BACTERIAL PURIFICATION OF SEWAGE

S. BARWISE

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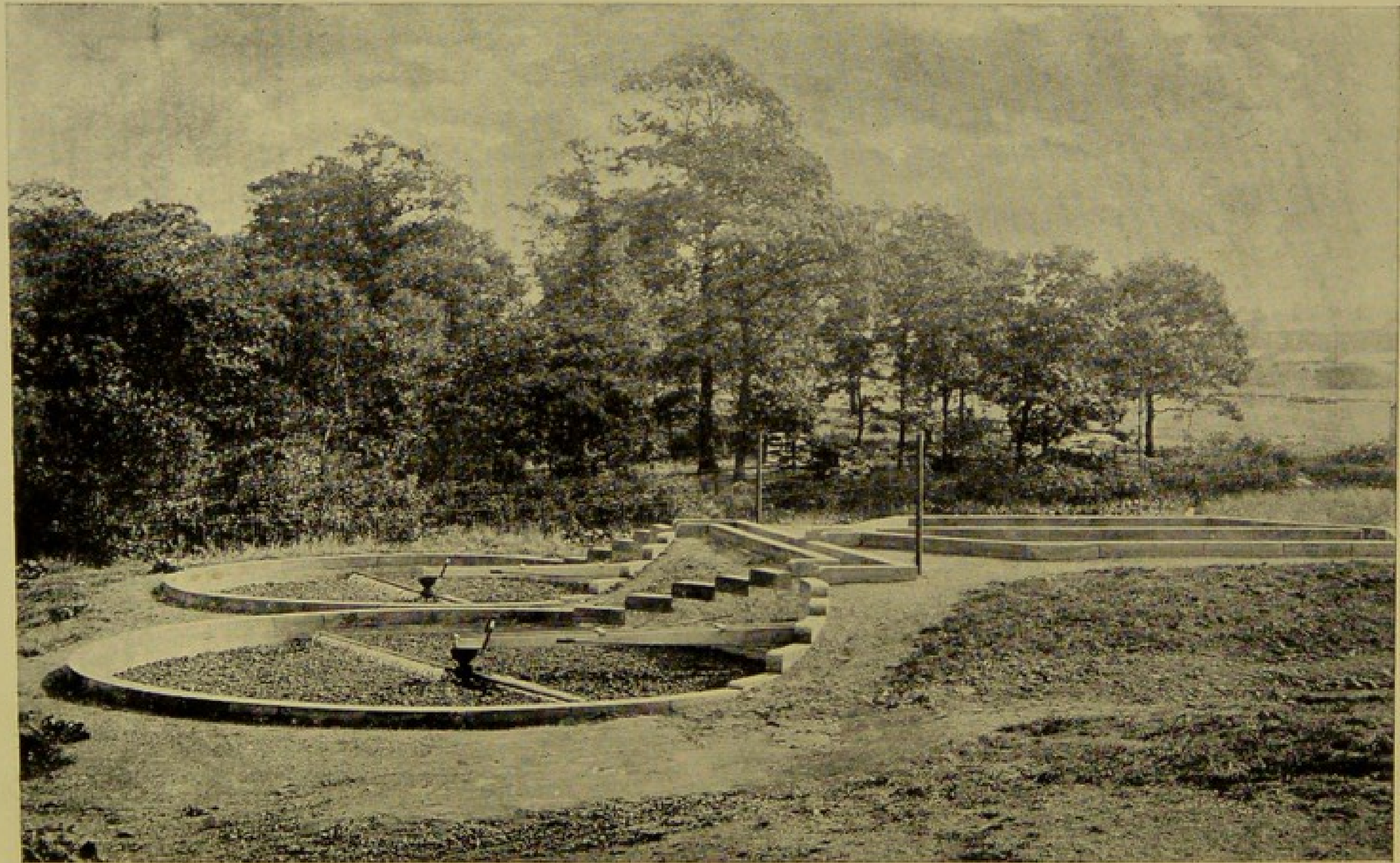

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ENGINEER—EDGAR LINES, C.E., CHESTERFIELD.

THE

BACTERIAL PURIFICATION OF SEWAGE

BEING

A PRACTICAL ACCOUNT OF THE VARIOUS MODERN BIOLOGICAL METHODS OF PURIFYING SEWAGE

BY

SIDNEY BARWISE

M.D. (Lond.), D.P.H. (Camb.), etc.

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COUNTY MEDICAL OFFICER OF DERBYSHIRE

LONDON

CROSBY LOCKWOOD AND SON

7, STATIONERS' HALL COURT, LUDGATE HILL

1901

PREFACE.

The present volume, devoted to the subject of the Bacterial Purification of Sewage, is intended as a supplement to my book on the "Purification of Sewage," published by Messrs. Crosby Lockwood and Son two years ago.

As a result of the Report of the Royal Commission on Sewage Disposal, there is no doubt that many Authorities will now proceed to deal with the problem of purifying their Sewage, and this small work is meant as a guide to them as to what process they should adopt. The subject matter of the book is practically the substance of a Report prepared by me for the use of the various District Councils of Derbyshire, and I have to thank the Public Health Committee of the County Council for their permission to retain the copyright and to publish the matter in book form.

It is impossible for any such work to deal with this question effectually unless it is prepared by an Engineer as well as a Chemist and Bacteriologist. In preparing this little book I have had the advantage of consulting with Mr. J. Somes Story, M.Inst.C.E., and Mr. George Story, C.E., who are responsible for the engineering details. The present work is the only one I am aware of in which there has been such collaboration, and I believe the plans which it contains will prove of great value to small Local Authorities.

The book is a small one. This is because I have been at pains to remove all padding. One of the evils of books of the present day is that they are infinitely too wordy; a fault, at least, of which this little work is not guilty.

Nor can it be said that this is in any sense a tradesman's catalogue. The only patents described are those of proved value. Because various processes have not been mentioned, it must not be supposed that they have not been investigated. No reference will be found to several patented processes and tanks. The reason for this is that I have had to investigate these processes on behalf of the Derbyshire County Council, and have officially reported that equally good results can be obtained by the ordinary methods at considerably less cost.

To the scientific reader, I must apologize for the dogmatic tone adopted, this is only the outcome of condensation of matter.

SIDNEY BARWISE.

County Offices, Derby,
August, 1901.

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SECTION I.

INTRODUCTORY.

IN 1898, a Royal Commission was appointed to enquire and report on the methods of purifying Sewage, and in July this year the Commissioners issued an important Interim Report. The Commissioners give as the reason for the appointment of the Commission and the re-consideration of the position of the Authorities on this question, that "It is now contended that in many cases the land available is either of unsuitable quality, is available in quite inadequate area for effective filtration through the soil, or is obtainable only at a prohibitive cost, and it is suggested that sewage purification may, in such cases, be carried out on comparatively small areas artificially prepared."

On this point I gave evidence before the Commission with reference to the stiff clay land, which was the only land available for the purification of sewage in many parts of Derbyshire, such as Chesterfield, Alfreton, Clay Cross, Heanor, Ilkeston, and at the County Asylum.

In 1899, I wrote *"The most unsuitable soil, and, unfortunately, one of our commonest, is clay land. It is said that lands can be rendered more fit for filtration by ploughing and digging-in ashes, which convert the impervious surface and allow the sewage to sink through. There are in Derbyshire two farms upon which considerable sums of money have been spent in thus preparing the land, in one instance as

* "Purification of Sewage," by S. Barwise: Crosby, Lockwood & Son.

much as £1,123 being spent in lightening the soil to a depth of two feet with engine ashes. It is perfectly true that this enables the sewage to pass through the clay, but it does not lead to the purification of the sewage, and where the land is a stiff clay it undoubtedly would be better to construct sewage filters."

"Clay lands, besides being too impermeable to permit the sewage to pass through them, are unfortunately open to another objection, viz., that in dry weather they crack and fissure, so that the sewage passes directly through the cracks to the land-drains without undergoing any purification. Worms also leave permanent holes in clay, which last for a considerable length of time, and permit the sewage to pass down. At a small farm at Brampton in Derbyshire, the sewage contains a considerable amount of dye-water, and upon a trial-hole being sunk on the said farm, which is a stiff clay, the author found innumerable worm-holes passing directly downwards to the effluent drains, the worm-holes having their sides saturated with dye, and showing how the sewage passed away absolutely unpurified."

Upon this point the Commission now reports:—

"Conclusion 1.

"We are forced to conclude that peat and stiff clay lands are generally unsuitable for the purification of Sewage, that their use for this purpose is always attended with difficulty, and that where the depth of top soil is very small, say six inches or less, the area of such lands which would be required for efficient purification would, in certain cases, be so great, as to render land treatment impracticable."

The next question which the Commission addressed itself to, was "whether it is practicable to produce by artificial processes alone, an effluent which shall not putrefy, and so create a nuisance in the stream into which it is discharged." Upon this important question, the Commissioners come to a positive decision which had best be given in their own words.

"Conclusion 2.

"After carefully considering the whole of the evidence, together with the results of our own work, we are satisfied that it is practicable to produce by artificial processes alone, either from Sewage, or from certain mixtures of sewage and trade refuse, such, for example, as are met with at Leeds and Manchester, effluents which will not putrefy, which would be classed as good according to ordinary chemical standards, and which might be discharged into a stream without fear of creating a nuisance."

"We think, therefore, that there are cases in which the Local Government Board would be justified in modifying, under proper safeguards, the present rule as regards the application of sewage to land."

The following is the classification which the Commissioners give of the artificial processes referred to:—

A. CONTACT BEDS.

1. Closed septic tank and contact beds.
2. Open septic tank and contact beds.
3. Chemical treatment, subsidence tanks, and contact beds.
4. Subsidence tanks and contact beds.
5. Contact beds alone.

B. ARTIFICIAL FILTERS.

1. Closed septic tank followed by continuous filtration.
2. Open septic tank followed by continuous filtration.
3. Chemical treatment, subsidence tanks, and continuous filtration.
4. Subsidence tanks followed by continuous filtration.
5. Continuous filtration alone.

As various County Councils have delayed pressing authorities in whose districts land is not suitable for the purification of sewage until the Commission had come to some decision on this point, and there is no longer any reason for further delay, it becomes advisable to explain the conditions which are favourable for the adoption of one or other of the ten processes scheduled by the Commission, and in order that the Report shall be of practical value, Mr. Story, M. Inst. C.E., has been good enough to prepare, in consultation with me, sketch plans on a sufficiently large scale to permit of their being adopted, with slight modifications to suit local circumstances, by the various District Councils.

Where, however, there is a sufficient area of sandy soil, such as is met with on the Bunter Sandstone, none of these artificial processes will be necessary. In this connection, I may repeat the following passage, with a few verbal alterations, my previously expressed opinion :—

*" The simplest method of purifying Sewage, and undoubtedly the cheapest and best where local circumstances permit of its being carried out, is by means of irrigation, by which I mean land treatment alone, including a certain amount of intermittent land filtration. Unfortunately, however, it is not everywhere that a suitable soil is to be found, and if it can be found, the price may be prohibitive."

" The conditions under which irrigation alone should be adopted, are where there is an open sandy loam or loamy gravel, which can be obtained at a price not much exceeding £150 per acre."

The geological maps will show that as far as Derbyshire is concerned, the only districts where these conditions are likely to be complied with, are at Swadlincote, and in some of the villages on the Bunter Sandstone, south of the Trent, and in the tract of Sandstone which reaches from Quarndon to Ashbourne.

The surface of the coal measures, and of the new red marl is of an extremely stiff clay, which may be useful enough for brick-making and other industrial purposes, but the area of which, necessary for sewage purification, would have to be " so great as to render land treatment impracticable." The same remark applies to a great deal of the surface of Mill-stone Grit. The shale with which the Gritstone is interstratified is quite impervious, as is evidenced by its bringing the springs in the Millstone Grit to the surface. Then, with regard to the large area of the county which is composed of the Mountain Limestone, the soil here is far too shallow to effect purification, frequently not being six inches in depth, while below the soil, we come to a rock which is riddled with fissures, many of which lead to underground caverns, in which the sewage would stagnate and putrefy, or to open channels connected with the

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* Op cit, page 53.

nearest river bed. Practically the whole of the sewage of the county will, therefore, have to be purified by one or other of the artificial processes referred to by the Royal Commission.

In order to appreciate the means by which these artificial processes effect the purification of sewage, it is necessary to have a good general idea as to the nature and composition of sewage, and the changes it is desired to effect.

At the present time, it is too frequently the practice of small Sanitary Authorities merely to go to a patentee and adopt some system which has attached to it the name of a place or person, on the strength of the statements of those financially interested in the particular process. The result of this is, that in many cases, the rateyayers have to pay for patent rights which are more or less worthless, and which, if the principles of the question had only been mastered, could have been easily avoided. Unless the principles involved are understood, not only will money be unnecessarily expended, but the works when constructed will fail to produce satisfactory effluents.

Preliminary Remarks and Definitions.

Sewage is a complex liquid, consisting of the liquid excretions of the inhabitants; the foul waters from the kitchens containing vegetable and animal matters, bits of fat, and other refuse; the "suds" from the washing of dirty linen, cooking utensils, and the people themselves, holding in solution and suspension, soap, fatty acids, and the exudations from the human skin. Such soapy slops, as everyone is aware, become most foul and offensive. Then there is the dirty water from the washing of floors, the swilling of yards, the solid and liquid excretions of animals in the streets, the drainage from stables and pigsties, the blood and other animal matters from slaughter-houses, silt from street-sweepings, and sometimes, if the town is an old one, the most offensive and concentrated filth of all,—the soakage from privy-middens.

In the case of water-closet towns, in addition to the above polluting matters, there are the solid excreta from the inhabitants, paper and other matter of a like nature, emptied through the closets into the sewers, but there is also a larger amount of clean water. As a rule, in both cases, the surface water from the streets and from the yards, and a certain amount of ground water finds its way into the sewers.

If kept for a few days, the liquid will undergo decomposition, through the action of putrefactive bacteria. The albuminous matters will be split up, Carbonic Acid, Marsh Gas and Ammoniacal derivatives being evolved. At the same time, the liquid turns black from the action of traces of Sulphuretted Hydrogen formed on the infinitesimal quantity of iron generally present in sewage.

Volume of Sewage to be dealt with.

Not only does the quality of the Sewage vary, but the quantity per head per day also varies considerably. The actual amount can, I find, in practice, be approximately estimated by the following rule: —

Let A = parts per 100,000 of Chlorine in the public water supply, and let B = the parts per 100,000 of Chlorine in the sewage; let X be the number of gallons of sewage per head per day required to be ascertained, then

$$X = \frac{125}{B - A}$$

This rule has as its basis the fact that the larger the quantity of water used, the more will the common salt contained in the sewage be diluted. In the coal-mining districts of Derbyshire, the volume may be taken at twelve gallons per head per day. A more usual allowance for small Urban Districts is twenty gallons per head per day; while in manufacturing towns, where the water carriage system is adopted, the quantity is from 35 to 40 gallons per head per day.

Recent reports I have been favoured with, shew that the quantity of sewage at Leeds is 36 gallons per head per day, at Leicester 37 gallons, at Manchester 38·4 gallons, and at Sheffield 50 gallons, while at Burton, owing to the large amount of brewery waste, the volume is 100 gallons per head per day; and at Buxton, owing to the large amount of bath-water, the volume is over 100 gallons per head per day.

Storm-water.

It should be understood that the volumes of sewage alluded to, are the dry-weather flow, but, as the backyards of houses are invariably drained into the public sewers, and, as a rule, the streets are also drained into the sewers, it will be obvious that the least fall of rain will considerably augment the volume of sewage to be treated.

The first washings of the streets and from the back yards produces sewage which is considerably stronger than that of the normal dry-weather flow, but, after the surface has been swilled, the surface drainage gradually becomes more and more dilute, and in time is little more than rain-water.

The question therefore arises " When is the sewage so diluted that it may be permitted to pass unpurified into the streams ?"

This is a question upon which great differences of opinion have existed in the past. On the one hand, those who are responsible for the purification of the rivers, have asked that the dilution should be eight times the dry-weather flow. On the other hand, those who are responsible for preparing sewerage schemes for large towns, have insisted that three or four dilutions is sufficient. The Local Government Board have adopted a practice which is a compromise, namely, that three times the dry weather flow must be fully treated as sewage proper, and between three and six times the dry-weather flow must be partially purified through streaming storm-water filters. These storm-water filters are constructed of clinker or other coarse material, to filter at the rate of 500 gallons per superficial yard, per day, or two-and-a-half million gallons per acre, per day.

This rule is quite fair as long as the dry-weather flow does not exceed 30 gallons per head per day, but, in a case like Buxton, where the dry-weather flow is 100 gallons, it is out of the question to suggest that six times the flow should be treated.

The rule would perhaps be more generally applicable if it were provided that the three times the dry-weather flow, which has to be treated, should not exceed 120 gallons per head per day.

Having briefly reviewed what the quantity and quality of the sewage to be treated is, a few words on the general principles involved will not be out of place.

Outline of the Chemical changes to be effected by Purification.

Having explained what crude sewage is before treatment, it will be well to lay down what a good effluent should be before it can be discharged into a stream. A reference to the analyses below will show that, first of all, the suspended solids should be removed. These suspended solids consist of about 10 grains per gallon of mineral matter. This is derived chiefly from the detritus from the surface of the roads and yards.

A gallon of crude sewage has the following average composition:—

		Grains per Gall.
1. Solids in suspension—		
	Organic	20
	Mineral	10
2. Soluble matters—		
	Organic	20
	Mineral	50
	Total ...	100

With regard to the total organic matter, about 50% of this can be precipitated as sludge, when chemical treatment is adopted as the first stage of purification; or as will be seen hereafter, the same proportion can be removed by fermentation into gaseous compounds, such as Marsh Gas, Carbonic Acid, and Ammoniacal derivatives, when the first stage of purification is effected in an open or a closed septic tank.

In the first stage, however, whether it be by precipitation or by septic tanks, it is practically only the solid matter in suspension which is touched, and no oxidation of the organic matter as yet takes place.

In the second stage, purification is effected by oxidation; the organic matter being oxidized into Organic Acids, Nitrous and Nitric Acids, all of which combine with the mineral matter of the sewage to form harmless mineral salts.

An average sewage would, in the process of purification, undergo the changes illustrated by the analyses below:—

	PARTS PER 100,000.								
	Total Solids.	Solids in suspension.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Oxygen absorbed at 80F in 3 minutes.	Oxygen absorbed in 3mins after 7 days incubation.	Putrescibility.	Nitrogen as Nitrates.
Crude Sewage ..	140	40	12	5·0	1·0	2·5	7·0	4·5	*Nil*
After precipitation or treatment in Septic tanks	105	5	12	6·0	·5	2·0	3·5	1·5	*Nil*
Effluent from Filters	100	*Nil*	12	1·5	.05	.01	0.01	*Nil*	1·5

The Standard of Purification.

A sewage effluent should be clear and bright, without suspended matter, and on shaking vigorously it should not froth.

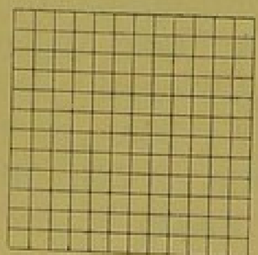
SHAKE TEST.

A simple test of purity can be readily applied: It is, to shake vigorously for one minute a bottle half-full of the effluent. All frothing should disappear in three seconds.

TESTS OF OPACITY FROM SUSPENDED MATTER.

The effluent should be so transparent that "PEARL" TYPE can be read by a normal-sighted person through a column 12 inches in depth. (The type below will illustrate this test.)

"A good test of the freedom of a Sewage Effluent from suspended matter is to measure the depth of a column of the Effluent through which 'PEARL' TYPE can be read. It can be read easily through twelve inches of a good Effluent. The only apparatus that is necessary for this test is a glass cylinder with a cut bottom, and some printing in 'Pearl' type the same as this."



A similar test has been devised by Dr. Reid, and consists of measuring the column of effluent which is necessary to obliterate the lines on the block shown above.

A good effluent will permit of the lines being distinctly seen through a column 12 inches in depth.

ALBUMINOID (ORGANIC) AMMONIA.

On chemical analysis, an effluent should contain *less* than 0·1 parts per 100,000 of Albuminoid Ammonia. This amount of Albuminoid Ammonia is taken as the index of the Nitrogenous Organic matter which remains unoxidized into Nitric and Nitrous Acids, and is not split up into other harmless products.

THE NITROGEN AS NITRATES (OXIDIZED NITROGEN).

The Nitrogen, in the form of Nitrates should *exceed* 0·5 parts per 100,000. As some 60% of the Nitrates formed consists of Oxygen which has been added to the sewage through the action of Nitrifying Organisms, it will be seen that the larger the quantity of Nitrates present, the more thoroughly the sewage is oxidized. The quantity of the Nitrates present is the best test therefore of the work done by the filters or contact beds in the final stage of purification.

THE INCUBATOR TEST.

The Oxygen absorbed by a good effluent, in three minutes, from Potassium Permanganate, should be less than 0·25 parts per 100,000, and it should not be capable of putrefaction. This is best told by incubating the effluent for one week, when, if the Oxygen stored up in the effluent, in the form of Nitrates and other highly oxidized compounds, is sufficient to complete the oxidation of the remaining unoxidized organic matter in the effluent, at the end of the week's incubation, it will not absorb more Oxygen from Potassium Permanganate than it did before incubation. This test is generally known as the "Incubator Test" and is the one which is now being generally adopted.

CONCLUSION WITH REGARD TO TESTS OF PURITY OF EFFLUENTS.

It should be clearly understood that a good effluent should comply with each of the above tests; any one without the rest may be complied with by an effluent which is only partially purified. On the whole, for a single test, the incubator test gives the most reliable results, and is easy of application.

Methods of Purification

There are two stages in the purification of sewage, just as there are two kinds of polluting matter in sewage, namely the solids in suspension and the soluble polluting matter. These two stages are: —

First Stage.—*Clarification, or the removal of the polluting matters in suspension.* This has in past years been effected by adding a chemical to the sewage and allowing it to settle in tanks. This process is known as precipitation. The solids in suspension being precipitated or thrown down to the bottom of the tanks as a sludge, which has to be periodically removed.

By bacterial processes, it is now practicable to liquefy by fermentation the solid matters in sewage, preferably in tanks (closed or open septic tanks), but also in upward flow or lateral roughing filters, or by means of first contact beds.

The resultant liquid from this process is very similar to the tank effluent produced by precipitation; it contains comparatively little suspended matter, but the polluting matters in solution are practically unaffected.

Second Stage.—*The oxidation and nitrification of the organic matter in solution by means of nitrifying and other oxidizing bacteria.* This change is the same however the sewage is treated, whether by irrigation or intermittent filtration, either through land or specially prepared filters of coal, clinker, destructor cinders, coke breeze, burnt ballast, or by means of contact beds.

Precipitation.

In the old methods, and under suitable circumstances with modern ones, the solid organic matters in suspension are removed as sludge by chemical precipitation.

The chemicals which are used for this purpose are Lime, Alum, or Copperas, or some combination of two or more of these substances sold under some fanciful trade name.

The simplest method of effecting precipitation is by means of Alumino Ferric blocks, used with a Dortmund tank.

This tank is shown on Plate I., and has been advocated by me in previous Reports upon this question.* The advantage of this form of tank is, that it permits the sludge being removed from the apex of the inverted cone by means of a hand suction pump, or a centrifugal pump, without first emptying the tank itself.

As the Sewage Commissioners have pointed out, chemical precipitation in combination with artificial filters or contact beds, are two of the processes which produce effluents which will not putrefy.

The size of the tank should be such that its capacity above the top of the cone is equal to one-third of a day's flow.

It cannot be too clearly understood that there are no patent rights attached to the use of the Dortmund tank.

*See Journal of State Medicine, in 1896, p. 496; Special Report on Sewage Purification, 1897; also Annual Report for 1896.

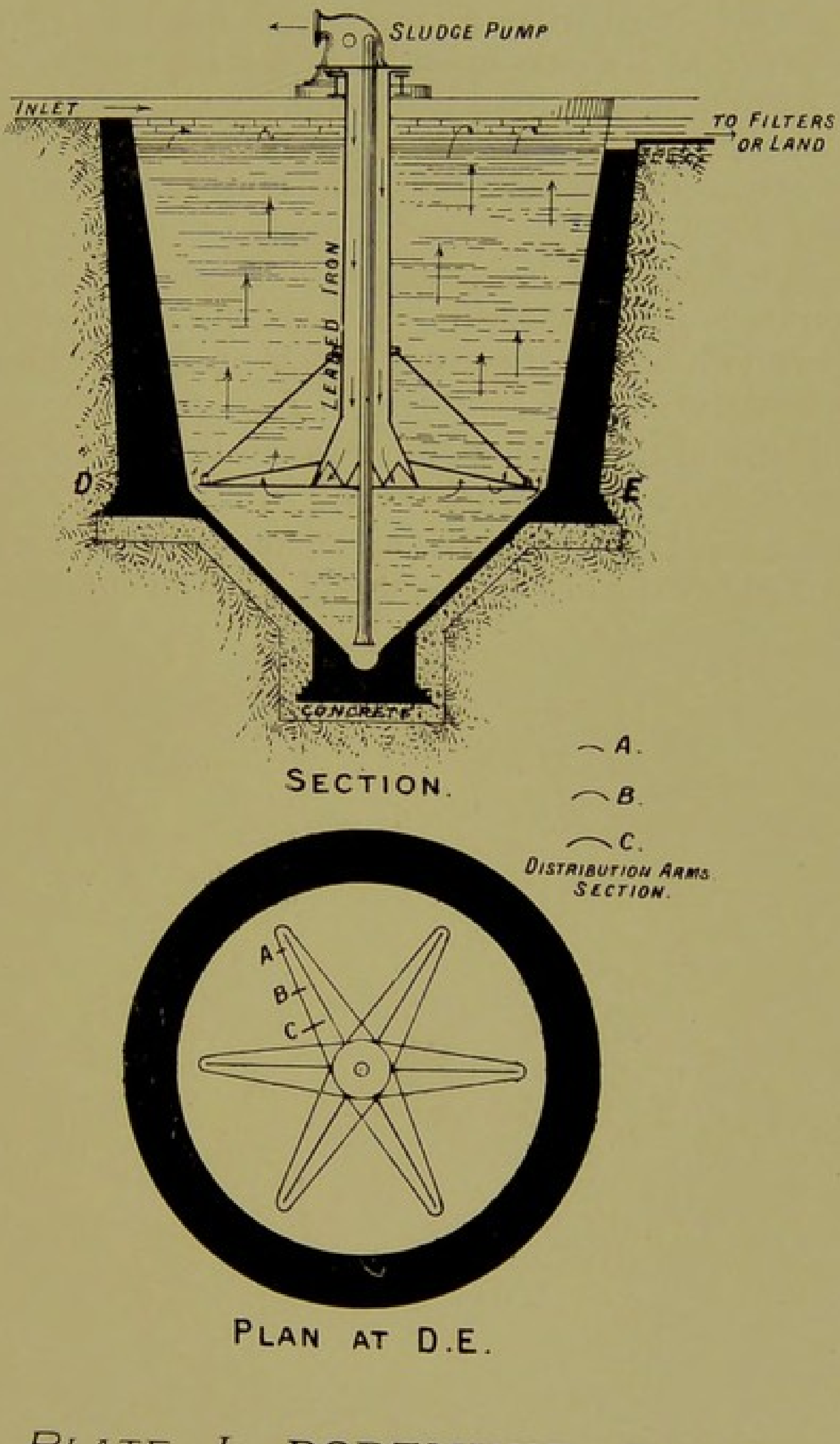


PLATE I.—DORTMUND TANK.

SECTION II.

The Purification of Sewage by the purely Biological Methods.

Before sewage can be thoroughly purified by biological methods, it has to undergo the following two changes :—

1. Liquefaction.
2. Oxidation.

Sewage has to go through these stages whether it be treated in closed or open septic tanks, contact beds, percolating filters, or any combination of these processes.

NECESSITY FOR DETRITUS TANKS.

If septic tanks are used, the liquefaction of the sewage takes place in the tank If tanks are not used, the solids in suspension in the sewage are deposited upon the surface of the filter or contact bed and in its interstices where it is gradually liquefied, but not until the bed has lost some 40 or 50 per cent. of its working capacity.

From the analysis of average sewage given on page 8, it will be seen that some 10 grains per gallon of the solid matter in the sewage, consists of insoluble mineral matter, the great bulk of which cannot be liquefied by the aid of bacteria. Where a precipitation process is adopted, such insoluble mineral matter, as road detritus, is useful in helping precipitation, but when a purely biological process is to be adopted, it is necessary to separate the detritus before the sewage is conducted to the septic tank, or is applied to contact beds or percolating filters; otherwise the tank will be unnecessarily silted up, or the contact beds or filters permanently plugged.

In every case, therefore, when a biological process is adopted, a detritus tank must be constructed.

The usual system is to have two shallow tanks of such a size that the velocity of sewage passing through them is reduced to about 40 feet a minute, when the coarse mineral matter falls to the bottom of the tank. When about a foot of detritus has settled, the other tank is used and the first one is emptied.

Colonel Ducat has recently introduced into this country, an admirable detritus tank, which is largely used in Indian waterworks, a modification of which is shown in Diagram I., Fig. 1. This tank permits the detritus being scraped out while it is still in use.

I have also introduced the centrifugal detritus tank shown in Diagram I., Fig. 2. The sewage is caused to pass through an ovoid tank in which it sets up a swirling movement, the detritus being carried by centrifugal force on to the sloping sides of the tank, high and dry, where it can be easily removed.

After passing through the detritus chamber, the sewage should pass through iron bars, about ½-inch apart, and under a scum board, to prevent old cloths, brushes, corks, and other large solids from passing into the tank or on to the filter.

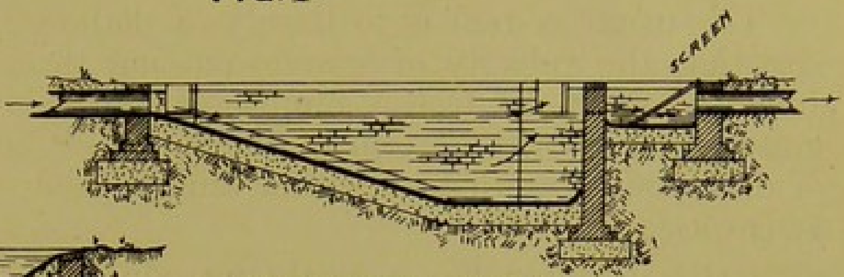
The Liquefaction of Sewage.

The credit for applying on a practical scale the knowledge of the bacteriologists, that certain organisms had the power of liquefying organic matters, belongs to Scott-Moncrieff, who, in 1891, liquefied the sewage from a household of ten persons by means of a continuous upward flow tank filled with coarse flints. Five years later, Mr. Cameron, of Exeter, introduced his septic tank. Cameron, having come to the conclusion that the organisms which have the power of liquefying organic matters are largely anaerobic, or thrive best in the absence of air, conducted his sewage into an elongated cemented water-tight covered tank. The inlet and outlet were submerged so as to prevent the access of air. The tank capacity was about equal to a day's flow. In the course of time, a thick tough scum formed on the top of the tank, and it was found that the sludge which settled at the bottom of the tank underwent decomposition with the evolution of Carbonic Acid Gas, Marsh Gas, Hydrogen, and Ammoniacal compounds, the resultant mixture being an inflammable gas, which Cameron utilised on the

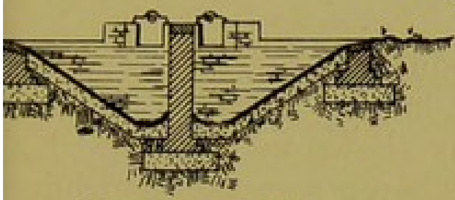
PLAN OF DETRITUS TANKS.

A. WITH SLOPING SIDES.

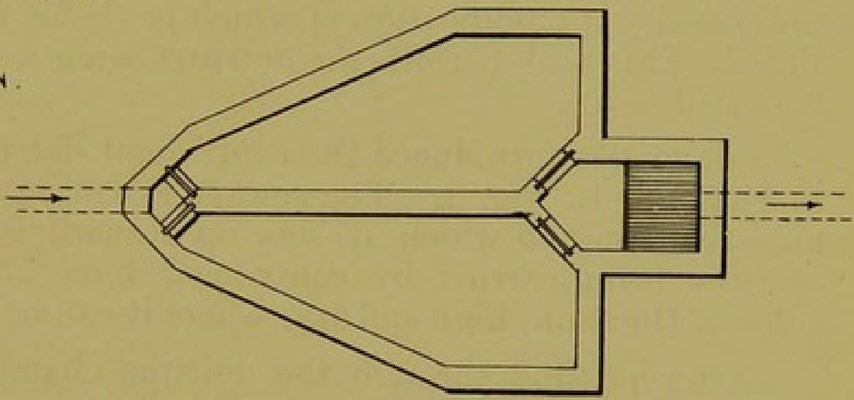
FIG: 1.



LONGITUDINAL SECTION.



CROSS SECTION.

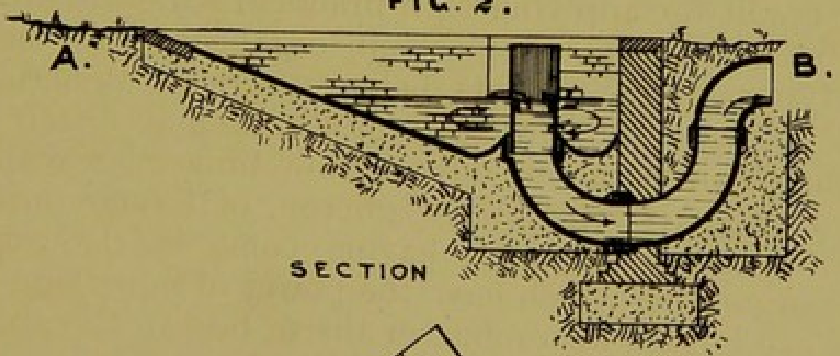


PLAN.

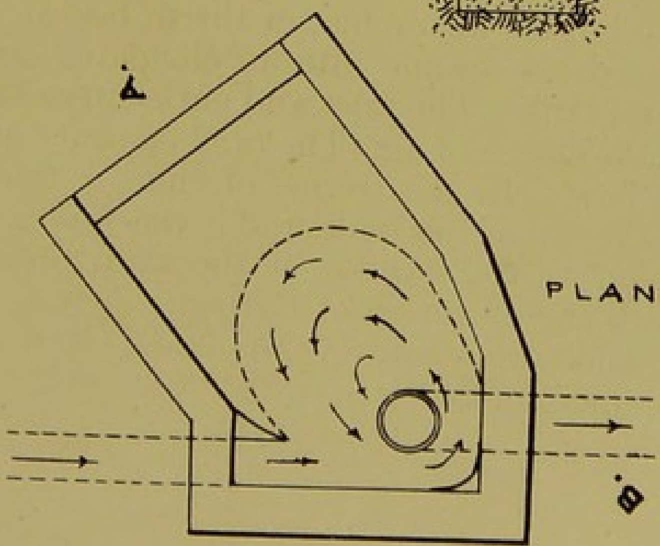
SCALE 8 FEET = 1 INCH.

B. CENTRIFUGAL DETRITUS TANK

FIG: 2.



SECTION



PLAN.

SCALE 4 FEET = 1 INCH.

JH.

sewage works. After the sewage had passed through the septic tank, Cameron oxidized it by means of contact beds Contact beds are filters, the outlets of which can be closed to fill the filter with the effluent from the septic tank, the liquid being left "in contact" with the filtering medium for an hour or so, when the outlet from the filter is opened and the sewage allowed to escape, air being drawn into the interstices of the filter.

Following on Cameron's Exeter experiments, came the investigations of Colonel Ducat and Mr. Dibdin. Their experiments were very similar. Colonel Ducat filtered crude sewage through a percolating filter eight feet deep, the sewage being uniformly distributed over the surface of the filter by means of narrow iron girders, in the sides of which V-shaped notches were filed, and through which the sewage continuously trickled. This filter had other special points, which will be described hereafter. Dibdin, on the other hand, purified crude sewage by directly applying it to contact beds: This was first done at Sutton, Surrey, and the process is often called the Sutton process.

In either case, solids in suspension are arrested in the upper layers of the filters, where they are gradually liquefied.

The question at once, therefore, arises, Is any form of septic tank necessary? If it is necessary, do any advantages attach to the closed form connected with the name of Cameron, of Exeter?

Perhaps the best and most authoritative experiments on purifying crude sewage, both before and after screening, with and without septic tanks, are those conducted by the Corporations of Leeds and Manchester.

The Leeds experiments consisted in applying crude sewage to a coarse contact bed, and filtering the effluent through a fine bed. The coarse bed was filled with coke not less than three inches in diameter. The fine bed, with coke from $\frac{3}{16}$ inch to $1\frac{1}{2}$ inches in diameter. The beds were filled three times in the twenty-four hours. The gross capacity of the rough bed was 174,800 gallons, the net liquid capacity after filling with coke 83,300 gallons.

The following table shows the rate at which the working capacity diminished when no septic tank was used:—

Oct. 2nd	83,600 gallons.
Dec. 2nd.	63,400 gallons.
Dec. 16th.	58,800 gallons.
Dec. 30th.	57,100 gallons.
Jan. 13th.	51,100 gallons.
Jan. 27th.	45,400 gallons.

Colonel Harding, the chairman of the Committee, and Mr. Hewson, the city engineer, estimate that about 80% of the sludge is liquefied, 20% of the solids accumulating; but this quantity they found might be reduced by allowing the beds to rest from two to five weeks. Wherever crude sewage is applied to the contact beds or filters, the surface becomes clogged with fibre, bits of cellulose, and with a kind of papier maché, from paper which has disintegrated in the sewage. Subsequently, the Leeds sewage was screened and then settled for one hour, and the filters were used at the rate of two fillings a day.

Even with this modification it was found that without a septic tank the process could not be relied upon to purify more than 80 gallons per square yard per day. It is found that the capacity of contact beds, even when supplied with thoroughly clarified sewage, decreases rapidly at first but more slowly afterwards, and becomes constant in about three months, when their normal capacity can only be calculated at two-thirds of the original water capacity.

In 1899, the Corporation of Manchester appointed Professor Percy Frankland, Professor Perkins, and Mr. Baldwin Latham, to report upon a scheme of sewage disposal for Manchester.

These experts came to the following conclusions, amongst others:—

1. "That suspended matter must be removed as far as possible by sedimentation."

2. "That any suspended matter not so removed should be retained as far as possible on the *surface* of the bed."

The Manchester experts also recommended that the sewage as it arrives at the works, should be screened and passed through tanks provided with scum boards, and submerged inlets and outlets. In the Parliamentary proceedings on the Leeds Bill last session, Colonel Harding, M. Inst. M.E., Chairman of the Leeds Sewerage Committee, who is also a Member of the Royal Commission on Sewage Disposal, gave it as his opinion, that all sewage should undergo some treatment in septic tanks of some form before it is submitted to the process of oxidation by filters, contact beds, etc.

In addition to the weighty opinions given above, from my own personal observations on various contact beds I have visited, and from experiments on the sewage at a private house, I have no hesitation in saying that sewage should not only be screened and passed through detritus tanks, but should also be submitted to treatment in septic tanks before it is applied to the filters or contact beds.

Liquefaction by means of Closed and Open Septic Tanks.

With regard to whether there is any particular advantage in the septic tank being closed, this point was submitted to a thorough test by the Manchester experts. Closed and open septic tanks were both constructed and the following analyses are given in the Manchester report of the effluents from the two processes:—

Weekly Averages from July 12th to Sept. 13th, 1899.

Week ending	OPEN Septic Tank Effluent	CLOSED Septic Tank Effluent.
	GRAINS PER	GALLON.
July 12th	·25	·30
,, 19th	·22	·31
,, 26th	·24	·35
Aug. 2nd	·21	·32
,, 9th	·23	·31
,, 16th	·22	·27
,, 23rd	·19	·30
,, 30th	·22	·34
Sept. 6th	·21	·25
,, 13th	·25	·305
AVERAGE	·22	·301

As a result of these Manchester experiments, open septic tanks have been tried in many places, and, provided that care is taken to properly submerge inlets and outlets, and to have the tanks constructed with efficient scum boards, the solids in the sewage are liquefied as thoroughly as in a closed tank. At Chesterfield, for instance, open septic tanks have now been in use for two years; a crude sewage, the Albuminoid Ammonia in which varies from 1·2 to 1·8, is thoroughly liquefied and the Albuminoid Ammonia reduced to from 0·5 to 1·0—a general purification of nearly 50%.

Similar results have been obtained at Kimberley, on the borders of Derbyshire.

I have mentioned these two places, because in each there is a difficult sewage to treat. The Chesterfield sewage containing tan liquor and brewery waste, and the quantity of water used per head per day being very small for a town of its size; while at Kimberley, the proportion of brewery waste is very high indeed. Where the tanks have to be constructed in close proximity to houses, there may be special reasons for having them closed.

A septic tank is generally constructed to hold about one day's dry-weather flow, and the bottom of the tank should be made to slope to two conical depressions, one near the inlet and the other near the outlet, so as to permit of any undue accumulation of sludge being removed.

Personally, I am in favour of liquefaction being started in a septic tank, the process being finished by means of an anaerobic bacteria bed, which is always kept full of sewage, as described below, and figured in the model scheme shown in Fig. III., also on the large sheet in the Appendix.

Liquefaction by means of Anaerobic Bacteria Beds or Cultivation Tanks.

In addition to sewage being capable of being liquefied in closed and open septic tanks, it may be liquefied in the manner originally advocated by Scott Moncrieff, namely, by upward filtration through tanks filled with coke breeze, clinker, or other hard material. In the old days before the science of bacteriology existed, upward filtration was a system of sewage purification which had its advocate. Unfortunately, however, they endeavoured to oxidise the sewage by upward filtration, and, needless to say, in this they signally failed. As a liquefying arrangement, however, an anaerobic bed acts well and has its place in the scheme of biological purification.

The original form of this bed, is one in which upward filtration takes place, but a simpler arrangement consists in lateral filtration through a tank filled with hard material of 1-inch to 3-inches in size. If the sub-soil is clay, to construct a tank on this principle, it is sufficient merely to dig a hole in the ground and allow the sewage which has passed through a detritus tank and some form of septic tank, to percolate laterally through the bed. By placing about six to nine inches of coarse clinker above the water-level of the bed, and covering with a little soil, good crops of rye grass may be grown. Beds constructed on this principle have been tried on a large scale by Dr. Richards, at Chesterfield, with the result that the Albuminoid Ammonia was reduced on the average from ·72 to ·38 parts per 100,000, and on the Burton farm, the Albuminoid Ammonia from about ·5 to ·25 per 100,000.

The following table shews the results obtained by this method, at Chesterfield:—

Experiments on Lateral Filtration through Anaerobic Bacteria Bed at Chesterfield.

Albuminoid Ammonia, Parts per 100,000.

	Septic Tank Effluent.	Effluent from Lateral Bacteria Bed.
	·52	·26
	·60	·36
	·60	·36
	1·00	·48
	·52	·36
	·20	·18
	·52	·32
	·64	·44
	·44	·32
	·68	·48
	·60	·28
	·60	·42
	·80	·28
	1·63	·80
	1·20	·48
	1.00	·28
Totals	11·55	6·10
Average	·72	·38

Kenwood and Butler speaking on the relative merits of septic tanks and anaerobic bacteria beds, write: "It appears to us that upward filtration offers a better means of effecting the separation and solution of the suspended matters of sewage, and at the same time of reducing the pollution of the effluent, than does any system which aims at their removal in a hollow chamber, such as the septic tank. The particles of the filtering medium seem to form a large area from which organisms can more effectively work."

With this view I am in cordial agreement, but, if the sewage is first partially liquefied in a septic tank, so constructed that any suspended organic matter which fails to liquefy, and accumulates, can be removed by a pump, or other means, and the partially liquefied effluent from the tank is further treated by lateral filtration through an anaerobic bacteria bed, the process of liquefaction will, in my opinion, be carried out under the best and most lasting conditions.

Conclusions with regard to the Liquefaction Stage of Purification.

The conclusions I wish to emphasise with regard to the liquefaction of sewage by the agency of bacteria, are:—

1. That efficient detritus tanks and screening chambers should be constructed to remove such mineral suspended matter as cannot be liquefied by the agency of bacteria; and such organic matter as can only be tardily liquefied.

2. That some form of septic tank is necessary in order to prevent the filters or contact beds becoming clogged, except where there is a fall of 20 feet or so.

3. That open septic tanks are as effective as closed ones.

4. That an anaerobic bacteria bed (upward or lateral flow filter), filled with coarse hard clinker may, with advantage, be made to take the place of part of the septic tank.

5. That the septic tank should hold one day's dry weather flow, except when an anaerobic bed is also employed, in which case half-a-day's dry weather flow will suffice.

SECTION III.

The oxidation of Sewage, by Filters and Contact Beds.

After the solid matter in suspension in sewage has been removed by precipitation, or has been liquefied through the agency of bacteria in septic tanks or bacteria beds, we still have the organic matter in solution to deal with.

Thanks to the investigations of Schloesing and Muntz, in France, and in this country to those of Warington and Percy Frankland, we now know that the nitrogenous organic matter in solution in the sewage can be mineralised by the agency of more than one micro-organism into the form of nitrates, similar to saltpetre or nitre. As illustrating this process, I may quote the following passage from a paper read in 1896, at the Glasgow Conference of the Royal Institute of Public Health.

*"The changes which take place in the oxidation of nitrogenous organic matter into nitrites and nitrates, is analagous to the fermentation of alcohol into vinegar; and the conditions which regulate the two fermentations are identical."

"The vinegar brewer allows a solution of alcohol *to drip slowly* over birch twigs, in a current of air, at a temperature of 77° F., for a fortnight. During this time, an organism, known as the "Mycoderma Aceti," which is seeded on the twigs, flourishes, and in its growth, takes up Oxygen from the air and unites it with the Hydrogen of the alcohol, to form water and acetic acid."

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*"Recent Advances in Sewage Purification," by S. Barwise, M.D., Journal of State Medicine," p. 499.

The change which takes place may be represented as follows:—

Alcohol		Oxygen		Water		Vinegar
C_2H_6O	+	O_2	=	H_2O	+	$C_2H_4O_2$

By substituting an ammoniacal fluid, such as sewage, for his solution of alcohol, the vinegar brewer could use his appaatus for the production of saltpetre.

Indeed, as the Franklands have pointed out,* "the process of nitrification has been carried on for ages, as a regular industry, in India, and even in some European countries; especially in France, during the Great Blockade. For a number of years past, however, the principal source of Nitric Acid and its derivatives has been the enormous deposits of Nitrate of Soda occurring in South America, which deposits themselves are, doubtless, the product of a vast nitrification process in a former period of the earth's history."

As long ago as 1882, Warington, in a paper read before the Society of Arts, pointed out, "that it would be possible to construct a filter bed having a greater oxidising power than would be possessed by any ordinary soil and subsoil."

About fifteen years ago, a company carried the suggestion into operation, and constructed many artificial filters, which produced very fair effluents.

The researches of the bacteriologist proved that the oxidation of sewage is not a chemical process, but a biological one, and that, therefore, there is no particular virtue in the material of which the filter is constructed, so long as it is hard enough to withstand weathering action, and the particles are so large that capillary attraction does not prevent the free passage of the air into the interstices of the filter.

†Nearly 60% of the Nitrates formed consists of Oxygen; three parts of Oxygen being required for the oxidation of each part of Nitrogen. Just as the Nitrogenous organic matter is oxidized into Nitrates, so the Carbonaceous matter is oxidized into Carbonic and Organic Acids.

From this it will be seen that the free passage of air into

* "The Nitrifying Process and its Specific Ferment," by Percy and G. C. Frankland; "Transactions of the Royal Society, 1890."

† The formula for Nitrate of Lime is $Ca(NO_3)_2$, it is probable in this form that the oxydized Nitrogen leaves the filter.

the interstices of the filter, is a necessary condition for its effective action, just as a current of air is necessary for the fermentation of alcohol in the manufacture of vinegar.

The whole problem consists of how to admit an excess of air into the interstices of the filter while the sewage is passing in at a rate of not exceeding 250 gallons per square yard per day when the filter is 4 feet deep; 400 gallons when it is 8 feet deep; 500 when it is 12 feet deep; and so on.

The difficulty is, that if the filter is constructed of particles of such a size ($\frac{1}{2}$-inch to $\frac{3}{4}$-inch) that the free entrance of the air is not prevented by capillary attraction, the sewage will pass through at so great a rate that no purification will be effected. The problem is to devise some special contrivance to regulate the quantity of sewage to the quantity of air which is supplied to the filter. It is to solve this problem that the whole of the ingenuity of chemists, bacteriologists, and engineers has during the last five years been directed.

The first method was to cover the filter with a layer of clean sand, about six inches in depth; this had the effect of uniformly distributing the sewage over the surface of the filter, and limiting the rate at which percolation into the filter took place, but, by capillary action between the particles of sand, the surface of the filter was sealed, and the air below the sand was simply churned round, and was not renewed as its oxygen was exhausted.

The next step was to construct the filter with a number of short earthenware pipes passing through the sand into the body of the filter, and projecting some six inches above its surface. As the sewage passed down through the filter, it drew the air after it. This arrangement was improved by applying the sewage intermittently by means of an automatic flushing tank and syphon, whereby about every quarter-of-an-hour a volume of sewage is discharged over the surface of the filter, and is absorbed in about five minutes. As the sewage percolates down through the body of the filter, air is drawn into the interstices, so that it becomes filled with alternate layers of air and sewage.

All filters covered with sand, however, require a great deal of attention, and unless they have it, eventually their surface becomes clogged, and they cease to carry on the nitrifying action if the filter is not allowed to rest and the sand is cleansed.

Following on this arrangement came the filters of Colonel Waring and Mr. Lowcock, of Birmingham. Both these engineers attempted to artificially aerate bacterial filters by means of blowers. They differed however in this, that Colonel Waring blew his air upwards, through the filter, while Mr. Lowcock introduced his air at the middle of the filter and blew it out with the effluent at the bottom. Both these arrangements, however, are expensive, and necessitate some mechanical force for working the blower.

While these methods were being tried, the problem was attacked in an entirely different manner, by Mr. Dibden, in his "contact beds," and Colonel Ducat, who is the author of the modern biological filter.

With CONTACT BEDS, the outlet of the filter is closed, and the sewage is gradually poured over its surface by means of rough distributing channels. The sewage passes down through the filter, which it gradually fills, thereby displacing the air in its interstices. As soon as the filter is full, it is allowed to rest for two hours with the sewage "in contact" with the filtering medium—hence the term "*contact beds.*"

The usual method of working contact beds is as follows:—

1 hour filling.
2 ,, standing full.
1 ,, emptying.
4 ,, resting empty.
—
8 hours × 3 fillings in 24 hours.

When, however, the purification effected is insufficient, the beds are only filled twice a day, and are allowed to have a longer period of rest.

It will be seen that the volume of sewage treated is the same as the volume of air it displaces.

I wish to emphasize this point, as I shall be able to prove that the volume of air drawn into intermittent filters which, are not covered with sand, may be more than five times as great as the volume of sewage treated.

THE MODERN PERCOLATING FILTER.

The next advance was to distribute the sewage over the surface of filters intermittently, by means of perforated pipes, etc., which will only permit the right amount of sewage to be supplied to each square yard of the filter, and so do away with the layer of sand upon its surface, which prevented the access of air to the body of the filter.

The first method of aerating filters was to apply the sewage for 8 hours and allow the filter to remain empty aerating for 16 hours.

The alternate periods of work and rest were then shortened by the introduction of the Automatic Flushing Tank, the sewage being applied intermittently every 20 minutes. The cycle of work and rest was then shortened to a few minutes by the introduction of tippers, each shortening of the period effecting an improvement.

Then came the Chesterfield experiments. in which the sewage was applied for as short a period as 10 seconds, and finally the so-called "continuous" filters of Colonel Ducat, Mr. Stoddart, and others, in which the sewage falls by single drops over the surface of the filters. In these the different parts of the filter receive a spot about every five seconds, the application, although continuous throughout the twenty-four hours, is essentially intermittent, as air is drawn in at the same time as the sewage. It is essential that these dripping distributors should have their bearings fixed independently of the filter, otherwise they will sag as the filter consolidates, and parts of the filter will be overdosed.

While an immense number and a great variety of improvements have been made in the method of filtering sewage, contact beds have also received their share of attention, so that there are several automatic arrangements for working the cycle of a contact bed without any skilled labour. The various arrangements and the merits of each will be discussed in the following section.

SECTION IV.

Contact Beds and Percolating Filters.

The following table shows the chief forms of contact beds and artificial filters, which may be taken as types of the rest:—

A. CONTACT BEDS.

1. Without automatic appliances, the beds simply being worked by hand.
2. Actuated by ordinary syphons.
3. Actuated by Adams' Automatic Controlled Syphon and Automatic Feed.
4. Actuated by Cameron's Automatic Alternating Gear.
5. Actuated by Mather and Platts' Automatic retaining Valve.

B. PERCOLATING FILTERS.

1. Filters with different methods of applying the Sewage intermittently.
   - i. Application of the Sewage being regulated by hand.
   - ii. Sewage being applied intermittently by means of Automatic Flushing Tanks:
   - iii. Sewage being applied intermittently by Automatic Tipplers.
   - iv. Sewage being applied intermittently by Mather and Platts' intermittent Distributor.
   - v. Filters with intermittent feeds, regulated by clockwork, or other machinery.

vi. Sewage being applied intermittently by means of Shone's Ejectors.

vii. By automatic revolving distributors, worked on the principle of "Hero's Fountain."

viii. So-called "continuous" filters, in which the sewage is applied by intermittent drops.

2. Filters with different forms of distributor.

i. Filters with Sewage distributed by top layer of sand.

ii. Distributors consisting of ordinary wooden troughs, laid herring-bone fashion.

iii. Distributor of $\frac{1}{2}$-channel stoneware pipes.

iv. Distributors of iron girders with V-shaped notches.

v. Distributors of fixed perforated pipes.

vi. Distributors of oscillating perforated pipes.

vii. Distributors of revolving perforated pipes.

viii. Distributors, perforated iron trays, such as Stoddart's Distributor.

The one drawback to the use of intermittent filters as opposed to contact beds, is the difficulty in applying the Sewage uniformly over the surface of large areas of filter; hence the variety of distributors which are being brought out to overcome this difficulty.

It will be seen that an almost endless variety of arrangements can be made by various combinations of different types of filter and different distributors. Some Authorities prefer to have a contact bed, and intermittent filters filtering the effluent from the contact bed through the intermittent filter. Any of the distributors may be used in combination with any particular method of applying the Sewage to a filter. There is still a great field for ingenuity in improving the methods of distributing sewage, as some of the arrangements which have been brought out are unnecessarily expensive, and in practice by no means as automatic as their authors claim.

Each arrangement has special advantages of its own, which must be understood in order that the full benefit of local circumstances can be obtained.

In this section I shall endeavour to briefly explain the special circumstances which may be regarded as indications for the adoption of any of these processes, and shall try to point out the advantages and drawbacks of each method.

Size of particles of medium for Filters.

Most important of all is the size of the material. After many experiments, I have come to the conclusion that it is most important that the material should be *quite free from dust.* For filters intended to be used for Sewage which has been properly liquefied in septic tanks and is distributed by perforated pipes or other proper distributor, the best sizes are, for the top layer of 3″ to be constructed of material which will pass through a $\frac{1}{2}''$ mesh and rest on $\frac{1}{4}''$ mesh; the rest of the filter being constructed of material which will pass through a $\frac{3}{4}''$ mesh and rest on a $\frac{1}{4}''$ mesh; the perforated pipes which collect the effluent being surrounded with material from 1″ to 2″ in size.

If the filter is intended for only sedimented sewage—an arrangement I do not approve of—doubtless the material of the filter would have to be larger.

Size of material for Contact Beds and Cultivation Tanks.

With regard to contact beds, speaking generally, the material must be much coarser. For first contact beds to deal with sedimented sewage, the beds are usually made of material from 3″ to 5″ in size; the second contact bed being constructed of material from $\frac{1}{2}''$ to $1\frac{1}{2}''$ in diameter. When, as should in my opinion always be the case, a septic tank is provided as well as the first contact bed, the first contact bed should be of material from 1″ to 3″ in size, and the second contact bed of material between $\frac{3}{4}''$ and $\frac{1}{4}''$.

Material for Filters.

Before considering the relative merits of contact and other filters, it may be useful to record that as far as material is concerned the same substances which act efficiently as bacterial filters, speaking generally, serve also for contact beds. As a rule, however, the material for filters should have a cleaner fracture than that for contact beds. For instance, the best material which has yet been tried for intermittent filters is hard coal. This probably has no advantage as material for a contact bed. The reason for the merits of coal as a filtering medium is that it has no little *cul-de-sacs* in which stagnant sewage or air collects. After coal, the materials which give the best results, in my experience, are: Destructor breeze, hard clinker, granite chippings, saggers from potteries, hard coke, cinders from ironworks after the sulphur has been oxidized, burnt ballast, and, in fact, any clean hard material.

The same material will also do for contact beds; but the cleaner material, such as coal and granite, will not have any advantage over such material as clinkers. Obviously, local conditions will govern the material which is used for the construction of biological filters.

If the district is provided with a refuse destructor, and this can with economy from the point of view of scavenging be placed upon the site of the Sewage disposal works, the district will automatically obtain filtering material in the clinkers from the destructor.

Relative merits of Contact Beds and Artificial Filters.

Below I have endeavoured to give succinctly, in tabular form, the relative advantages and disadvantages of these two systems of carrying out the oxidizing stage of Sewage purification:—

CONTACT BEDS.	CONTINUOUS FILTERS.
ADVANTAGES OF	CONTACT BEDS.
1. There is no great necessity for carefully distributing the Sewage.	The Sewage must be distributed by stationary or revolving perforated pipes, or other means.
2. The filter material need not be so carefully graded, 1″ to 2″ diameter giving average results.	To obtain the best results, material must be free from dust, and be from $\frac{1}{4}''$ to $\frac{3}{4}''$ diameter.

ADVANTAGES OF PERCOLATING FILTERS.

1. Contact beds must be constructed with water-tight walls, which must necessarily be expensive.	Percolating filters cost less, as retaining walls of any kind are not necessary, in fact, *are harmful.*
2. Double contact beds are required to approach the same resnlts as one percolating filter.	Percolating filters give best results.
3. The air supplied to a contact bed is only equal to the volume of Sewage treated, therefore, oxidation is limited.	The air supplied to intermittent percolating filters may be more than five times the volume of the Sewage treated, therefore more highly oxidised effluents are attainable.
4. The Sewage, owing to being stagnant in the contact bed, has a greater tendency to plug it up.	The filter does not deteriorate, the only plugging which takes place is on its surface.
5. Double contact beds require 1 yard for every 112 gallons.	Continuous filters may purify over 500 gallons per yard when there is ample fall.

It will be seen that on the whole the advantage rests with percolating filters, which not only give better effluents, do not become so readily plugged, but, owing to there being no necessity for expensive brick retaining walls, are less costly. There are, however, circumstances in which contact beds may be preferred; this may be the case where the subsoil is so stiff a clay that the beds may be made water-tight without any retaining walls, and where there is very little fall.

A brief description of the main points about the different ways of working contact beds is therefore desirable.

Contact Beds.

The maximum efficient depth for contact beds is four feet, and in all calculations it will be assumed that the beds are this depth. Where the beds are not worked automatically, it is impossible to rely upon more than two fillings in the course of the twenty-four hours.

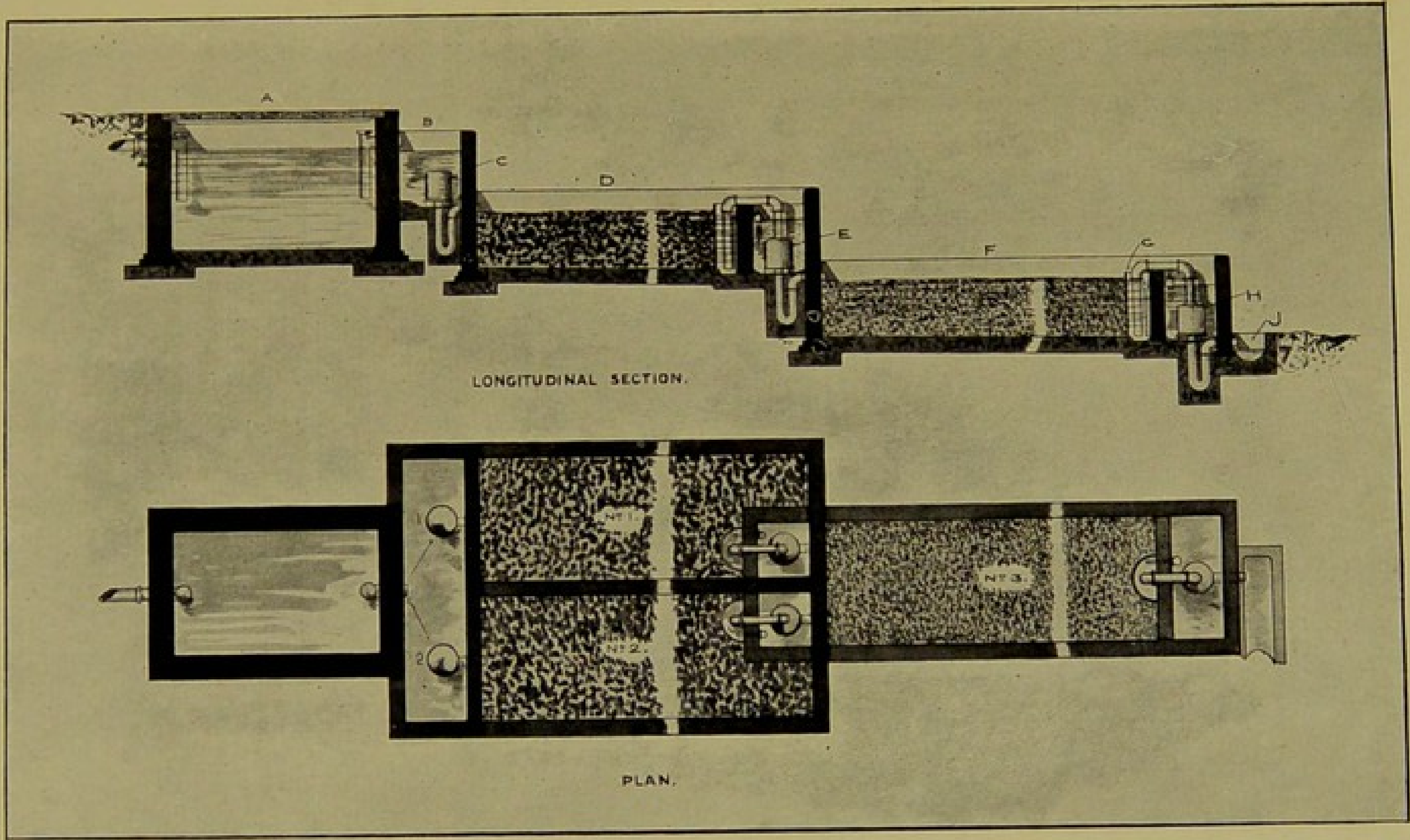


Plate II.—DOUBLE CONTACT BEDS.

With Adams's Automatic Feed and Discharge Syphons.

The normal working capacity of a contact bed, supplied with Sewage which has been previously clarified in a septic tank or bacteria bed, may be estimated at one-third of the total capacity, so that the volume of Sewage which can be passed through, per square yard, at each filling, is one-third of the total capacity of a superficial yard of the contact bed which we have assumed is four feet deep. This is 12 cubic feet, or 75 gallons at each filling, or 150 gallons per square yard per day.

If, however, automatic apparatus is adopted, three fillings a day may be relied upon, which will enable 225 gallons per square yard to pass through the contact bed.

When, however, "contact beds alone" are relied upon on account of silting up of the first or coarse bed, only one-fourth of its original cubic capacity is eventually available for alternately filling and emptying with sewage and air. This gives 9 cubic feet per superficial yard of filter, or 56 gallons at each filling in the twenty-four hours; and as the Leeds experiments have shewn, only two fillings a day, under these circumstances, are effective.

The experiments at Manchester, Leeds, London, Sutton. Chesterfield, Kimberley, and other places, have proved that to produce an effluent in which the Albuminoid Ammonia is less than .1 part per 100,000, and in which the Oxygen absorbed from Permanganate of Potash, in four hours, at 80° F., is less than 1.0 part per 100,000, or in which the Incubator Test gives uniformly good results, it is necessary that the Sewage should be passed through contact beds twice, that is to say, that the effluent from the first contact bed should be discharged upon the surface of a second contact bed, and it should be submitted to the process of oxidation twice over, the second contact bed being constructed of material of smaller size than that used for the first contact bed; under these circumstances, some automatic arrangement is almost indispensable.

The advantages which may be claimed for automatic apparatus for working contact beds, are:

1. That they permit of the beds being used for three fillings a day instead of two.

2. That their satisfactory working does not depend upon the man in charge of the works.

The automatic arrangements for working contact beds which are most generally adopted, are: Ordinary Syphons, Adams' Automatic Supply Syphon and Discharge Valve, Cameron's Automatic Alternating Gear, and Mather & Platt's Automatic Retaining Valve and Alternating Gear.

The simplest plan for the automatic working of bacteria beds, is to insert at the outlet of the contact bed, a syphon, which comes into action as soon as the bed is full. Unfortunately, for the more general adoption of this arrangement, it has been assumed that the nitrifying organisms require the sewage to remain for at least two hours in contact with the filtering medium, upon the surface of which the organisms grow. There is, however, no sufficient evidence to warrant this assumption.

In the first place, it should be borne in mind that when the contact bed is full there is no longer any air in the interstices of the filter, the oxygen of which the nitrifying organisms can seize hold of to carry on their vital process.

It is possible, however, that prolonging the period of contact is useful in permitting the contents of the contact bed to become intimately mixed, thereby making the effluent more uniform. The analogous process of the working of percolating filters shows that nitrification takes place almost immediately. An actively nitrifying continuous filter, the passage of the sewage through which takes place in less than half-an-hour, produces a grain of nitrates per gallon in this time. It appears, also, from experiments quoted by Professor Frankland, that while the contact bed is resting empty highly oxygenated compounds are formed upon the surface of the particles of the filter, which yield their oxygen to the sewage the moment it comes in contact with the particles of the contact bed. The following figures were quoted by Professor Frankland at the Aberdeen Congress of the Royal Institute of Public Health. It will be seen from them that as much purification is effected by a five minutes' contact as by half-an-hour's contact.

	Potassium Permanganate required for oxidation of Sewage. Parts per million.
Raw Sewage	555
Effluent, after 5 minutes' contact ..	93·5
Effluent, after ½-hour's contact.. ..	93·5
Effluent, after 12 hours' contact ..	48·6

The same conclusion is borne out by the following experiments I have made with small experimental filters—the Burton sewage, previously clarified by lime, being used for the experiment. Effluents from contact bed filters taken at different periods of contact have yielded the following results:—

Nitrogen as nitrates. Parts per 100,000.

	1st Experiment.	2nd Experiment.	3rd Experiment.	4th Experiment.
With no contact	2·5	2·5	2·2	1·75
After 10 minutes contact ..	2·3	2·3	1·5	1·0
,, 20 ,, ...	2·0	2·0	1·0	·75
,, 30 ,, ...	1·5	1·3	·5	·3
,, 40 ,, ...	1·0	1·0	·3	nil
,, 50 ,, ...	·8	·75	trace	nil
,, 60 ,, ...	·75	·75	nil	nil
,, 1 hour 10 minutes ..	·6	·5	nil	nil
,, 1 ,, 20 ,, ..	·5	·5	·3	trace

From the above experiments and others, I think it is clear that what happens is that during the period of rest highly oxydised compounds are formed, including nitrates, and the first sewage which is applied to the contact bed washes these nitrates down to the bottom of the bed, and by locking the sewage up for two hours something is done to equalise the amount of nitrate in the various portions of the filter's contents. This is further proved by the fact that by pouring distilled water over a laboratory filter, worked on the contact principle, more than a grain per gallon of nitrogen as nitrates has appeared in contact bed effluent.

Again, when filters have been so overworked that the amount of nitrogen in the form of nitrates in the effluent has gradually been reduced from one grain per gallon to nothing, by allowing the filter to rest for a few days, the nitrogen in the form of nitrates immediately mounts up to three or more grains per gallon, even though the sewage does not remain in contact with the filter at all, but merely passes through it, the whole process taking only a few minutes.

The following are results illustrating this point, which have been obtained with the Burton Sewage on experimental filters :—

EXPERIMENTS SHOWING EFFECT OF RESTING FILTERS.

The figures give the Nitrogen as Nitrates in the Effluents expressed as Parts per 100,000.

EXPERIMENT **A.**

	With Laboratory Coal Filter.
April 6 ..	·5
" 7 ..	Trace
Filter resting 2 days	
April 10 ..	·2
" 11 ..	Trace
" 12 ..	Nil
Filter resting 5 days	
April 18 ..	3·5

EXPERIMENT **B.**

	Filter kept at 67° F.	Filter kept at 80° F.
May 29 ..	1·75 ..	1·5
" 30 ..	1·5 ..	1·3
" 31 ..	1·0 ..	1·8
June 1 ..	·6 ..	1·3
Filter resting 4 days		
June 6 ..	2·0 ..	3·0
" 7 ..	1·5 ..	2·5
" 8 ..	·9 ..	2·0

That the nitrifying bacteria and the other oxidizing organisms are most active while the filter is in its so-called "resting" stage is also supported by the observations of Mr. W. H. Harrison, B. Sc., recorded in the Leeds Report, that the temperature of the contact beds was 1·2 degrees higher before filling than after the sewage had been left in contact for one hour. The average temperature after the bed had been left resting was 64·5, while the temperature after the sewage had gone through the contact process was 63·3. These observations show that an active process of oxidation was taking place during the period the bed was supposed to be resting.

Automatic Appliances for working Contact Beds.

I therefore see no reason why an ordinary simple syphon should not be used to regulate the discharge from a contact bed; it will, however, be necessary to have the syphon placed in a small separate chamber, with holes at the bottom, permitting the passage of the effluent from the bed while the material from the filter is not disturbed.

Adams' automatic apparatus is a most ingenious arrangement whereby the sewage rising in one contact bed compresses air in a dome, cuts off the sewage from this bed, and applies it to another. The whole apparatus is perfectly automatic, and can be used for keeping the sewage in the contact bed for any length of time it is desired. The arrangement can be seen, at work at a small plant, at Killamarsh, in the Chesterfield Rural District, and is shown in Plate II.

The alternating gear devised by Mr. Cameron, of Exeter, is equally ingenious; the effluent from the filter rising in a chamber, lifts a counterpoised bucket, which in turn closes a valve, and diverts the sewage on to a second filter and unlocks the first contact bed.

Another arrangement is that of Messrs. Mather and Platt. The outlet of the contact bed is kept closed by the weight of fluid in the bed pressing against the valve. When the bed is full, the sewage overflows into a tank poised at the end of the long arm of a lever, and when a certain quantity has passed into the tank, the weight is sufficient to open the valve. They also have an arrangement for feeding the beds in regular succession. This consists of a tank in which there is a large float; the filling and the emptying of the tank by means of a syphon, causes the float to rise and fall; each time the float falls it turns a shaft round $\frac{1}{6}$th of a revolution. The shaft is armed with six cams, which in turn press upon different levers, opening valves supplying the different filters or contact beds. It is obvious that a similar arrangement, actuated by the effluent, might be used for holding sewage up in contact beds. This alternating gear is illustrated in Plate III.

Results obtained with Contact Beds.

DOUBLE CONTACT BEDS NECESSARY.

At Manchester, the results obtained on an experimental plant, worked on the same lines as the Exeter process, yielded an effluent from a *closed* septic tank which contained ·42 parts per 100,000 of Albuminoid Ammonia, and the Filtrate from a contact bed contained ·155 parts per 100,000 of Albuminoid Ammonia, by no means a good effluent. The sewage treated in an *open* septic tank yielded ·314 parts per 100,000 of Albuminoid Ammonia. This was passed through a coarse contact bed made of material which passed through a $\frac{3}{4}$-inch screen and rested on a $\frac{1}{4}$-inch screen. The Albuminoid in the effluent from this first contact bed was ·15 parts per 100,000 of Albuminoid Ammonia. It, therefore, became necessary to pass this effluent through a second contact bed which was made of material which passed through a $\frac{1}{2}$-inch screen and rested on a $\frac{1}{8}$-inch screen. The result was, that the final effluent contained ·064 parts per 100,000 of Albuminoid

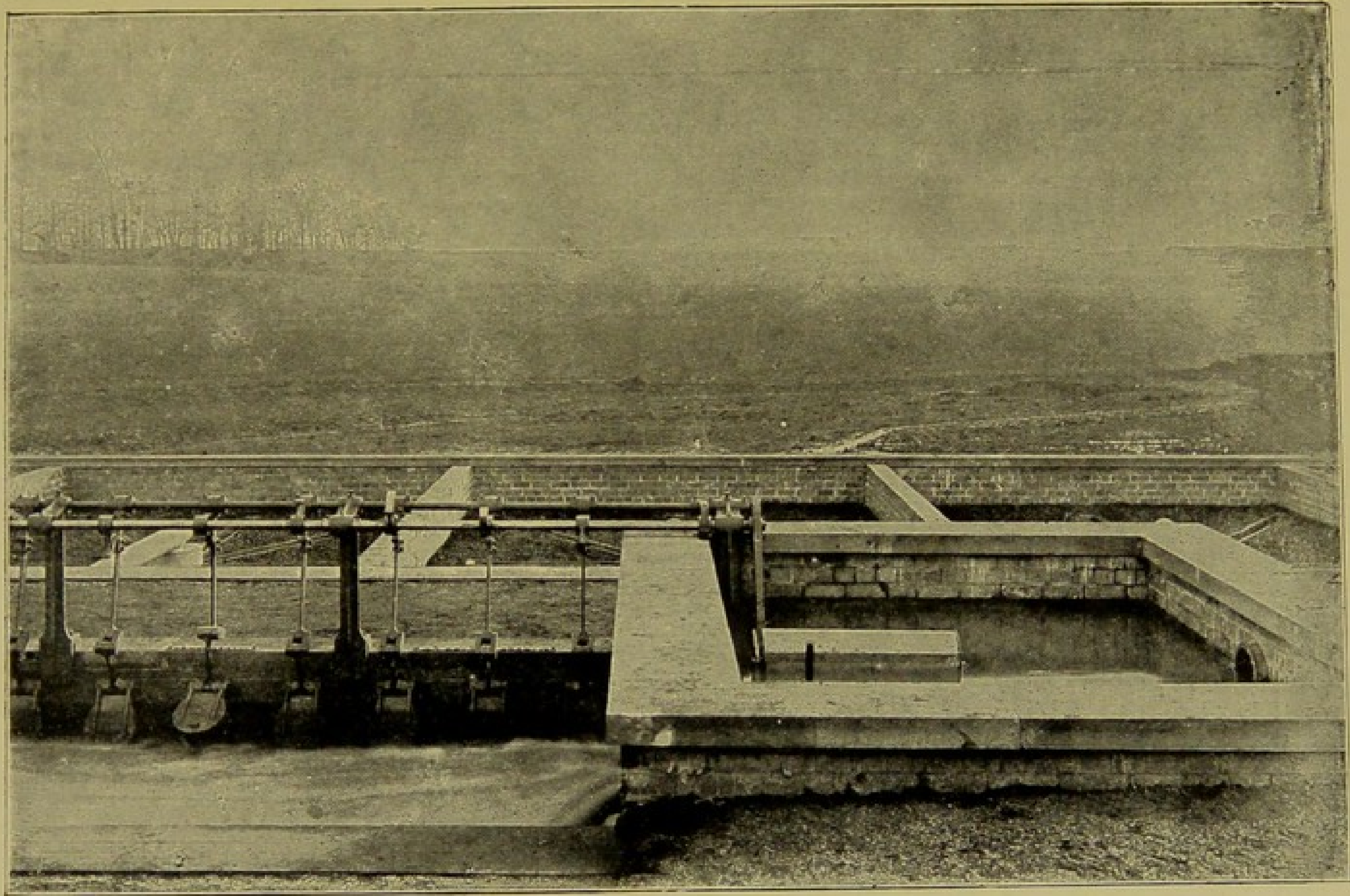


PLATE III.—MATHER & PLATTS' AUTOMATIC ALTERNATING GEAR FOR CONTACT BEDS AND CONTINUOUS FILTERS.

Ammonia. The names attached to the Manchester Report are a sufficient guarantee of the accuracy of the experiments, and they may be held, as the Committee sitting on the Derby Extension Bill of 1901, evidently held them, as proving that where the process of purification consists of septic tanks and contact beds *double contact is necessary.*

The results obtained at Leeds with sewage which was screened and then merely filtered through contact beds without the intervention of a septic tank show that an effluent containing ·07 parts per 100,000 of Albuminoid Ammonia can be obtained when the contact beds are only filled twice a day. I ought to point out, however, that the effluent which gave these results was settled, and *that the suspended solids were not included in the analyses.*

At Sheffield, the settled Sewage is being treated without the intervention of a septic tank, on two bacteria beds, which are being worked three fillings a day at about the rate of 100 gallons per square yard per day.*

The Albuminoid Ammonia in the effluent is ·077 parts per 100,000, while the Oxygen absorbed in three minutes before incubation is ·02, while after incubation it is ·021, the putrescibility being practically *nil.*

The results of my analyses of the sewage at Kimberley, which is a particularly strong one, may be expressed as follows :—

	PARTS PER 100,000.	
	Albuminoid Ammonia.	Nitrogen as Nitrates.
Raw Sewage	2·3	Nil
Open Septic Tank Effluent ..	·6	Nil
Effluent from Coarse Bed ..	·13	·4
Effluent from Fine Bed.. ..	·09	·8

* I am indebted to Mr. Wike, C.E., the City Engineer, for the following details :—

The coarse bed is 5,000 square yards and is 5 feet deep.

The fine bed is 4,500 square yards and is 5 feet deep.

The volume of sewage by three fillings a day is about 900,000 gallons.

This bears out the suggestion made on a previous page that a quarter of the total capacity of a contact bed should be taken as its working capacity when no septic tank is used.

The cost was £5,000, including £1,500 for coke.

The Kimberley Sewage contains a large amount of brewery waste. The septic tanks are open, but the first has automatically closed with a hard scum which is largely composed of the corks from beer barrels. This scum is so thick and firm that it is possible to walk across it. In this case, again, anything short of septic tanks and double contact would, in my opinion, fail to purify the sewage. The tanks in question probably, however, do not hold more than a third of a day's flow.

The following table gives the results I have obtained from the single contact beds at Exeter:—

	PARTS PER 100,000.					
	Total Solids.	Free Ammonia.	Albuminoid Ammonia.	Nitrates.	Nitrogen as Nitrite, and Nitrates.	Chlorine.
Sewage	63·0	1·60	·48	Nil	Nil	5·6
Septic Tank Effluent	65·6	4·00	·25	Trace	·13	6·3
Filtrate	65·2	·185	·09	Nil	2·00	5·6

It will be noticed that the Exeter Sewage is a particularly weak one, and for such sewage single contact beds would be satisfactory.

At Chesterfield, double contact beds and an intermittent percolating filter worked by means of a Shone's Ejector were put down side by side. They were both constructed of destructor breeze, which was crushed to the same size, namely, $\frac{3}{4}$-inch to about $\frac{1}{4}$-inch. The Albuminoid Ammonia in the effluent from the percolating filter is about ·06 to ·07 parts per 100,000, while that in the effluent from the contact beds was over ·11. The Sewage Committee were so satisfied of the superiority of percolating filters that they have ceased to use the contact beds, so that at present no figures of prolonged comparative tests are available for comparing the two processes of double contact and single filtration.

CONCLUSION WITH REGARD TO CONTACT BEDS.

Where sewage is previously submitted to liquefaction in a septic tank either open or closed, or a subsidence tank, in conjunction with a lateral or upward flow bacteria bed, a

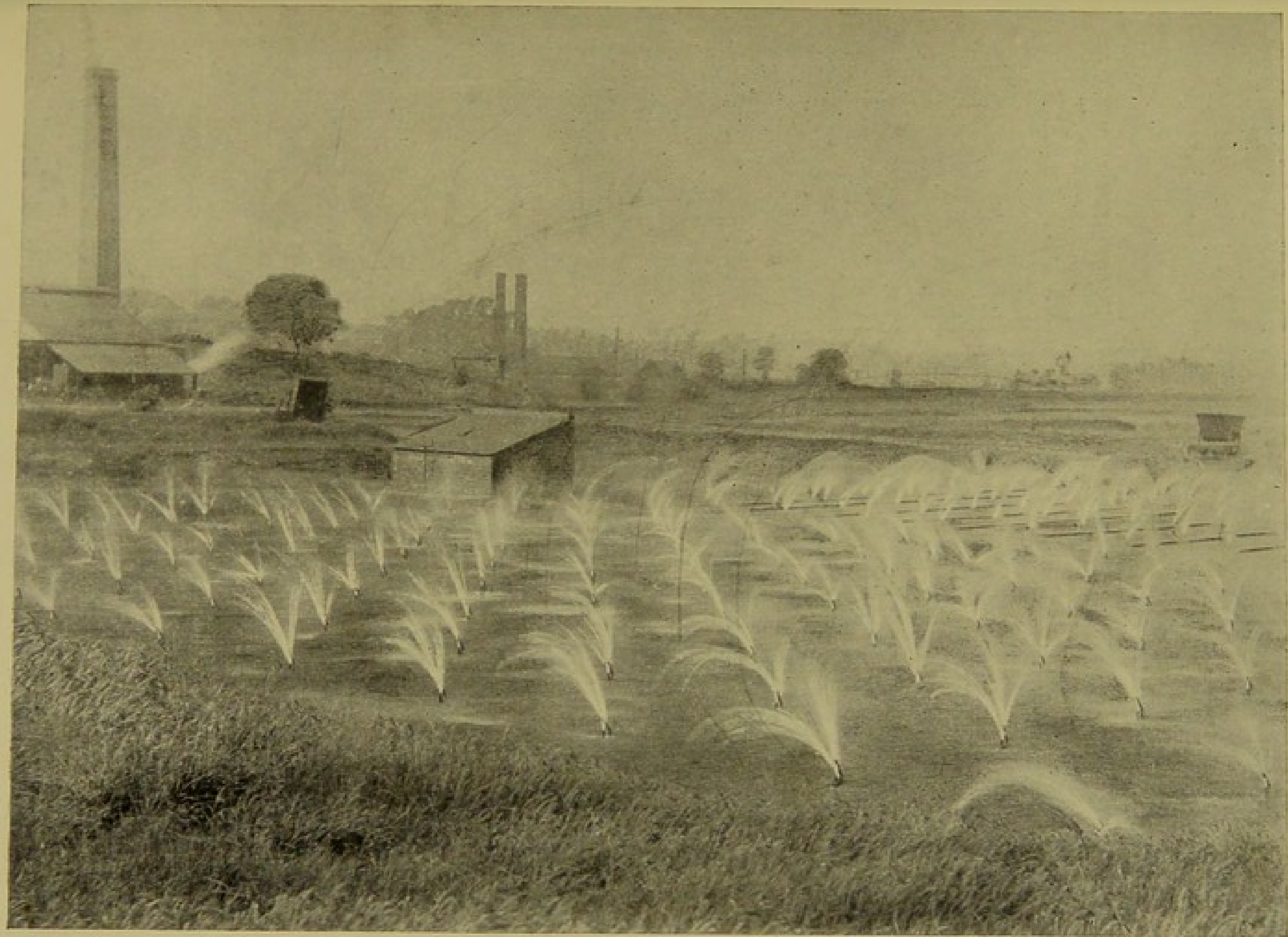


PLATE IV.—CHESTERFIELD INTERMITTENT PERCOLATING FILTER.

satisfactory effluent can be obtained by means of double contact beds worked with three fillings a day. If the plant for the preliminary treatment of the sewage is curtailed, contact beds can only be relied upon when worked with two fillings a day, and consequently the area to be provided must be increased 33 per cent.

When, however, the sewage for any particular reason is exceptionally weak, and an adequate septic tank space is provided in conjunction with a small upward flow or lateral filter, single contact beds may be sufficient, if the sewage is properly distributed and the filter material is small.

Percolating Filters.

The Commissioners in their Report speak of two artificial filtration processes—Contact Beds and Continuous Filtration.

In this book I have adopted the phrase "Percolating Filters," instead of that of "Continuous Filters," because some of the continuous filters are worked intermittently, and intermittent continuous filtration is a verbal contradiction. Doubtless the expression "continuous filtration" has been adopted in contra-distinction to contact beds, the outlets of which are closed, and which have two or three fillings a day. With continuous or percolating filtration the outlet of the filter is open all the time, the sewage being distributed over the surface of the filter bed through perforated pipes or some other arrangement percolates uninterruptedly through the filter and out at the bottom, the process taking place in the free presence of air. To enable as much air as possible to enter the filter, the supply of the sewage to the filter is frequently made intermittent, the sewage being distributed over the surface of the filter in thin films or single drops. The films of sewage soaking down into the filter displace the air in front and draw air in after them. This intermittency of action is to be encouraged in every way. It appears to me that the expression "Intermittent Percolating Filters" most correctly describes the arrangement, which, I believe, gives the best results.

The process of purification by intermittent filtration can best be understood by a careful study of the Chesterfield filters, shown in PLATE IV. The filters here are two in number, each with an area of 616 square yards, the area of the two being a little over a quarter of an acre. Between the two filters is a Shone's ejector, from which an iron main supply pipe passes to each filter, and branch mains pass over its surface. The branch mains, which are perforated every four feet, become less and less in size. Each time the ejector goes off, 100 gallons of sewage is propelled through the perforated holes in the distributing pipes by means of the compressed air working the ejector. The sewage which is driven out through the holes impinges with a decreasing force against pieces of hoop iron, which are bent round the distributing pipe. This arrangement is well shown in PLATE V. The ejector takes less than ten seconds to drive out 100 gallons of sewage, and it is sprayed all over the surface of the filter. One filter has been constructed of coal, the other of destructor breeze. Both give excellent results, which have continued to improve ever since the filter was started two years ago. The filter is under-drained by perforated pipes, and has no concrete floor or retaining walls. There are no ventilating pipes leading to the effluent drain, yet there is always a good current of air coming out at this pipe. This air must have passed through the filter along with the sewage On the 14th and 15th of August this year I carefully measured the amount of air blowing out at the effluent drain, and fonnd that it varied considerably with the atmospheric conditions in different readings from 80 to 140 cubic feet a minute. Sewage was being applied to the filter at the rate of 100 gallons a minute, while the air coming out of the effluent drain was from 500 to 900 gallons per minute, that is to say, there is with this filter five to nine times the amount of air available for the oxygenation of the sewage than is the case with a contact bed.

Samples of the air coming out at the effluent drain of this filter have been carefully analyzed by me, and give the following results :—

ANALYSIS OF AIR PASSING FROM EFFLUENT DRAIN OF CHESTERFIELD PERCOLATING FILTER, COMPARED WITH ATMOSPHERIC AIR.

	Effluent Drain Air.	Atmospheric Air.
Oxygen	19·20 to 19·5	20·96
Carbon Di-oxide	·5 to 1·7	·04
Nitrogen (by exhaustion)	80	79·00
Excess of Carbon Di-oxide	·5 to 1·7	
Oxygen given up to Sewage	·76 to 1·76	

PLATE V.—CHESTERFIELD DISTRIBUTOR.

It is on account of the very rapid intermissions in the application of the sewage to the filter that this large excess of air has been introduced into the body of this filter. The change which was being effected in the sewage which was being applied to the filter is shown in the following result of the analyses of the Chesterfield sewage before and after filtration. The results are the counterpart of the analyses of the air.

	Albuminoid Ammonia.	Incubator Test. Oxygen absorbed in 3 minutes at 80° F. A Before Incubation.	Incubator Test. Oxygen absorbed in 3 minutes at 80° F. B After Incubation.	Putrescibility, B—A.	Nitrogen as Nitrates.	Relative Alkalinity as Carbonate of Lime.
	PARTS PER 100,000.					
Tank Effluent applied to Filter	·56	2·7	4·8	2·1	Nil	40·5
Filtrate from Coal Filter ..	·05	·01	·01	Nil	2·0	20·5
,, Destructor Breeze Filter	·04	·01	·01	Nil	2·1	20

It will be noticed that the result of the oxygenation of the sewage is that the nitrogenous organic matter as indicated by the albuminoid ammonia is reduced 91 and 92 per cent., while sufficient oxygen is added to prevent the effluent undergoing putrefaction. This oxygen is partly present in the form of nitrates, two parts per 100,000 of nitrogen being completely oxidised into the form of nitrates, while the carbohydrates and other organic matter is oxidised into organic acids, so as to effect a reduction of 50 per cent. in the alkalinity of the sewage estimated as carbonate of lime.*

Plate IV. shows the Chesterfield Intermittent Percolating Filter at the moment the Shone's Ejector is discharging, while Plate V. shows the detail of the spraying arrangement. This form of spray is also suitable for the distribution of the sewage by automatic flushing tanks or tipplers.

* I find a ready method of ascertaining the work a biological filter is doing is estimating before and after treatment the alkalinity as carbonate of lime, by deci-normal sulphuric acid, using methyl orange as an indicator. A daily record of this should be kept at all sewage works. The operation takes five minutes.

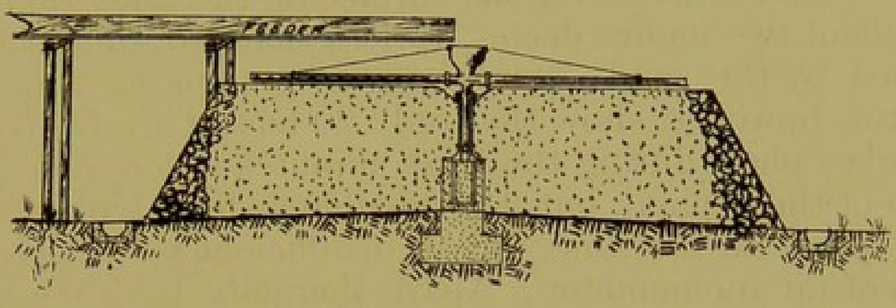
Having examined the degree of aeration obtained at Chesterfield by means of intermittent percolating filters, which are not covered with sand, it will be worth while to examine the results obtained with a filter which is covered with sand. For the point to be investigated the Dronfield filters were taken. Here each filter has an area of 294 superficial feet. The sewage accumulates in an automatic flushing tank, 5ft. square and 2ft. deep, so that every time the syphon discharges 50 cubic feet of sewage is distributed over the surface of the filter and forms a layer about two inches deep. In less than two minutes, this is absorbed by the sand: careful investigations at the outlet of the filter, however, show that only 20 feet of air is driven out. This takes place during the three minutes succeeding the discharge of the syphon, but it is possible a slight current of air is taking place all the time, but is insufficient to be detected by means of an anemometer. Apart, therefore, from the practical difficulty resulting from the sealing of the surface of the filters covered with sand, there is no doubt that the layer of sand should be avoided if possible, but if for any reason, such as absence of fall, the sand distributor is deemed necessary, its surface should be perforated by numerous sanitary pipes carried above the water level, so as to permit of the passage of the air into the body of the filter.

The proper distribution of the sewage is the all-important point. Apart from this, all that is necessary is a heap of clean hard clinker or other suitable hard material, either thrown upon the surface of the ground without retaining walls, or thrown into a hole in the ground, the size of the material being between one-quarter and three-quarters of an inch diameter, the top six inches being between one-eighth and half an inch, the whole filter being some 4ft. 6in. deep, and absolutely free from dust, and, in fact, of all material less than one-fourth of an inch. These details are of such importance that they cannot be repeated too frequently.

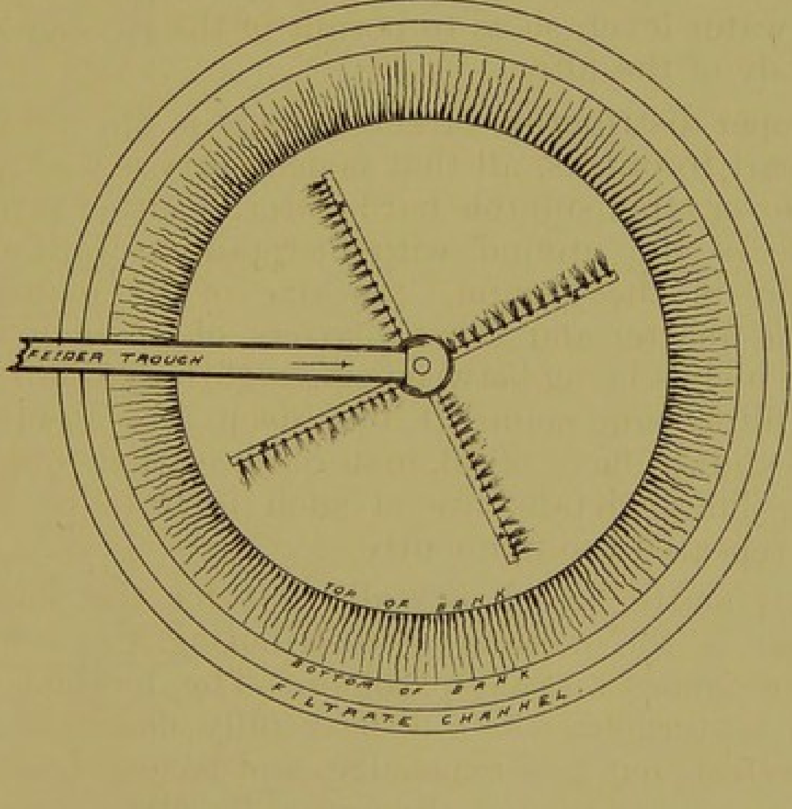
The only matter which is really left for the ingenuity of the engineer is the method of distributing the sewage: but this is by no means an easy problem. The method of distribution at Chesterfield, which I have fully described, is theoretically perfect, but it is expensive, and is out of the question except where an ejector has to be used for other reasons.

What has to be accomplished is to apply a definite quantity of sewage to every square yard of filter in an intermittent

PERCOLATING FILTER WITH REVOLVING DISTRIBUTOR



SECTION.



PLAN.

manner. When the filters are 4 feet deep, the amount should be about 250 gallons per diem, more or less, depending upon the strength of the sewage.

As far as the intermissions are concerned, the tendency is to make the cycles of work and rest shorter and shorter. The intermissions are generally effected by means of automatic tipplers, or automatic flushing tanks, which may be actuated by floats or syphons, clock work, which alternately turns the sewage on and off by means of revolving taps, or, instead of clock work, the force of the sewage itself can be utilized by means of water wheels; turbines, or the revolving outlet known as Barker's Mill, which is the principle involved in the familiar American sprinkler used for watering lawns.

A revolving sprinkler is shown in Diagram II. The Frontispiece shows the works for the village of Heath, which have been designed by Mr. E. Lines, C.E., the sewage engineer of the Chesterfield Rural District Council. The block fully shows how the apparatus works, and hardly any description is necessary. The revolving perforated arm reaches right across the circular filter, and is self-propelled by the sewage running out through the perforated pipe. This revolving arm is not in action all the time, the sewage accumulating in a tank; as soon as it is full, some of the sewage syphons over into a vessel which counterpoises the outlet valve of the tank, as soon as this vessel receives a given weight of sewage it lifts up the valve and the tank empties into the revolving distributor, the counterpoise gradually emptying so as to be ready for the next discharge. Obviously, revolving distributors require circular filters. It would be even better to make them hexagonal, the six corners being used for aerating purposes. Expensive retaining walls are unnecessary, and several filters would fit into each other honeycomb fashion.

Plate III. shows Messrs. Mather & Platts' Automatic Distributor, which may be used with perforated pipes for percolating filters, or, as shown in the plate, for contact beds.

Another ingenious distributor is that invented by Mr. Stoddart, F.I.C., of Bristol. This arrangement is shown in Plate VI. and consists of perforated corrugated iron, the corrugations on section showing like repeated M's. The holes are at the top apex, and from the bottom part of the M a series of points project, from which the sewage drips in intermittent drops. This distributor requires less fall than any other I am acquainted with. To be successful it must be set dead level.

In Colonel Ducat's filter, a very similar arrangement is adopted, the distributor consisting of narrow iron girders with V-shaped notches. Also, the walls of this filter consist of agricultural drain pipes, the outer ends of which are slightly raised so that the air may continually blow into the body of the filter.

Where the sewage is pumped, obviously the simplest method of diverting the sewage to different filters and making each intermittent is by intermissions in the pumping, and working the filters as the pumps are worked in different shifts. For large schemes, Mr. Scott Moncrieff has devised large distributors which move on rails and automatically distribute the sewage as required.

It is claimed that there is a great advantage in warming the sewage by means of injecting steam, but my own investigations* have led me to conclude that this course has no practical advantage, and that nitrification absolutely stops at a temperature of 110 degrees F.

Tabulated below are some of the results which have been obtained by means of percolating filters. Speaking generally, it will be seen that they are better than the results obtained by contact beds, even when the sewage has been filtered twice by this method.

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* The first suggestion for warming filters, I believe, was made by myself from purely theoretical considerations.—*Vide* "Journal of State Medicine," Nov., 1896, p. 505.

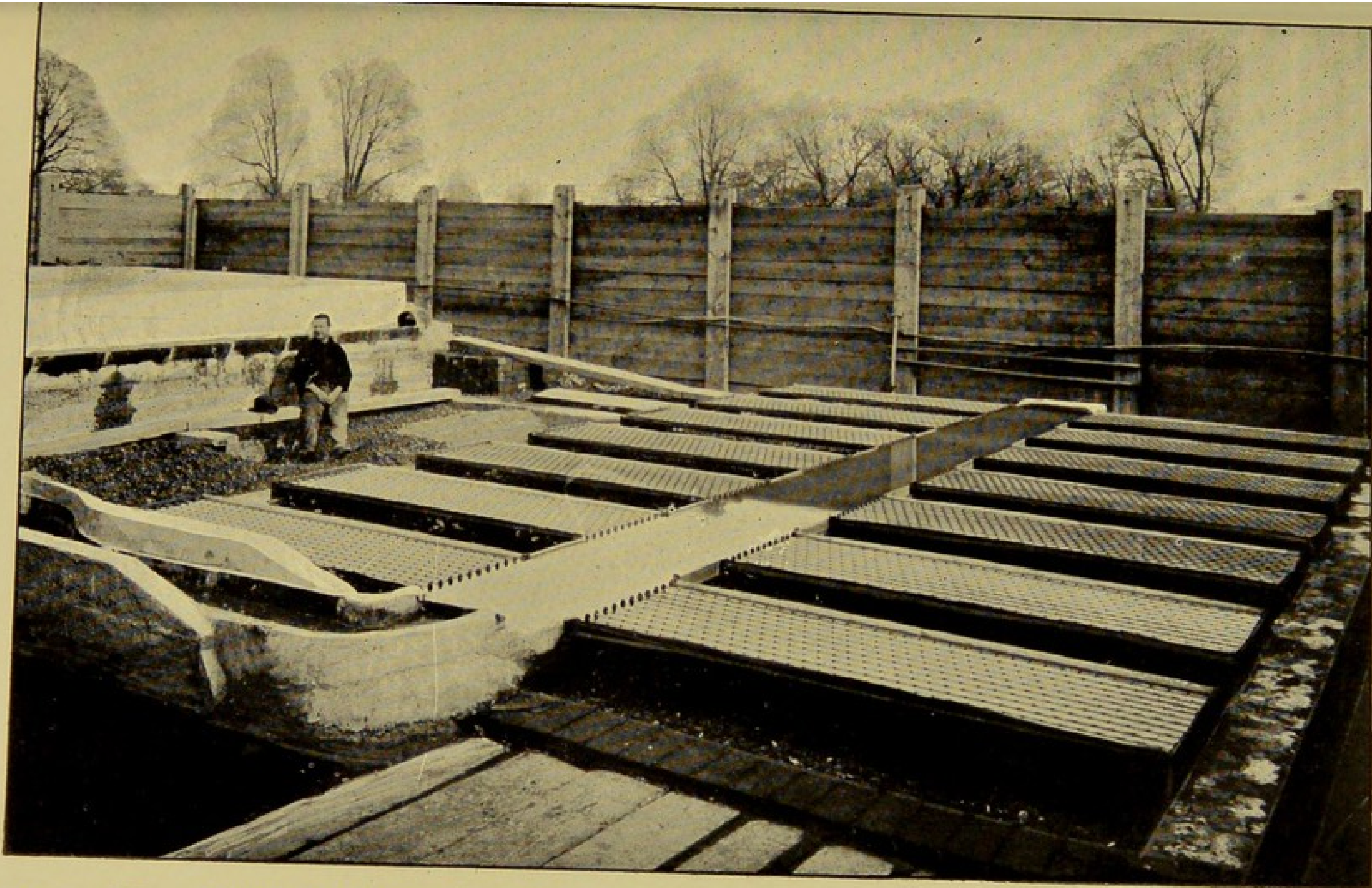

PLATE VI.—FILTER WITH STODDART'S CONTINUOUS DRIP DISTRIBUTOR.
The Sewage applied in intermittent drops.

Results obtained by Percolating Filters.

Worked at the rate of Half-a-million Gallons per acre per day.

Parts per 100,000.

CHESTERFIELD.

Date.	Albuminoid Ammonia.	Nitrogen as Nitrates.
Tank effluent	·38	Nil.
1899.		
June 9	·08	
,, 14	·10	
,, 15	·08	
,, 29	·10	
,, 30	·06	·8
July 11	·08	1·2
,, 19	·08	
,, 26	·04	
Aug. 3	·08	
,, 10	·10	
,, 12	·06	
,, 17	·08	
,, 24 to 29	·08	
,, 31	·10	
Sept. 15	·12	
Oct. 31	·08	
Nov. 2	·08	
Dec. 12	·06	
,, 14	·06	
1900.		
Jan. 1	·10	1·5
May 17	·10	1·25
Sept. 7	·08	
Oct. 12	·05	1·0
,, 15	·04	1·5
Dec. 10	·04	
1901.		
Jan. 17	·08	1·3
,, 28	·06	1·8
March 5	·04	2·5
,, 10	·10	
April 23	·06	3·1
May 14	·05	2·2
July 1	·03	5·0
Aug. 16	·05	2·0
AVERAGE	·07	1·93
Per centage of Purification	81·5	

BURTON.

Date.	Albuminoid Ammonia.	Nitrogen as Nitrates.
	·25	Nil.
1900.		
May 29	·10	1·3
June 1	·04	1·5
,, 7	·06	1·5
,, 8	·06	1·75
,, 9	·04	1·75
,, 11	·05	1·5
,, 13	·05	1·3
,, 14	·04	1.25
,, 19	·04	1·7
,, 20	·04	1·5
,, 21	·04	1·3
,, 22	·05	1·3
,, 23	·06	1·0
,, 25	·07	·2 *
,, 26	·04	·4
,, 27	·04	·45
,, 28	·05	·4
,, 29	·05	·4
,, 30	·04	·4
July 2	·04	·25
,, 3	·05	·3
,, 4	·04	·25
,, 5	·04	·25
Filter partially rested to enable Nitrifying Organisms to recover.		
Aug. 14 to 18	·04	1·56
,, 20 to 25	·04	1·42
,, 27 to Sep. 1	·04	·30 †
Sept. 3 to 8	·04	·26
,, 10 to 15	·04	·26
,, 17 to 22	·04	·23
,, 24 to 28	·06	·24
	·047	·82
	81·2	

* During June the rate of filtration was increased from 100 to 200 gallons per square yard, and the nitrates began to diminish.

† Sewage contained 5 grains per gallon of free lime.

I have set out *in extenso* the results obtained at Chesterfield and Burton, because both these sewages are extremely difficult to treat. The Chesterfield sewage contains waste from tanneries and breweries, and the Burton sewage contains a large amount of brewery waste, which rapidly undergoes decomposition, with the production of a large amount of sulphuretted hydrogen.*

At Buxton the average amount of albuminoid ammonia in the effluent from a percolating filter is ·04 parts per 100,000. The average from three samples obtained at Wolverhampton is ·08. The average of twelve samples from Long Eaton is ·06. The results at Long Eaton are interesting, because the filter is constructed of the slag from the Stanton Ironworks, a material which is generally supposed to be unsuitable for the construction of biological filters on account of the trace of sulphur that it contains.

Although I have only referred to the albuminoid ammonia it should be clearly understood that I am not basing my opinion on this one factor, but upon this in conjunction with the incubator test, the amount of nitrogen as nitrates, and the freedom of the effluent from suspended matter.

Set forth below are analyses of average effluents from percolating filters which have recently been made, the filters working at an average rate of 200 gallons per square yard per day.

	Albuminoid Ammonia.	Oxygen absorbed in 3 min. at 80° F.			Nitrogen as Nitrates	Depth through which pearl type can be read	Remarks.
		Before Incubation	After Incubation	Putrescibility measured as oxygen required			
						ins.	
Langwith	·02	·03	·03	nil	·4	over 12	Clear and sparkling; keeps well
Chesterfield Borough ..	.06	·01	·01	uil	1·8	" 12	"
Long Eaton	·08	·01	·01	nil	·6	" 12	" "
Buxton (Experimental Filter)	·03	·01	·01	nil	·25	" 12	" "
Dronfield	·03	·09	·07	nil	1·3	" 12	" "

The figures refer to parts per 100,000.

* This sulphuretted hydrogen is neutralized with lime, so as to prevent aerial nuisance. The clarified sewage, containing some 5 to 8 grains of free lime, was distributed over a percolating filter. No nitrification, however, took

Such effluents as the above are examples illustrating the truth of the conclusion of the Royal Commission, that "By artificial processes alone it is practicable to produce effluents which will not putrefy, which could be classed as good according to ordinary chemical standards, and which might be discharged into a stream without fear of creating a nuisance."

Although the bacterial treatment of sewage is so satisfactory from a chemical point of view, yet the researches of Houston and others have proved that they cannot be relied upon to remove pathogenic organisms. Where, therefore, an effluent is to be discharged into a stream above the intake of a water company, the effluent should be continuously strained through a sand filter working at the rate of 500 gallons per square yard per day.

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place. The lime was next neutralized, and nitrates appeared in the effluent, and when the limed sewage was again used without being neutralized, the nitrates began to diminish. This point is worth recording as showing that large amounts of lime are harmful to the nitrifying process.

SECTION V.

CONCLUSION.

What Bacterial Process should be adopted?

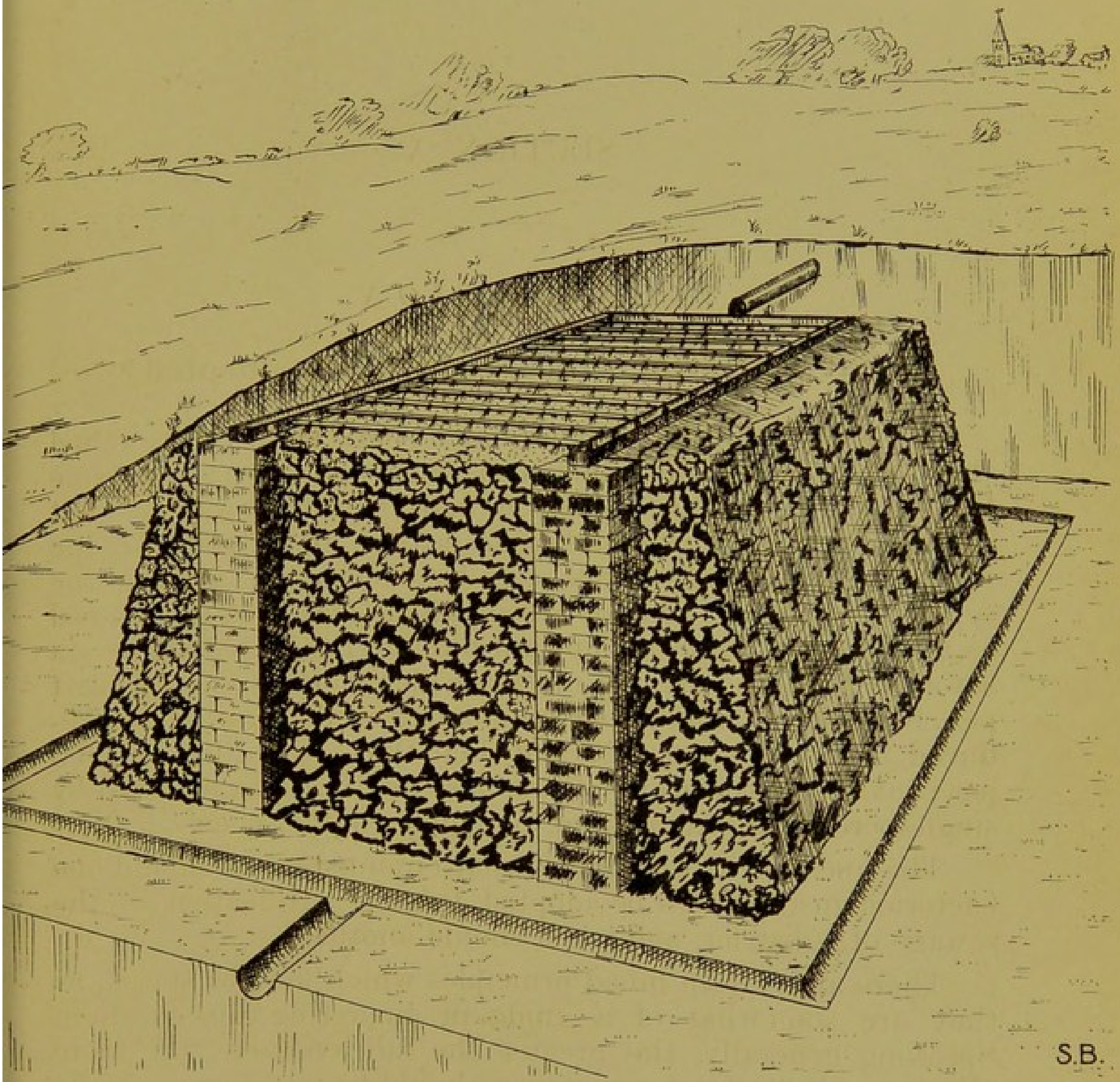
We have seen that open or closed septic tanks can be relied upon (i) To liquefy the solids in suspension, and (ii) at the same time reduce the organic polluting matter in the sewage. That a further reduction, amounting to nearly 50 per cent. of the remaining polluting matter can be effected by passing the sewage through an anaerobic bed, which may be a lateral bed as at Chesterfield, or an upward filter. By these changes a sewage containing organic matter which would yield 1·0 part per 100,000 of albuminoid ammonia, would first be so reduced as to yield, say, 0·5, and then 0·3. Finally, some 90 per cent. of purification of this last fluid can be effected by single percolating filters, and by double contact beds,

The question arises, under what circumstances should one bacteriological process be adopted for the purification of the sewage of a district, and when should another?

There are certain broad principles which may be stated, as they are somewhat of a guide in answering this question. Speaking generally, the greater the fall available, the more filtration (multiple, if necessary) should be relied upon. The less the fall, the larger the capacity of the septic tanks and anaerobic beds should be, so as to leave as little work as possible for the shallow filters.

I. In the first place, detritus tanks and screens should under all circumstances be employed.

II. Next, it should be borne in mind that the more fall which can be obtained at the outfall works, the simpler the purification plant, the more thorough the process of aeration, DIAGRAM 3.



MODERN BIOLOGICAL FILTER WITH OPEN WALLS
(CONTINUOUS DRIP.)
PARTICLES INSIDE ¼" TO ¾"

and the easier the task of obtaining a good effluent. The outfall sewer should therefore be laid with just sufficient fall to make it self-cleansing. No fall should, however, be wasted. For this reason, it is always advisable, whenever it is possible, for the outfall sewer to be brought to the outfall works in an embankment as high above ground as convenient.

III. Where there is a large amount of fall at the outfall works, say 20 or 30 feet, the sewage may be purified by multiple filtration *without any septic tank*, the effluent from the first bed being collected in a tippler or automatic flushing tank, and then distributed by perforated pipes or by a continuous drip distributor over a second bed, and so on over a third, the first bed being a coarse one, and the subsequent filters gradually finer. The filters need only consist of heaps of clean clinker, etc., without retaining walls, as shown in Diagram III., the distributors being supported above the filter and the sewage being sprayed all over the surface.

IV. Where there is a moderate fall, a septic tank, say to hold half the daily flow, and a lateral flow bed to hold one-third of a days flow, in conjunction with percolating filters, is a scheme which will utilize a fall of about 10 feet to the greatest advantage. When less than 10 feet is available, the capacity of the liquefying portion of the plant (septic tanks and anaerobic bed) should be increased, so as to lessen the work to be done by the filters. Diagram IV. gives details of a typical scheme for a population of 1,000. Diagram V. gives details of schemes for populations of 100 and 2,000.

V. When, however, there is extremely little fall, say only four or five feet, the maximum amount of purification that can be effected by the anaerobic bacteria should be aimed at. The septic tank itself requires no fall, nor is a fall wanted for an upward flow filter or a lateral filter. A septic tank should therefore be constructed capable of holding at least a day and a half's flow. The effluent from the septic tank shonld also be passed through a lateral bed capable of holding half a day's flow. The sewage should be admitted to the lateral bed through a strainer of fine material, as shown in Diagram IV. The effluent from the lateral bed should then be conducted to a distributing chamber and then either to such a filter as Stoddart's, as shown in Plate VI., or by perforated pipes over contact beds, the top layers of which for this purpose should be made of material from one-fourth to half-inch in size, the rest of the bed being of material between one-quarter and three-quarter inch in size. The effluent rising in the effluent chamber should be utilized to work the contact beds in rotation by some such mechanism as Cameron's or Adams'.

It will be noticed that in this case it is suggested that single contact beds, in conjunction with the septic tank and a lateral bed, are sufficient, but it should be understood that a sufficient area of contact bed must be provided, under these circumstances, to work with two fillings a day, and that the sewage should be uniformly distributed by perforated pipes or a Stoddart's distributor over the whole surface of the contact bed. By such a scheme a satisfactory effluent could be produced, although only four or five feet of fall is available at the purification works, and by this means the expense of pumping could be avoided.

VI. When it is necessary to pump the sewage, advantage should be taken of this fact to apply the sewage intermittently to the filters by starting and stopping the pumps or by working in shifts. To enable this to be done wherever the the engineering aspect of the question permits, the sewage should be allowed to gravitate through the septic tank or anaerobic bed, both of which require a slow continuous movement of the sewage, and it should not be pumped until after it has been screened and liquefied. The motive power used for pumping should be also employed for spraying the sewage and making the intermissions in its application. For this reason, if a Shone's ejector is employed to lift the sewage, it should also be used to spray the sewage over the filter, as is done at Chesterfield.

VII. Lastly: coarse storm water filters to work at the rate of 500 gallons per superficial yard must be constructed in every case; 180 yards superficial being provided for every 1,000 inhabitants.

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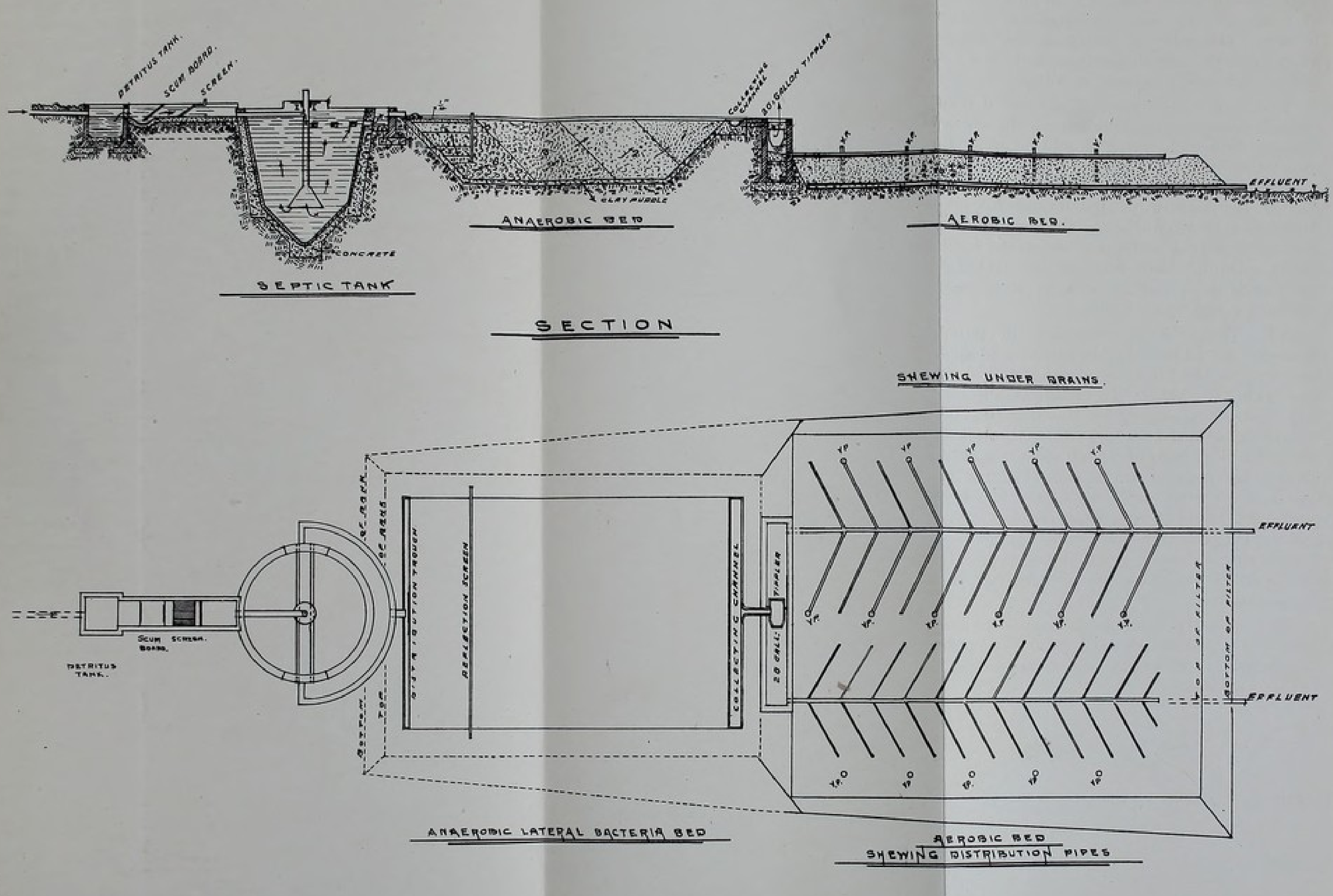
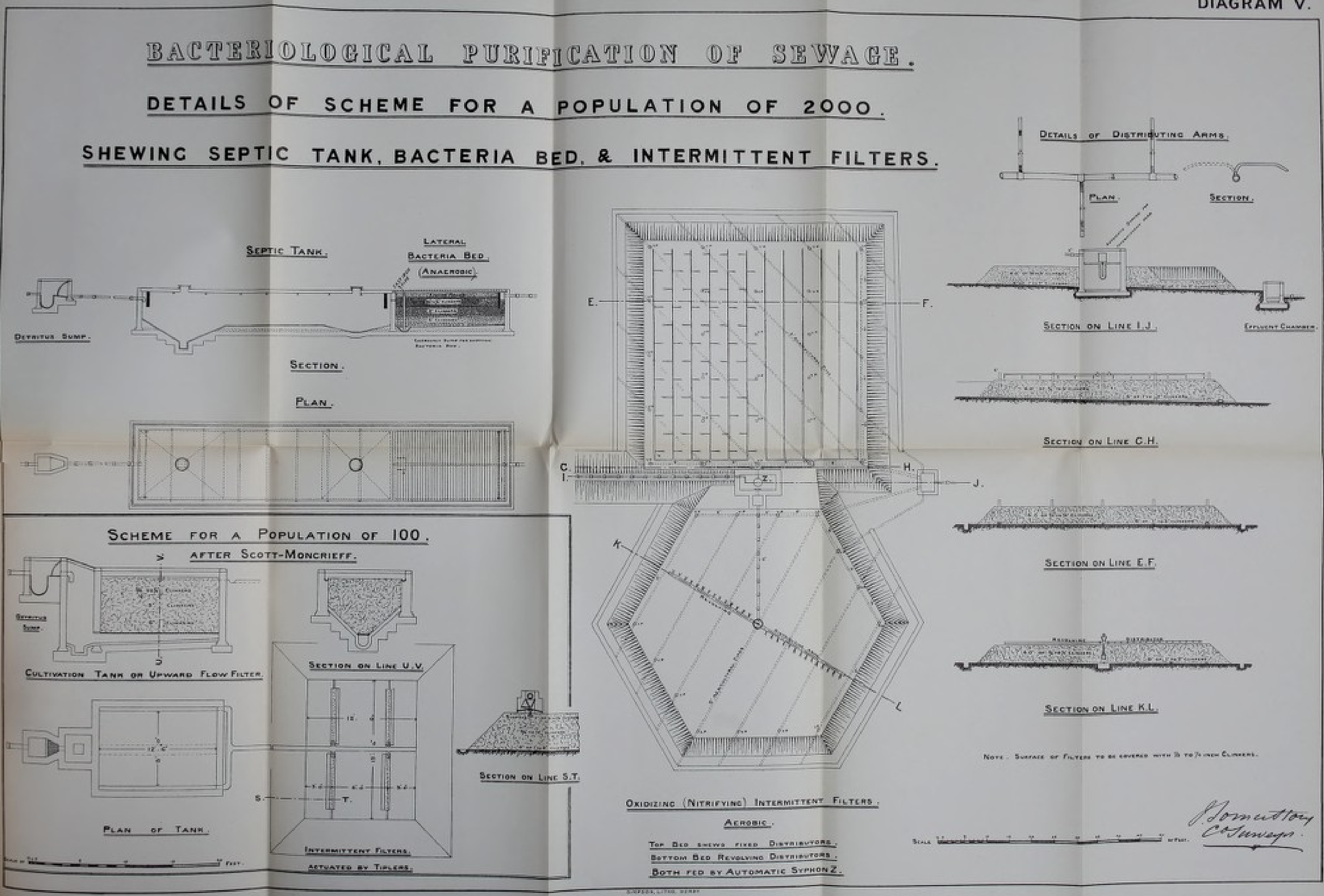
Diagram 4.

Diagram shewing Sewage Purification Plant for a Population of 1,000



SCALE 16 FEET TO 1 INCH.

DIAGRAM V.



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Lateral Bacteria Bed.
(Anaerobic).
Detritus Sump.
Section.
Plan.
Scheme for a Population of 100.
after Scott-Moncrieff.
Cultivation Tank or Upward Flow Filter.
Section on Line U.V.
Section on Line S.T.
Plan of Tank.
Intermittent Filters.
Actuated by Tiplers.
Oxidizing (Nitrifying) Intermittent Filters.
Aerobic.
Top Bed shews fixed Distributors.
Bottom Bed Revolving Distributors.
Both fed by Automatic Syphon Z.
Details of Distributing Arms.
Plan.
Section.
Section on Line I.J.
Effluent Chamber.
Section on Line C.H.
Section on Line E.F.
Section on Line K.L.
Note. Surface of Filters to be covered with ½ to ¾ inch Clinkers.
Scale

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