,,	,,	0·0002	0·0068	1·30	0·020	0·028	13·8	,,	8·5	4·5	16*	Very slight trace. Little *débris*.
	Average per cent. reduction.	—	100	35	—	—	—	Nil	23	—	—	25	—	—	64	—	87	

* After fifteen days gelatine still solid. Three moulds and few colonies.

of the New River supply the reduction of dissolved organic impurity was equal to 25 per cent., as shown by the oxygen absorbed, whilst 64 per cent. of the total hardness was removed and 87 per cent. of the bacteria, and with these the whole of the matters in suspension.

On applying these results to the average analytical figures given below, it will be found that the "albuminoid ammonia" in the summer supply would fall, by the adoption of the process of softening, from 0·0045 to 0·0034, or identically the same quantity as that in the unfiltered Welsh supply, whilst the winter supply would be improved to the quality of the present summer supply; that the oxygen absorbed in four hours would fall from 0·057 to 0·043 in summer, and from 0·079 to 0·059 in winter, against 0·048 in the Welsh water, or a yearly average of only 0·003 grain per gallon in excess; that the organic carbon and nitrogen would be less in proportion, whilst practically the whole of the "suspended matters" would be removed, and with them 87 per cent. of the bacteria, thus reducing the summer number (apart from their character) of microbes from 167 to 21, and the winter from 298 to 38, against 26 in the Welsh water, or an annual average difference of + 3. In addition to these enormous improvements the hardness would be reduced in summer from 12·5 deg. to 4·4 deg., and in winter from 17·0 deg. to 6·1 deg., or an annual average of 5·2 deg. against 3·1 deg., which was the average hardness of the Welsh waters as examined in May, 1894.

It would therefore seem that, by the adoption of the system of softening, the present supply, in respect of its chemical quality and number of bacteria, would be improved to a degree comparable with that of the Welsh sources.

CHAPTER XVI.

THE ACTION OF SOFT WATER UPON LEAD.

The quality of dissolving lead shared by many upland waters, as those supplied to several of the larger towns in the north of England, is a subject that has long engaged attention in this and other countries; and the cause has of late years been the subject of anxious inquiry, especially with a view to the determination of the methods which must be adopted to prevent lead poisoning. This has been more particularly the case since 1886, when abundant lead poisoning was found in Sheffield to result from the use of one of the moorland supplies to that town. Since that time lead poisoning, also due to upland water supply, has been recognized in a number of other communities, including Bradford, Wakefield, Batley, Huddersfield, Shipley, Morley and Keighley, and one or other method of treatment has already been adopted in all these towns except Huddersfield and Batley. In the case of the former town, it has been found necessary to exclude from domestic use some of the more actively plumbo-solvent tributaries.

It has been found that, whereas all waters act to some extent upon new lead surfaces, the distribution of hard waters through lead pipes is not generally attended with risk, for the reason that a protective coating is quickly formed on the lead surface exposed to the water. This protective power is not shared by rain or distilled water, or by the greater number of the very soft waters which are obtained from moorland sources; and in respect of those moorland waters which have an acid reaction, the ability to dissolve lead is always strongly marked, even to the extent of constituting a grave danger to health. These soft acid waters are chiefly met with where the gathering ground is peaty, but since more or less water of a different character—such as spring water—is usually included in moorland supplies, the ability to attack lead possessed by the peat-derived water is often neutralized by qualities possessed by the spring water, and the mixture is free from the risk referred to. In such cases, however, the inability of this mixture to attack lead is dependent on the relative proportions of the various kinds of water which constitute the mixture; and inasmuch as these are liable to great variations due to seasonable conditions, it is found that the mixture may be at one time inoperative upon lead although at other times operative.

It appears from a report of the Medical Officer of the Local Government Board, issued in 1895, that the action of water upon lead is of two kinds, the one leading to solution of the lead, the other to its erosion and deposit in a loose powdery form readily swept away by the current in a pipe, and conveyed to the consumer.

The actual cause of this solvent action is little understood. It is by some ascribed to the presence of acids derived from the decomposition of vegetable substances, such as exist in peat and moorland ground generally, and the fact that a slight addition of calcareous matter is sufficient to remove the plumbo-solvent action would appear to confirm this view. Such, however, could not be the reason in the case of recently fallen rain water or of pure distilled water, both of which act energetically on lead. According to Miller, the necessary conditions are combined action of air and pure water. In this case the surface of the lead becomes oxidized, and the oxide is dissolved by the water. By the absorption of carbonic acid hydrated carbonate of lead is formed, which is deposited in silky scales. The corrosion is increased by the presence of chlorides or nitrates, but diminished by sulphates, phosphates and carbonates, the oxide of lead being scarcely soluble in water containing these salts.

But, although the cause of the solvent action is obscure, nevertheless remedial measures can generally be successfully employed. The removal of lead pipes from a town in which they already exist, and their substitution by other materials, is scarcely practicable; but it has been found that the use of various substances in small quantities will in most cases effectually remove the danger. The mixing of spring, or of more or less hard or calcareous, water with the moorland supply has been shown above to be uncertain; and, generally, remedial measures are not applicable indifferently, but the particular remedy best adapted for a given water must be found by experiment, and by consideration of the local circumstances. At Sheffield and Bradford water has been deprived of its dangerous condition by the addition of comparatively trifling amounts of chalk, increasing the hardness by some one and a half degrees. At Wakefield a similarly successful result has been attained by the use of carbonate of soda. In other places the desired result has been produced by filtration through calcareous sand. In some cases the mere passage of the water through an aqueduct of sufficient length will furnish enough lime to destroy the solvent action upon lead. The water of Loch Katrine, for instance, is powerfully plumbo-solvent, but loses this character entirely in its passage to Glasgow.

It has been stated by some that the deposit formed in lead pipes by the previous passage of hard water is an effectual safeguard against attack by pure soft water afterwards admitted; and that, therefore, it would be quite safe to furnish a moorland water supply to a town which, like London, has for many years had hard water passing through its pipes. This view, however, I believe to be erroneous, as the protection thus afforded is only temporary in the case of waters having an acid reaction.

"Many men, many opinions," applies to considerations affecting the analysis or the purification of water more particularly, and various experts have given expression to the most widely divergent views on this special question of the action of lead on water, and the means to be employed to obviate it. This is, no doubt, due to our want of precise knowledge on the subject, and to the fact that a water examined by one observer is found to act strongly on lead, whilst one of apparently exactly similar character in all other regards, but from a different, although like, source, has been found by another observer to be quite without such action. Mere storage for a short time will frequently remove such power from a water which, when first collected, possessed it in a marked degree. It will be seen that the question is a very difficult one, and one in which generalising would appear at present unwise. As already stated, each case should be dealt with on its merits as it arises.

CHAPTER XVII.

THE APPLICATION OF THE BIOLOGICAL PROCESS TO THE PURIFICATION OF WASTE WATER FROM PRIVATE PROPERTIES, ASYLUMS, SCHOOLS, ETC.

The subject matter of this chapter would perhaps have been more appropriately introduced earlier in the work; but repeated applications having been made for information on this head, compel me, at the very moment of going to press, to make such general statements as are possible in a subject in which each case peculiarly needs individual consideration.

One of the great advantages of the biological system is that it can be readily applied to the disposal of the refuse water from very small communities and collections of houses, such as small villages, country houses, asylums, and public schools. By many it has been thought that the scheme is only adapted for sewage works where constant attention is available. This attitude can only arise from a want of appreciation of the fundamental principles upon which it is based; or possibly from the fact that in the earlier stages of the work, when speaking of the proper method of applying it to existing sewage works, I have referred to the careful supervision which is necessary in order to provide against falling into the error of using the bacteria beds according to the old ideas of filtration, which would inevitably lead to failure. As I have repeatedly explained, the biological scheme is not "filtration" in the ordinarily accepted meaning of the word, the continued success of the system depending upon the careful observance of conditions quite other than those which obtain in the employment of a filter proper. Now that our information has been so greatly enlarged, we may look for results more generally attainable than was thought possible a short time back.

In connection with the application of the system to small properties, or individual houses, the work of Dr. Poore must not be lost sight of. That gentleman has been working in the right direction for some years past, and his recent paper, read before the Sanitary Institute Congress, at Leeds, during the present year, is entirely in accordance with all that I have put forward on the subject. In his paper, Dr. Poore described how the slop-water of a house should be treated, and there is very little to be added to his admirable digest of the matter.

For the past two and a half years a bacteria bed, worked on the lines referred to in the earlier chapters of the present work, has been daily treating the whole sewage from a house containing, on an average, from fifty to sixty persons, and at the time of writing this bed is still doing its work in a most satisfactory manner. With the exception of such coarse particles as are kept back by screening, the whole of the organic matter passes into the bed, and is there in greater part oxidised and destroyed; and no one passing by the spot, and previously unaware of its existence, would have the least reason to suspect the presence of this bed. The brook into which the effluent is discharged is perfectly free from any offensive deposit or odour, and a little lower down the water is drunk by cattle without any complaint having been made on the subject by the farmer.

It is claimed for certain processes that they will work successfully for an indefinite period without any attention whatever, but I have not yet seen one which is left to run alone, for say a year, without being watched. What will happen in the future in the case of these "self-acting" schemes remains to be seen. It will be understood that I do not here refer to automatic arrangements intended to minimise the labour and watching required, such as that already referred to as devised by Mr. Cameron. A reduction in the number of persons engaged in watching and attending to the various parts is, of course, always desirable; but this is a very different thing from leaving an installation to work itself entirely. It is not a little remarkable that, although the public have now been given a process which will solve their difficulties at comparatively a very slight cost, they still ask for something which will give them equally good results without either cost or trouble. The argument that a process which is more or less dependent upon human supervision is foredoomed to failure is, to my mind, bad from its foundation. How many processes are there in daily operation which we do not hesitate to employ, although our very lives depend upon the due exercise of such human care and supervision? Who would refuse to travel by train because the engine is controlled by a driver, or the signals are not automatic? If in such matters we do not hesitate to place ourselves in the hands of our fellows, why need we be so anxious to procure an automatic process for the purification of waste water, merely to save the small expense attending its proper control, and on the ground that man is a fallible creature.

It will readily be seen that in dealing with the sewage of small communities, I have no method to propose which will work without some supervision; but it has been reduced to a minimum and requires no skill for its execution, but merely an ordinary sense of duty, and the intelligence which may be found in the average farm labourer.

In arranging a bacteria bed in which the sewage of a village, or small collection of persons, is to be disposed of, without the necessity for constant attention, we shall have to work with a larger cubical capacity of bed than usual, and, therefore, the first cost will be greater in proportion than would otherwise be the case. This statement need not cause alarm, as no modification of the bacteria bed can lead to any relatively large expenditure, and the standard of comparison—the expense of the bacterial system as applied to a large place—is very small indeed compared with that involved in the use of other methods.

As the process of bacterial treatment is only now beginning to be understood, it is not desirable to plan out a definite scheme which will be applicable under all circumstances; each case must be dealt with as it arises, the local conditions often necessitating very material modifications. As a general idea, however, it may be remarked that the capacity of each of the beds should be sufficient to hold a day's flow, and that they should be in duplicate. The sewage, after screening, should be allowed to pass on to one of the coarse beds during twenty-four hours, and at the expiration of that time should be diverted on to the other, whilst that which has collected in the first should be allowed to discharge slowly on to one of the fine beds. At the end of another twenty-four hours the sewage flow should be diverted on coarse bed No. 1, the water stored in coarse bed No. 2 should be allowed to pass slowly on to fine bed No. 2, and fine bed No. 1 should be gradually emptied. In some cases it might be desirable to have a third pair of beds, in order to put one of the others out of action occasionally for a rest.

Another phase of the disposal of crude sewage, viz., its discharge into the sea, is also a point that claims some attention. In view of the extremely simple and economical method now applicable, it is to be hoped that at no distant date this will be entirely abandoned. It is indeed a disgrace to some of our watering places that, within only a short distance of favourite bathing spots, crude sewage can be seen floating about. It is true that the immensity of the volume of the sea water is such that one would think no difficulty could be experienced in the matter. As a simple fact, however, I have seen such a state of things, in a case where great expense had been incurred in carrying the sewage a mile or more down the coast, that it is a wonder that the long-suffering public has not risen in rebellion.

CHAPTER XVIII.

SYSTEMATIC EXAMINATION OF POTABLE WATER.

The necessity for special investigation into the character of the microbes in water is brought out very clearly by the presence of epidemics in various parts of the country. Over and over again the same sequence of events has happened. Individuals and authorities have been warned that, if a certain condition of things continues, disease will infallibly follow, and in response one is often told that one is only an alarmist. The sad object lesson which we have before us at the present time is but Nature's answer to all those who persistently adhere to the old methods. If the Maidstone and other epidemics have the result of waking up the authorities to the fact that practical immunity can be secured by taking advantage of the knowledge obtainable by means of systematic analyses of the water daily, or at least weekly, we shall be in a far stronger position to defeat the foe which insidiously approaches in the form of disease of a most deadly character.

What would be thought of a military encampment in which sentinels were posted only when the enemy was in sight? And yet what is the difference between this state of things and that in which we allow ourselves to be as regards the approach of the foe in the shape of disease? The objection to a daily analysis can only be on the score of expense. If in the course of a series of analyses conducted on the ordinary simple lines a water should show a departure from its normal character, further more elaborate investigation might be called in to elucidate the point, just as the signal fired by a sentry calls out the guard. Water companies and authorities think nothing of the employment of an extra labourer now and then, and yet they seem to view with horror, and as something altogether unnecessary, the idea of appointing a chemist whose duty it would be to stand on guard and to give them instant notice of the first approach of danger. I know that in speaking thus plainly I lay myself open to the charge of trying to make a case for my professional brethren as well as myself. Well, let that be so to those who choose to lay this to my account: it does not alter the fact that even in the case of the vast multitude of people gathered together in the mighty city of London their interests in this respect are only officially safe-guarded by the examination of one sample of water taken from each company's supply once a month. True it is that the companies themselves have for some time past, since they have come to the conclusion that their interests are in jeopardy, taken matters into their own hands, and also that the water consumers, as represented by the London County Council, have made investigations with the result of showing certain defects hitherto unsuspected, and which the companies have wisely remedied in great part. But these examinations have been carried out more from political and commercial motives than from the proper standpoint, viz., the systematic examination of the water for the purpose of safe-guarding the health of the consumers. There can be no shadow of doubt that if the Maidstone water had been subjected to a systematic daily analysis of samples drawn from each source of supply the present sad disaster would never have happened. The lesson is obvious. Let all authorities, whether companies or councils, take the matter to heart, and insist upon the examination being *daily*, or nearly so. Once a month or once a quarter is insufficient, and would only show a degree of confidence altogether misleading and dangerous. What a tremendous to-do there is if the dust is not frequently removed from our premises, or if the roads are not swept to our liking—if all the little matters which go to make up modern life are not regularly looked after. And yet we allow one of the most vital of our daily requirements virtually to look after itself.

In the course of my evidence before the last Royal Commission on the Metropolitan Water Supply, I instanced this absurdity, and drew attention to the fact that in the case of our gas, which chiefly concerns our pockets, we spend thousands of pounds annually in making daily examinations as to its quality and quantity. In London alone there is a staff of no less than twenty-three gas examiners, whose daily duty it is, at as many stations, to examine and report as to the quality of the gas supplied to their respective districts. There are two superintending gas examiners, one under the City of London and the other under the London County Council, whose duty it is to supervise the above staff; a Chief Gas Examiner, who holds a position equal to that of a judge in regard to technical points in connection with the operations of the examiners and the pleas of the companies, as to the defects, if any, arising from unavoidable causes or accidents; and three Gas Referees, appointed by the Board of Trade, whose duty it is to prescribe and certify from time to time the mode of testing, and the apparatus to be used in making the tests. All this elaborate machinery costs the ratepayers, directly or indirectly, no less than £6,000 per annum merely in regard to that which touches their pockets, while, on the other hand, the only money spent in looking after the water supply is a few hundred pounds paid by the Local Government Board on the examination of one sample of the water supplied by each of the eight companies per month. What a contrast! In the case of gas, a large staff of examiners is on duty each day, carrying out the most severe tests, while in the case of the water supply one poor pint or two is tested once a month. Truly, we are a logical people!

Since the agitation with respect to the proposed purchase of the water companies has become almost incessant, they have thought fit, and rightly so, to protect their interests by having the water examined daily in order that they may be able to show that it is above suspicion. In this case, however, the work is not undertaken so much for the purpose of showing any default, should it exist, as to protect the commercial interests of the shareholder. The effect may be good, but the motive is not the true one. The work should be undertaken wholly and solely in the interests of the public, and not to support commercial interests, however good and reasonable they may be.

In regard to the methods of analysis, the biological processes which have come to the front of late years must have a foremost place so far as the ultimate information which may be obtained is concerned, but in regard to the practical utility for the moment as serving to sound the note of warning, the chemical and microscopical methods are far to be preferred, as they are capable of giving almost instant notice of the approach of danger. In this respect it is questionable whether any method can exceed in rapidity, simplicity, as well as reliability, the micro-filter method of examination, already explained in a previous chapter, and further illustrated in connection with the examination of the London water supply. By its means, within an hour or so, more or less, according to the skill of the operator and the quality of the water, the character of a sample can be indicated with the utmost reliability, and the test can be repeated again and again upon sample after sample from different reservoirs and filter beds or sources of supply, and the cause of the trouble, when it arises, sought out at once and stopped long before any serious damage is done; whereas by the biological methods days must elapse before any indications are obtainable. In the latter case it is the old story of locking the stable door after the steed has flown, whilst in the former the groom is always on guard, and the thief is detected at the moment of his approach. In consequence of the simplicity of the micro-filter method the expense of the examination is reduced to a minimum, and, therefore, there is all the less excuse for its neglect.

The proper course to be pursued, I suggest, is that a sample of water should be examined each day, or nearly so, by the micro-filter process, and that this should be supplemented by a thorough chemical and bacteriological examination undertaken from time to time, the more often the better. By such a systematic search the danger of the propagation of disease by water-carried impurities would be, to all intents and purposes, removed.

It is not necessary to recite here the *modus operandi* of the various methods involved in a systematic bacteriological examination. These are clearly set out in the various text books devoted to that object; all that is necessary being to point out the advantages to be derived from their employment in a definite and well-considered system of application.

APPENDIX I.

THRESH'S METHOD OF ESTIMATING OXYGEN DISSOLVED IN WATER.

The process of Dr. J. C. Thresh is based on the fact that whereas, in absence of oxygen, nitrous acid and hydrogen iodide interact to form iodine, water and nitric oxide; in presence of oxygen the nitric oxide becomes re-oxidised, and, serving as a carrier of the oxygen, an amount of iodine equivalent to the oxygen present is liberated in addition to that resulting from the initial action of the nitrous acid; hence, deducting the amount liberated by the nitrous acid, and by the oxygen dissolved in the solutions used from the total amount, the difference will be that corresponding to the oxygen dissolved in the water examined.

The apparatus is shown on p. 123.

The solutions used are:—(1.) A solution containing 0·5 grm. sodium nitrite, and 20 grms. potassium iodide in 100 c.c.; (2.) a solution of 7·75 grms. sodium thiosulphate in 1 litre, 1 c.c. of which corresponds to 0·25 mgrm. of oxygen; (3.) a clear solution of starch; and (4.) diluted pure sulphuric acid (1 : 3).

The apparatus required is as follows:—A wide-mouth, white glass bottle of about 500 c.c. capacity, provided with a caoutchouc stopper, through which four holes are bored. Through one passes the neck of a cylindrical "separator" funnel of known capacity, and through the second a tube drawn out to a fine point, which is connected by a short length of caoutchouc tubing with the thiosulphate burette; while inlet and exit tubes for coal-gas are passed through the third and fourth holes, the exit tube having attached to it a sufficient length of caoutchouc tubing to permit of connection being established between the bottle and the separator when the stopper of the latter is withdrawn.

The separator is filled with the water to be examined, and 1 c.c. of the nitrite iodide, and 1 c.c. of the acid solution, are added. If the pipette be held vertically, with its end just below the surface of the water, the solutions flow in a sharply-defined column to the lower part of the separator, so that an infinitesimally small quantity (if any) is lost in the water which overflows when the stopper is inserted. The admixture of the liquids having been effected by inverting the apparatus several times, a sharp current of coal-gas is passed into the bottle to displace the air, the escaping gas being allowed to burn at a jet attached to the exit tube. Fifteen minutes after adding the solutions to the water the flame is extinguished, a cork is attached in place of the jet, and is inserted in place of the stopper of the separator, and the water is then allowed to flow into the bottle; the exit tube having been disconnected from the funnel and the gas set fire to, thiosulphate is run in until the colour of the iodine is nearly destroyed; about 1 c.c. of starch solution is then added from the separator, and the titration is completed. The effect of the nitrite, dilute acid and starch solutions is readily determined by removing the separator and adding 5 c.c. of each in succession, and then titrating; the effect of the oxygen in the thiosulphate may be allowed for on the assumption that as much oxygen is dissolved in it as distilled water would contain at the same temperature. It appears that there is no advantage in passing the coal-gas through alkaline pyrogallol.—*Journal Soc. of Chem. Ind.*, Mar. 31, 1890, p. 327.

APPENDIX II.

This Volumetric Process for the Determination of the Dissolved Oxygen in Water may be used as an Alternative to that of Dr. Thresh.

SCHUTZENBERGER'S PROCESS FOR THE DETERMINATION OF THE DISSOLVED OXYGEN IN WATER.

Arranged and Modified by Dr. Dupré and Mr. W. J. Dibdin.

The apparatus at first sight appears more complicated than it really is. The essential parts consist of two burettes with their dropping tubes passing through a stopper inserted in the centre neck of a Wolff's bottle, through which a constant current of hydrogen is kept passing for the purpose of excluding atmospheric air. Through the stopper in the right hand neck the tubular of a tap funnel or separator is passed to the bottom of the bottle, for the purpose of introducing the water to be tested. This separator should hold about 250 c.c. A small bent glass tube passes just through the cork, and is connected by india-rubber tubing to a wash-bottle partially filled with water, which acts as a seal for the purpose of preventing the diffusion of the hydrogen from the Wolff's bottle. Through the left hand cork of the Wolff's bottle, two glass tubes pass, one for the admission of hydrogen from the generating apparatus, stopping short above the surface of the liquid, and the other to the bottom of the bottle for the purpose of withdrawing the liquid from time to time, a length of india-rubber tubing, provided with a clip, being attached to it so as to convert it into a syphon. Through the same cork a second, but smaller separator is passed for the purpose of introducing small quantities of fully aërated water, when it is necessary to neutralise any excess of the standard hyposulphite solution which may have been inadvertently run into the bottle.

The standard solution of hyposulphite is contained in the large bottle on the stand, and is run into the burette through the length of india-rubber tubing connecting it with the bottom of the burette, and terminating below the surface of the liquid in the bottle, a clip being provided for regulating and stopping the flow. To prevent the introduction of atmospheric oxygen into the bottle of standard solution the tube supplying the hydrogen to take the place of the removed solution dips through the cork of a small bottle containing an alkaline solution of pyrogallic acid; through this cork a second tube passes to the bottom of the bottle so that the gas is washed by the solution and deprived of its oxygen, if any. The second small bottle is provided as a catchpit to catch the alkaline solution in case of accident or expansion of the gas in the stock bottle. A screw clip is provided on the india-rubber connection between the stock bottle and the inlet tube for the purpose of preventing the gas, in case of expansion, from driving the pyrogallic acid solution out of the absorption bottle, and thus leaving a free passage for the diffusion of oxygen into the stock bottle, which would weaken the hyposulphite solution. A similar arrangement of bottles, or rather tubes, is provided at the top of the burette for absorbing atmospheric oxygen from the gas before it enters the burette when the standard solution is run out.

The second burette is for the solution of indigo which is to be used as an indicator, only sufficient being run into the Wolff's bottle to give a distinct colour.

Before commencing a titration all the hyposulphite solution in the burette and the tubes is to be carefully run off, and the burette refilled with fresh solution from the stock bottle. The hydrogen is sent through the apparatus to remove all atmospheric oxygen, which is best kept out when the apparatus is not in use, by stopping the current with a tap or plug inserted in the sealing bottle connected to the right hand cork of the Wolff's bottle, so that a pressure of hydrogen is always maintained; the tap of the generating apparatus being left open.

To make an experiment, syphon off the liquid in the bottle and run in a small quantity of clear and fully aërated water from the separator, then add just sufficient indigo solution from its burette to give a decided blue tint, and add drop by drop the hyposulphite solution until the blue colour is just discharged, now add an excess of hyposulphite solution; then immediately run in the water to be tested from the separator, which has been previously filled by means of a syphon to prevent, as far as possible, the water from coming in contact with the air. As soon as the blue colour of the indigo returns add more hyposulphite. The object of this method of procedure is to prevent the oxygen of the water being displaced by the hydrogen, thus interfering with the accuracy of the determination. If the hyposulphite is kept in slight excess until just the end of the reaction no free oxygen will be present, as it is instantly absorbed. As soon as the separator is empty shut off the cock, and add the hyposulphite solution, drop by drop, until the blue colour is just discharged. The quantity of hyposulphite solution used is to be noticed. The strength of the hyposulphite solution is readily ascertained by making a similar experiment with fully aërated water, the mean of two determinations being taken in all cases. The use of the table is obvious. Note the temperature of the fully aërated water used to standardise the solution, and also that of the water under examination, then the necessary calculations can be readily made. As the same quantity of water is used in all cases no correction for quantity is needed, as the results so far are strictly comparable. The results should be stated in percentages of the quantity of oxygen which the water is *capable of absorbing at its particular temperature*, as well as in actual cubic inches.

Table, showing the Quantity of Oxygen Dissolved by Water at various Temperatures. Corrected to 0° *C. at* 760 *m.m. pressure.*

Temperature Fahrenheit.	Temperature Centigrade.	Cubic Inches of Oxygen per Gallon.
41°	5·00	2·40
42	5·55	2·37
43	6·11	2·34
44	6·66	2·31
45	7·22	2·28
46	7·77	2·26
47	8·33	2·23
48	8·89	2·19
49	9·44	2·17
50	10·00	2·15
51	10·55	2·12
52	11·11	2·09
53	11·66	2·07
54	12·22	2·04
55	12·77	2·02
56	13·33	2·00
57	13·89	1·97
58	14·44	1·95
59	15·00	1·93
60	15·55	1·90
61	16·11	1·88
62	16·66	1·86
63	17·22	1·83
64	17·77	1·81
65	18·33	1·79
66	18·89	1·77
67	19·44	1·75
68	20·00	1·73
69	20·55	1·72
70	21·11	1·70

APPENDIX III.

REPORT by the Chemist to the London County Council on the Experiments on the Filtration of Sewage Effluent during the Years 1892-3-4-5.

To the Main Drainage Committee.

On the 10th of March, 1891, the Committee ordered a series of experiments to be conducted as to the best methods of filtering the sewage effluent obtained at the northern outfall precipitation works. After these had been carried out, with the result that coke-breeze was found to be the most suitable material for the purpose, the Committee on the 24th of November, 1892, ordered that the experiments with that material should be resumed on a larger scale, the size of the new filter being one acre. In accordance with the order of the Committee of the 7th of March, 1895, I now submit the following statement of the methods of procedure and the results obtained.

From the foregoing it will be seen that the experiments may be conveniently divided into two main groups, viz. :—

(1.) Experiments with small filters and various filtering materials.

(2.) Experiments with a 1-acre filter, using coke-breeze only as material.

The latter may be again sub-divided into—

(*a*) Preliminary trials on velocity of passage, &c.
(*b*) Experiments on biological lines.
(*c*) Experiments with doubled means of filling.
(*d*) Experiments with increased facilities for emptying.
(*e*) Experiments on recuperative power.

Series No. 1.

The tanks for filters used in the first series of experiments were built of wood, and were each equal in area to $\frac{1}{200}$th part of an acre. They were four in number and were filled with pea ballast, coke-breeze, burnt clay, and a proprietary material (with gravel and sand) respectively. All four were worked at the same rates and during the same hours. During the first six weeks sewage effluent was passed through at the rate of 500 gallons per square yard per day, whilst from the middle of July to the end of August the rate was reduced to one-half, or 250 gallons per square yard in 24 hours. The filtration was intermittently continuous, the filters passing effluent constantly for 8 hours daily and resting during the remaining 16 hours, being allowed to run dry at the end of each day's work. The outlet valve was closed just sufficiently to keep the filters full, the effluent being level with the surface of the filter material.

Filter No. 1. Burnt Ballast.—The material for this filter was obtained by burning clay taken from the marsh land adjoining, and was placed in the tank to a depth of 4 feet, the larger pieces being laid at the bottom, and the remaining unsifted portions being placed above.

The whole quantity of effluent passed through amounted to 185,000 gallons, in a total of 2,160 hours, of which the filter worked 484 hours and rested empty 1,676 hours. The average rate, therefore, inclusive of rest periods, was 411,000 gallons per acre in 24 hours. The filtrate was sampled and analysed frequently, a sample of the crude effluent being also examined for the purposes of comparison, great care being taken that the two sets of samples corresponded, *i. e.*, that the filtrate analysed represented the crude effluent.

Date, 1892.	Oxygen absorbed in 4 hours.		Albuminoid ammonia.	
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.
June 14th	3·311	1·897	—	—
,, 15th	2·154	1·615	—	—
,, 17th	1·909	1·431	—	—
,, 21st	2·255	1·244	·250	·170
,, 24th	2·205	·826	·230	·110
,, 29th	·890	·636	·150	·150
July 7th	1·533	·805	·220	·070
,, 8th	1·330	1·260	·200	·120
,, 11th	1·624	1·120	·250	·140
,, 13th	1·230	·590	·380	·210
,, 15th	1·610	·952	·330	·140
,, 18th	2·611	1·043	·270	·160
,, 20th	1·260	1·050	·170	·120
,, 22nd	2·415	1·372	·350	·110
Aug. 10th	2·198	·735	·230	·100
,, 15th	1·351	·637	·260	·050
,, 22nd	2·093	1·008	·210	·100
Average purification effected=43·1 per cent.				

The purification effected by this filter was less than that attained by any of the remainder. The clarification was also less than in the case of the pea ballast and proprietary filters, being exactly the same as effected by the coke-breeze. This was undoubtedly owing to the extreme looseness and porosity of the materials. The filtrate was free from putrefactive odour, remaining sweet for many months in either stoppered or open bottles. No work of any kind was done on the filter after the experiment started beyond filling up a few holes that formed during the first week's running.

Filter No. 2. Pea Ballast.—This filter, of precisely the same form and dimensions as the last, was filled with Lowestoft shingle, of pea size. The clarification effected in the filtrate was 75 per cent. more than in the case of the burnt ballast. The purification was also greater, the reduction of oxidisable organic matter amounting to 52·3 per cent. The following table shows the several analyses made:—

Date, 1892.	Oxygen absorbed in 4 hours.		Albuminoid ammonia.	
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.
June 14th	3·311	1·631	—	—
,, 15th	2·154	1·615	—	—
,, 17th	1·909	1·518	—	—
,, 21st	2·255	1·011	·250	·260
,, 24th	2·205	·826	·230	·090
,, 29th	·890	·509	·150	·130
July 7th	1·533	·805	·220	·090
,, 8th	1·330	·770	·200	·130
,, 11th	1·624	·812	·250	·250
,, 13th	1·230	·371	·380	·230
,, 15th	1·610	·875	·330	·140
,, 18th	2·611	·448	·270	·090
,, 20th	1·260	·770	·170	·120
,, 22nd	2·415	1·246	·350	·130
Aug. 10th	2·198	·488	·230	·150
,, 15th	1·351	·399	·260	·060
,, 22nd	2·093	·868	·210	·120
Average purification effected=52·3 per cent.				

In the case of this filter also no renovation or alteration was needed.

Filter No. 3. Coke-Breeze.—The filter was filled with coke-breeze to a depth of 4 feet, and 3 inches of gravel was placed on the top to prevent the coke from floating. As far as clarification is concerned, this filter ranked just even with the burnt ballast; but the purification effected was higher than in the case of any of the other materials, the reduction of the oxidisable organic matter in solution amounting to 62·2 per cent. No renewal of the material was required, the only work done being the filling up of a few subsidence holes. The results of the various analyses made are set forth in the following table:—

Date, 1892.	Oxygen absorbed in 4 hours.		Albuminoid ammonia.	
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.
June 14th	3·311	1·442	·430	·120
,, 15th	2·154	1·346	—	—
,, 17th	1·909	1·431	·270	·120
,, 21st	2·255	·233	·250	·070
,, 24th	2·205	·352	·230	·080
,, 29th	·890	·381	·150	·100
July 7th	1·533	·539	·220	·040
,, 8th	1·330	1·050	·200	·070
,, 11th	1·624	·609	·250	·110
,, 13th	1·230	·294	·380	·160
,, 15th	1·610	·511	·330	·100
,, 18th	2·611	·448	·270	·140
,, 20th	1·260	·560	·170	·140
,, 22nd	2·415	1·183	·350	·110
Aug. 10th	2·198	·658	·230	·140
,, 15th	1·351	·322	·260	·040
,, 22nd	2·093	·728	·210	·110

Average purification effected=62·2 per cent.

Filter No. 4. Sand.—This filter, having an area of 16 square yards, or $\frac{1}{300}$th of an acre, was filled with gravel, walnut size 5 inches, bean size $2\frac{1}{2}$ inches, pea size $1\frac{1}{2}$ inches, and sand 10 inches, taken in order from below upwards. It formed part of the compound proprietary filter. The rate at which effluent was passed through was one-half more per square yard than in the case of the other filters, the sand filtration being a preliminary to the treatment by the proprietary article, and the areas of the two portions being together equal to one of the remaining filters, already described.

The clarification effected was much greater than in the case of Nos. 1, 2 and 3, but the purification, measured by the reduction in the amount of oxidisable matter in solution, was considerably less than in the case of the coke-breeze, somewhat less than by the pea ballast, and only very slightly better than by burnt clay. On two occasions the filtrate became slightly putrid, the results thereby differing from those obtained from any other filtering material employed. Doubtless this tendency to become putrid was to a great extent due to the deficient aëration of the interior of the filter, in consequence of the capillary attraction of the finer particles of sand holding the water, and thus choking the pores when the filter was emptied. This filter had to be repeatedly raked and cleared, whilst 2½ inches of sand were removed and replaced by new on the 11th of July.

The following are the results of the analyses made:—

Date, 1892.	Oxygen absorbed in 4 hours.		Albuminoid ammonia.	
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.
June 21st	2·255	1·555	·250	·200
,, 24th	2·205	·735	·230	·050
,, 29th	·890	·750	·150	·100
July 7th..............	1·533	1·267	·220	·080
,, 8th..............	1·330	1·050	·200	—
,, 11th	1·624	1·218	·250	·190
,, 13th	1·230	1·106	·380	·240
,, 15th	1·161	·875	·330	·110
,, 18th	2·611	·378	·270	·150
,, 20th	1·260	·700	·170	·080
,, 22nd	2·415	1·442	·350	·150
Aug. 10th	2·198	·980	·230	·110
,, 15th	1·351	·798	·260	·140
,, 22nd	2·093	1·155	·210	·120
Average purification effected=46·6 per cent.				

No. 5. Proprietary filter.—This filter contained an area of 8 square yards, and was filled with 3 inches of gravel walnut size, 2 inches gravel bean size, 1½ inches gravel pea size, 1 inch sand, and 12 inches of the proprietary material; taken in order from below upwards.

The effluent which it received had already passed through filter No. 4 (sand), and had thus been greatly clarified, whilst the dissolved impurity had been removed to the extent of 46·6 per cent. The rate of filtration was three times that of the other filters, so as to bring up the rate of the combined filter to an equality with the rest. The filter was supplied with perforated pipes, leading to the surface, for aëration. In general appearance the filtrate from this compound filter was slightly superior to all the others, the clarification effected being a little more than in the case of the sand forming the first portion. The purification effected by this process of double filtration amounted to 61·6 per cent., a figure practically the same as was obtained by the use of coke-breeze. None of the filtrates showed any signs of putrescence when kept for lengthened periods in either open or closed bottles.

This compound filter was erected by the proprietors of the special filtering material, and worked in accordance with their wishes. It will be observed that sand and gravel played a very large part in the process. The following are the results of the analyses made :—

Date, 1892.	Oxygen absorbed in 4 hours.		Albuminoid ammonia.	
	Crude effluent.	Filtrate.	Crude effluent.	Filtrate.
June 14th	3·311	·679	·430	·170
,, 15th	2·154	·808	·270	·220
,, 17th	1·909	·955	·270	·160
,, 21st	2·255	·700	·250	·150
,, 24th	2 205	1·841	·230	·090
,, 29th	·890	·953	·150	·090
July 7th..............	1·533	·539	·220	·110
,, 8th..............	1·330	·910	—	—
,, 11th	1·624	·609	·250	·090
,, 13th	1·230	·231	·380	·090
,, 15th	1·610	·371	·330	·100
,, 18th	2·611	·749	·270	·110
,, 20th	1·260	·350	·170	·070
,, 22nd	2·415	1·246	·350	·050
Aug. 10th	2·198	·406	·230	·040
,, 15th	1·351	·322	·260	·100
,, 22nd	2 093	·581	·210	·060
Average purification effected=61·6 per cent.				

SUMMARY OF EXPERIMENTS WITH SMALL FILTERS AND VARIOUS FILTERING MATERIALS.

The average rate of working, including rest periods, was 411,000 gallons per acre in 24 hours. The mechanical cleansing, or clarification, is shown as follows, the figures representing units of depth required to obscure a standard mark :—

Burnt ballast	1
Coke-breeze	1
Pea ballast	$1\frac{3}{4}$
Sand (1st portion of compound filter)	$2\frac{1}{4}$
Proprietary article (2nd portion of compound filter after sand) ..	$2\frac{1}{2}$

The following table shows the extent of the purification effected, as indicated by the reduction in oxidisable organic matter in solution :—

Burnt ballast	43·3 per cent.
Sand (1st portion of compound filter)	46·6 ,,
Pea ballast	52·3 ,,
Proprietary article and sand combined	61·6 ,,
Coke-breeze	62·2 ,,

From the results obtained it appeared that a considerable amount of purification could be effected by any filtering material, the desiderata evidently being porosity and consequent power of re-absorbing atmospheric oxygen. For foul waters sand proved too fine; whilst the burnt ballast used was too coarse. Coke-breeze seemed to unite the necessary qualifications, and as it is also a cheap material it was selected for the further trials on a large scale. There can be little doubt, however, that the question of cost of material should be allowed to decide what should be used for a filter in any given place, since burnt ballast or gravel may be made much more efficient by using a greater depth of more finely granulated material combined with a slower rate. The proprietary filter excelled the coke-breeze only in appearance, the actual purification not being quite so much, while the cost is prohibitory.

In the course of the above experiments, numerous gelatin plate cultivations were made, to ascertain the effect of filtration upon the number of micro-organisms present. The number in the tank effluent before filtration and in the filtrates was found to vary very considerably, those in the filtrate generally being present in larger numbers; but it soon became apparent that the presence of comparatively few or more microbes afforded no indication of the degree of purification effected, the main point being that the presence of a large number of organisms was evidence of the activity of the process of splitting up the organic compounds in the sewage matters passing through the filters. A considerable reduction of organisms might have been effected by the use of a finer grained material and slower filtration, but the object held in view during the experiments was the attainment of the highest degree of speed consistent with such purification as would remove all objectionable characters, such as odour, colour, and liability to putrefaction.

Series No. 2.

In the second series of experiments a filter was constructed covering exactly one acre of land. The ground was levelled and embanked where necessary and perforated drains laid, meeting in a common trunk for discharge. The filtering material consisted of 3 feet of coke-breeze, covered with 3 inches of gravel.

(*a*) In the first part of the series under notice the special object of the experiments was rather the ascertaining of the rate at which it was possible to pass effluent through the filter, and not the manner of producing the best results. The filter, however, speedily became clogged with sludge, and after the sixth week all the filtrates were putrid. The daily quantity that could be passed fell rapidly until at the end of twelve weeks the filter was quite useless, being putrid throughout. Valuable information was thus gained, for it was shown that rest and aëration were vital, and also that in order to obtain the best work from a filter, the quantity poured on it must increase very gradually, so as to permit of the proper biological condition being reached. The rate of working varied from close on one million to a quarter of a million gallons per diem. The filling was during several weeks continued until the water stood 6 inches above the surface; when the filter was emptied this portion ran through without having time for purification, and this fact doubtless aided largely in reducing the efficiency of the filter during this set of experiments.

During this period the following analytical results were obtained:—

Date, 1893.	Oxygen absorbed in 4 hours.		Albuminoid ammonia.		Nitrogen as nitrates.		Purification effected on oxygen absorbed. Per cent.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	
28th Sept. to 6th Oct. ..	3·631	2·128	—	—	·000	·083	41
9th Oct. to 13th Oct. ..	2·884	·509	—	—	·029	·215	82
16th ,, to 20th ,, ..	3·295	·502	—	—	·029	·117	85
23rd ,, to 30th ,, ..	3·915	1·447	—	—	·103	·021	63
30th ,, to 6th Nov...	4·420	1·546	—	—	·000	·000	65
6th Nov. to 13th ,, ..	4·404	1·285	·394	·110	·283	·203	71
13th ,, to 20th ,, ..	4·122	1·125	·368	·097	·299	·317	73
20th ,, to 27th ,, ..	4·336	1·203	·403	·091	·304	·241	72
27th ,, to 4th Dec..	4·832	1·135	·457	·119	·180	·175	77
4th Dec. to 8th ,, ..	4·745	1·070	·435	·109	·077	·080	77
11th ,, to 18th ,, ..	3·821	·979	·401	·092	·021	·130	76
19th ,, to 23rd ,, ..	4·877	1·387	·393	·191	·000	·000	71·6

(*b*) The first series of experiments on biological lines conducted with the same filter as the preceding was then commenced. The surface was raked, and the bed was allowed to rest during three and a half months. For fully three months of that time a putrid odour was observable when the filter was disturbed, but this gradually disappeared, and during the last fortnight the coke-breeze was perfectly sweet. From that time the filter was kept practically constantly at work for nearly a year, the only rest of any length being from the 17th of November, 1894, to the 2nd of January, 1895, when alterations in the arrangements were made to admit of more rapid emptying.

The process adopted was to begin with small quantities, the filter being merely filled and emptied twice daily, with a view to getting it into the necessary biological condition. This was commenced on 2nd of April, 1894, and continued for a few weeks, the purification effected gradually rising. The quantity of effluent passed was about 500,000 gallons per diem, and the purification between 70 and 80 per cent. The highest state of efficiency was reached on the 3rd of May, or after a full month's working. The purification reached 83 per cent., and fish placed in the filtrate were kept alive for many weeks. In fact, fish (minnows and sticklebacks) came up the ditch by which the filter was emptied to the very mouth of the outlet.

The following are the weekly averages of the analytical results :—

1894. Week ending.	Oxygen absorbed from permanganate in 4 hours.		Albuminoid ammonia.		Nitrogen as nitrates.		Purification on oxygen absorbed.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	Per cent.
April 7th..	4·634	1·428	·440	·159	·455	·721	69·1
,, 14th..	4·627	1·027	·521	·128	·095	·212	77·8
,, 21st..	4·283	·954	·485	·105	·095	·104	77·8
,, 28th..	3·977	·800	·507	·107	·471	·745	79·9
May 5th ..	4·300	·722	·502	·096	·0636	·106	83·2
,, 12th ..	4·105	·844	·394	·090	·0308	·1145	79·4
,, 19th ..	3·879	·814	·308	·055	·0000	·0413	79·0
,, 26th ..	3·877	·657	·303	·059	·0000	·1310	83·1
June 2nd..	4·033	·703	·401	·086	·0000	·1041	82·6
,, 9th ..	3·247	·611	·303	·069	·0700	·0994	81·2

(*c*) Alterations were then made in the arrangements for filling, the feeding trough being doubled. The daily quantity was increased to over 600,000 gallons, the analytical results continuing to be highly satisfactory, as shown by the following weekly averages :—

1894. Week ending.	Oxygen absorbed from permanganate in 4 hours.		Albuminoid ammonia.		Nitrogen as nitrates.		Purification on oxygen absorbed.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	Per cent.
Aug. 3rd..	3·195	·685	·365	·094	·0350	·2245	78·6
,, 10th..	3·217	·661	·329	·081	Not est	imated	79·5
,, 17th..	3·345	·661	·332	·079	,,	,,	80·2
,, 24th..	3·132	·661	·271	·057	,,	,,	78·9
,, 31st..	3·504	·819	·296	·077	,,	,,	76·6
Sept. 7th..	4·495	·785	·390	·082	·0350	·0876	82·5
,, 14th..	3·530	·712	·356	·087	·0000	·1341	79·8
,, 21st..	4·080	·767	·419	·136	·0700	·0632	81·2
,, 28th..	3·540	·745	·521	·103	·0000	·1344	79·0
Oct. 5th ..	4·006	·808	·553	·244	·0000	·1690	80·0
,, 12th ..	3·648	·828	·519	·243	·0350	·0989	77·3
,, 19th ..	4·242	·781	·439	·117	·0000	·0675	81·6
,, 26th ..	3·964	·740	·460	·132	·0000	·0678	81·3
Nov. 2nd..	2·497	·540	·292	·080	·0708	·3063	78·4
,, 9th ..	3·726	·762	·406	·089	·0000	·2020	79·5

(*d*) Towards the end of 1894, the emptying arrangements were supplemented by a pump, and later the resting time was shortened, until finally the filter passed $1\frac{1}{6}$ million gallons daily for six days, resting empty from 10 p.m. on Saturdays until 6 a.m. on Mondays. The method adopted was to fill the filter to just level with the surface as quickly as possible; allow it to remain standing full for one hour, and then draw off with the least possible delay. Working in this way, the filter passed an average of one million gallons a day, including all times of rest, during a period of eight weeks, the filtrates being clean and sweet, and the purification effected 78 per cent. Nitrification proceeded satisfactorily, and the filter was apparently capable of continuing for an indefinite time.

A point of the greatest importance is the fact that the filter was able to do its work satisfactorily during the exceptionally severe weather in January and February, 1895. A thin coat of ice was formed on the surface, but the filtration proceeded without intermission, the only noticeable change being the decreased production of nitric acid.

The following are the weekly averages of analytical results:—

Week ending.	Oxygen absorbed from permanganate in 4 hours.		Albuminoid ammonia.		Nitrogen as nitrates.		Purification on oxygen absorbed.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	Per cent.
1894.							
Nov. 16th..	2·412	·491	·259	·079	·5648	·8618	79·6
1895.							
Jan. 4th ..	5·240	1·190	·447	·150	·6371	1·6386	77·3
,, 12th ..	4·045	1·103	·434	·162	·3765	·8973	73 0
,, 19th ..	4·202	·817	·441	·112	·3830	·9805	81·0
,, 26th ..	3·762	·742	·352	·085	·7826	1·1130	80·3
Feb. 2nd ..	3·695	·801	·362	·098	·3681	·6196	78·3
,, 9th ..	4·016	·971	Not est	imated.	·3830	·4549	75·8
,, 16th ..	4·281	·891	,	,	·2547	·3438	79·2
,, 23rd ..	4·967	1·047	,	,	·1122	·0804	78·9
Mar. 2nd..	4·524	1·293	,	,	·0937	·0000	71·4

(*e*) After the filter had been successfully dealing with one million gallons daily for about eight weeks, a large quantity of sludge, amounting to at least ten tons, was run upon it accidentally. This occurred during the week ending 23rd February. The result was an immediate falling off in the quality of the filtrate; a putrescent odour was observed; and finally the filter had to be thrown out of work. Remarkable evidence of the recuperative power of the coke-breeze was, however, obtained, as after 20 days' rest it was quite sweet again, nothing objectionable being observed on digging down to a depth of about two feet. The coke had only the odour of ordinary earth when moist, and on being burnt gave no objectionable smell.

On resuming work, 28 days after resting, the following satisfactory results were obtained :—

Date. 1895.	Oxygen absorbed from permanganate in 4 hours.		Albuminoid ammonia.		Nitrogen as nitrates.		Purification on oxygen absorbed.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	Per cent.
April 8th..	3·048	·810	·370	·096	·0000	1·0166	73·5
,, 9th..	4·095	·810	·418	·124	·0000	·6350	80·2
,, 10th..	2·571	·905	·358	·104	·0000	·6584	64·8
,, 16th..	3·238	·705	·401	·123	·0000	·7559	78·3
,, 17th..	3·429	·762	·261	·080	·4941	·9438	77·8
,, 18th..	4·476	·952	·343	·104	·3335	·8161	78·8
,, 19th..	4·381	1·048	·385	·080	·0000	·7008	76·1
,, 20th..	2·857	·762	·348	·104	·3171	·6336	73·4

From this time until the end of September in the same year the filter was kept continuously at work (except during one week in August) on the same system, viz., alternate filling, resting full, and emptying, with 24 hours' entire rest each week. The results are shown in the following table; the figures given are weekly averages of daily analyses, the samples on which the latter were made being themselves averages of quarter-hour samples from each filling and emptying.

Date. 1895. Week ending.	Quantity of effluent passed daily per acre. Average of 7 days.	Oxygen absorbed in 4 hours. Average of 7 days.		Purification, per cent.	Remarks.
		Effluent.	Filtrate.		
May 4th	1,049,776	3·592	·753	79·0	
,, 11th	1,050,878	3·576	·861	75·9	
,, 18th	1,128,138	3·867	·865	77·6	
,, 25th	1,076,939	3·657	·862	76·4	
June 1st	932,171	4·009	1·013	74·7	
,, 8th......	725,718	3·399	·841	75·3	
,, 15th......	980,408	3·247	·872	73·1	
,, 22nd	925,621	3·496	·698	80·0	
,, 29th......	779,282	3·441	·566	83·6	
July 6th	959,512	3·576	·614	82·8	
,, 13th	1,049,042	3·282	·572	82·6	
,, 20th	956,825	3·219	·531	83·5	
,, 27th	964,416	2·852	·490	82·8	
Aug. 3rd......	839,472	3·359	·538	83·8	
,, 10th......	—	—	—	—	Filter not used.
,, 17th......	966,881	2·810	·450	87·6	
,, 24th......	959,341	2·928	·485	83·5	
,, 31st	966,042	2·670	·467	82·5	
Sept. 7th.. ...	971,502	2·683	·503	81·3	
,, 14th......	1,013,071	2·573	·470	81·8	
,, 21st	1,014,667	2·746	·461	83·2	
,, 28th......	1,013,071	2·889	·491	83·0	

The experiments taken as a whole show that sewage, especially if previously clarified by precipitation, may be purified to any desired degree, the actual amount of purification depending upon (1) the length of time during which the effluent is allowed to remain in contact with the filter, and (2) the length of time allowed for aëration. If a reduction of 75 per cent. in the oxidisable organic matters in solution be considered as sufficient, the quantity that can be treated per diem on one acre of coke breeze is one million gallons, which gives a required area for the treatment of the whole of the Metropolitan sewage—taken at 180 million gallons—of 180 acres only. This rate is probably the highest that can be worked under all conditions of seasons.

If, however, only the effluents from the strong day sewage were submitted to filtration, as those from the weak night sewage obtained by precipitation after chemical treatment are sufficiently satisfactory, the area required would be proportionately reduced, viz., to about 120 acres.

Experiments with Sewage collected on the "Separate" System, excluding Rainfall.

By the courtesy of the Sutton (Surrey) Urban District Council I am enabled to append the following statement of results obtained by similar treatment of the sewage as carried out at the sewage works of that Council. The trials in question were made during the period of office of the late Sutton Local Board, of which authority I was at that time a member, and therefore am able to speak of the results from personal experience. The works were under the direction of Mr. A. D. Greatorex, Assoc. M.I.C.E., surveyor to the Board.

The filters employed are seven in number, as follows:—

2 proprietary, 35 feet by 20 feet	........area	700	sq. ft. each.
2 coke breeze ,, ,,	.... ,,	700	,,
2 sand ,, ,,	.... ,,	700	,,
		4,200	,,
1 burnt ballast {142 / 120} feet by 34 feet	.... ,,	4,454	,,
	Total area......	8,654	,,

The filters are constructed as follows:—

Proprietary.

Top, 6½ inches, medium sand.
3 ,, pea gravel.
10½ ,, proprietary article mixed with sand.
5 ,, extra coarse sand.
4 ,, pea gravel.
Bottom, 5 inches, coarse shingle round the pipes.

Coke breeze.

Top, 8 inches, medium sand.
12 ,, coke breeze.
5 ,, extra coarse sand.
4 ,, pea gravel.
Bottom, 5 inches coarse shingle.

Sand.

Top, 8 inches, medium sand.
12 ,, ,,
5 ,, extra coarse sand.
4 ,, pea gravel.
Bottom, 5 inches coarse shingle.

Burnt ballast.

Top, 4 inches, soil.
6 ,, fine ashes.
Bottom, 18 inches, burnt ballast.

120,000 gallons of effluent water are passed through the filters per day, working nine hours. The six small filters are worked one day and the large the next day, thus allowing alternate days of rest; the six filters have been at work nearly two years and the large one three months, with the exception of the bad days in the winter.

The percentage purification of the oxidisable organic matters effected is shown in the following table, which is prepared from analyses made by Dr. Jacob, medical officer of health for the Sutton district:—

Date. 1894.	Proprietary Filter.	Coke Breeze Filter.	Sand Filter.
May 2nd	36·4	47·6	31·0
July 13th	51·5	41·0	32·2
,,	—	50·0	—
,,	—	53·0	—
October 16th	61·0	51·0	30·0
,,	54·0	48·0	24·0
November 24th	53·3	14·9	50·0
,,	44·2	26·5	51·6
Average	50·1	41·5	36·5

On the 24th April, 1895, Mr. Greatorex kindly collected for me a series of samples of crude sewage, precipitation effluent and filtrates, the samples being averages of ten hours' working.

These were analysed in the Council's laboratory, and yielded the following results:—

24th April, 1894.	Sewage, including suspended matters.	Sewage, excluding suspended matters.	Effluent before Filtration.	Burnt Ballast Filter.	Sand Filter.		Proprietary Filter.		Coke Breeze Filter.	
					No. 1.	No. 2.	No. 1.	No. 2.	No. 1.	No. 2.
Oxygen absorbed ..	8·98	4·29	2·92	2·54	1·13	1·08	1·22	0·85	0·85	0·66
Purification per cent. on unfiltered effluent	—	—	·0	13 0	61·3	63·0	58·3	70·9	70·9	77·4
					62·1		64·6		74·1	

From the first table of the results obtained at Sutton, it would appear that the proprietary filter gave the best results; but this was caused by the lower rate at which this filter worked, as in many instances, in consequence of the finer grain of material and frequent choking, the quantity passing through the bed was far less than that passed by the remaining filters. In the case of the experiments conducted at Barking Creek the rates of flow were maintained at equal speed. In the second table of Sutton results, however, the coke breeze filter excelled all the others, the proprietary and sand filters being very close together.

From the above results it would appear that the burnt ballast filter has been overworked and requires a short period of rest, as a former result was exceedingly satisfactory.

In his report of the 18th July, 1894, Dr. Jacob stated that the effluents from the various filters were quite fit to be discharged into the brook without further treatment.

Conclusions.

The action of a filter is twofold:—(1) It separates mechanically all gross particles of suspended matter and renders the effluent clear and bright. (2) It effects the oxidation of organic matters, both those in suspension and those in solution, through the agency of living organisms. It is the preliminary establishment and subsequent cultivation of these organisms which is to be aimed at in the scientific process of purification by filtration.

The ordinary putrefactive and other similar organisms commence the work by breaking down the organic compounds and converting them to less complex forms, principally water, carbonic acid and ammonia; the nitrifying organism then acts upon the ammonia, the nitrogen being converted into nitric acid. For this process to go on, three conditions are essential. Firstly, the organisms must be supplied with plenty of air; secondly, there must be present a base, such as lime, with which the nitric acid can combine; and thirdly, the biological action must take place in the dark, *i.e.*, in the body of the filter and not in the water exposed to the light above the filtering material. Filtration on biological lines of sewage or other foul water containing in solution but little free oxygen and a large quantity of oxidisable organic matter therefore means:—

(1) That the filter, by cautious increments in the quantity of effluent, which in itself contains the necessary organisms, must be gradually brought to a state of high efficiency. This condition will be shown by the existence in the filtrate of a constantly increasing proportion of nitric acid.

(2) That the contact of the micro-organisms with the effluent to be purified must be effected by leaving such effluent at rest in the filter for a greater or less time according to the degree of purification required, the process being analogous to that of fermentation. The system employed in many places is to run the water straight through the filter and thus allow insufficient time for the work, with the result that the filtrate is soon in an unsatisfactory condition.

(3) That after each quantity of effluent has been dealt with the micro-organisms must be supplied with air, which is readily effected by emptying the filter from below, whereby air is drawn into the interstices. The filter must stand empty for an hour or more previous to another filling and a longer period of aëration, say 24 hours, must be allowed every seven or eight days.

The life of a coke breeze filter worked in this manner is practically without a limit.

From the general results obtained by these several trials under various actual working conditions, it is apparent that there is no difficulty in obtaining any desired degree of purification by means of a system of filtration conducted on biological principles. If a higher degree of purity be required than that indicated by the foregoing it can be obtained by an augmentation of the filtering appliances at a comparatively small cost, as, where clay is obtainable, the method of construction employed in making the new burnt ballast filter bed at Sutton may be adopted, viz., by simply digging out the clay so as to form a pit about 3 feet deep, and filling it up with the same clay after burning, and thus a cheap and efficient filter bed is obtained, the cost of the large filter bed at Sutton, having an area of 4,454 square feet, or rather more than one-tenth of an acre, being less than £100, including all charges.

By such a system the necessity for costly farms is entirely obviated. The results are completely under control, and the filters can be arranged to suit all requirements it is possible to contemplate.

W. J. DIBDIN,
Chemist.

40, Craven Street, W.C.,
October, 1895.

APPENDIX IV.

FILTRATION OF SEWAGE EFFLUENT.

REPORT by the Chemist to the London County Council as to the amount of Work performed by the One-acre Coke Breeze Filter-bed at the Barking Outfall Works from the commencement of operations to the 1st of November, 1896.

The one-acre coke breeze filter-bed at the Barking Outfall Works having now passed a total of 500 million gallons of crude sewage effluent, a review of the whole work accomplished by it is of the greatest importance, because of the evidence which it offers as to the powers of such a filter to dispose of organic matter during a prolonged period without suffering deterioration in any way, and also as bearing on the experiments about to be instituted on the filtration of crude sewage, without previous chemical precipitation.

Since the effluent which is passed on to the filter contains on an average seven grains of suspended matter per gallon, a quantity equal to 2,232 tons of sludge of 90 per cent. moisture has been entirely removed, the filtrate containing practically no suspended matter. Of the matter thus removed about 110 tons were organic, the whole of which has been oxidised; whilst the sand amounted to about 40 tons which, calculated at 24 cwt. per cubic yard, would cover the filter to a depth of 0·267 inch if spread equally over its surface. Such sand has, however, been carried into the body of the coke, and any danger of choking arising from this cause is thereby removed.

The organic matters in solution in the crude effluent absorb on on an average 3·5 grains per gallon of oxygen from permanganate in four hours, while the filtrate absorbs only one-fifth of this, or 0·7 grains. The amount of oxidation effected, measured in this way, would require 90 tons of oxygen, or, in other words, is equal to the effect which could be obtained by the use of nearly 2,000 tons of commercial manganate of soda.

The organic matter that has been completely removed, as determined by the difference between the loss on ignition of the solids in the crude effluent and the filtrate respectively, amounts to 250 tons.

The organic matter that remains in the filtrate is in such a condition that no signs of after-putrefaction are exhibited, however long the filtrate may be kept, either undiluted or diluted, in open or closed bottles.

The filter is in perfect condition, exhibiting no signs of deterioration; the organic matter in it does not increase; and it remains quite sweet to the smell. No addition has been made to the material, and the only attention given has been an occasional levelling of the surface with a rake. I see no reason to alter the opinion expressed in my report to the Main Drainage Committee on the 26th of September, 1895, viz., that if properly worked the life of such a filter would be practically without limit.

W. J. DIBDIN,
Chemist.

40, Craven Street, W.C.,
12*th November*, 1896.

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