RECENT IMPROVEMENTS

IN METHODS FOR THE

BIOLOGICAL TREATMENT OF SEWAGE.

WITH A DESCRIPTION OF THE AUTHOR'S

MULTIPLE SURFACE BIOLOGICAL BEDS,

(Patent No. 16851. 1903)

FOR EFFECTUALLY DEALING WITH

SUSPENDED MATTERS,

With Aërobic Action throughout.

BY

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

Formerly Chief Chemist to the Metropolitan Board of Works and the London County Council;
Past Vice-President of the Society of Public Analysts;
Fellow of the Royal Microscopical Society;
Fellow of the Royal Sanitary Institute, &c.

SECOND EDITION,
REVISED AND ENLARGED.

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FIG. 1. BACILLUS TYPHOSUS. × 2500. *Photo by* W. J. DIBDIN.

Powell & Lealand $\frac{1}{12}''$ Apochromatic Oil Immersion, Apochromatic Condenser, Clifford's Screen and Limelight.

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1907.

PREFATORY NOTE.

The following condensed account of the rise and progress of modern methods of effecting the Purification of Sewage, particularly in regard to the inoffensive disposition of the sludge by Biological agency unaided by chemical processes, has been written to meet the repeated requests for some such statement, and to embody as succinctly as possible an account of improvements effected by the Author since the publication of the third edition of "The Purification of Sewage and Water." In fact these pages may be looked upon, in some respects, as a supplement to that work, and show how the sludge difficulty is overcome as the result of Laboratory, followed by Works, practice.

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June, 1907.

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RECENT IMPROVEMENTS

IN METHODS FOR THE

BIOLOGICAL PURIFICATION OF SEWAGE.

The first practicable method of purifying sewage water by means of bacteria, &c. was that worked out by the experimental operations initiated and developed at the Northern Outfall Works of the London County Council at Barking Creek. Many suggestions had been made, and much work done, particularly by the Massachusetts State Board of Health, but no practicable method had been placed before the public until, in pursuance of my work in connection with the purification of the River Thames, upon which I had then been engaged since the year 1878, I devised and carried out the contact bed system at Barking Creek. The success which attended these experiments was followed by an extension of the principle at the works of the Sutton District Council, on my suggestion, and since then the process has spread with remarkable rapidity.

The various modifications proposed with the view of effecting improvements may shortly be summed up by a consideration of the two chief alternative methods, viz.:—the "Septic Tank" and the "Sprinkling Beds."

In the first of these, sedimentation and mixed aërobic and anaërobic decomposition are adopted in place of chemical treatment or aërobic action in coarse contact beds, as a preliminary to the use of the fine contact beds as first introduced at Barking Creek. With this view the sewage is allowed to run through a tank holding some twenty-four hours' flow of sewage. In this the heavy solid matters settle to the bottom, whilst the lighter fatty and other matters float as a scum on the surface, and the partially clarified water passes on through the tank to the bacteria beds. Originally it was hoped and claimed that the whole of the solid matters in the sewage would be destroyed in the tank and thereby the sludge question settled. Experience, however, has shown that these anticipations were not founded on fact, but that a residuum of from 50 to 70 per cent. of the solid matters collected in the tanks, which therefore must, like chemical tanks, be cleaned out from time to time, although far less frequently.

The second alternative to the contact bed is that known as the sprinkler bed. In this case beds from six to ten feet deep are required, and the sewage is distributed upon it by means of a rotating arm, which discharges the sewage intermittently over the bed as the arm swings round; or in some cases the surface of the bed is covered with troughs or gratings fitted with plugs or pins, through or from which the sewage drops on to the bed material below, thus becoming aërated and, as it trickles down through the substance of the bed from particle to particle, is brought into contact with the bacterial growth on the surface of the coke or other material with which the bed is filled and is thus subjected to the essential processes of aëration, contact and bacterial action. In this case, however, it has been found that the solids choke the bed unless the sewage is submitted to a preliminary process of deposition to remove the grosser solids, and tanks have therefore been employed, with the resulting accumulation of sludge.

In neither of these two instances is the *crux* of the sewage problem affected, viz., the inoffensive disposition of the sludge.

Aërobic *v.* Anaërobic Action.

This essential point is most interesting as bearing upon the contention that sewage *must* undergo preliminary *anaërobic* action—*i.e.*, bacterial action in the *absence* of air—before it can be finally purified by the *aërobic* action—*i.e.*, bacterial action in the *presence* of air. In order to show the fallacy of such a contention, the history of the purification of the Thames may be cited.

Before the present system of main drainage was constructed the sewage of London escaped into the River Thames between the bridges at all states of the tide, with the result that a more or less stagnant accumulation took place. Most of the sewers having to pass under the low grounds on the margin of the river, discharged their contents at or about the low water level, and at the time of low water only. As the tide flowed it closed the outlets, and thus the sewage flowing from the high grounds accumulated in the low-lying portions of the sewers, where it remained stagnant, in many cases, for eighteen out of the twenty-four hours.

The mischief caused by emptying the sewers into the Thames in the middle of London was intensified by the discharge taking place at low water. The sewage was carried by the rising tide up the river, to be brought back to London by the falling tide, there to mix with each day's additional supply, the progress of many days' accumulation towards the sea being almost imperceptible except in periods of heavy flood. Moreover, the small volume of water in the river at low water was quite incapable of effectually diluting and neutralising the offensiveness of the vast quantity of sewage poured into it, with the result that the river in the part affected was converted into a large "septic" tank.

In consequence of this intolerable state of affairs the Main Drainage Scheme was carried out by the Metropolitan Board of Works. The sewage hitherto discharging into the river direct was intercepted and conveyed to new outfalls at Barking Creek and Crossness, about twelve and fourteen miles respectively below London Bridge. At these points the sewage was stored until the time of high water, when it was discharged in about two hours during the first portion of the falling tide. The effect was marked. The whole of the sewage of London was thus disposed of year after year for over ten years without the slightest sign of anaërobic action. There being a sufficiency of oxygen dissolved in the water for its complete destruction, the natural aërobic agencies did their work without nuisance of any kind. After some ten years it became evident, in consequence of the increased quantities of sewage brought to the outfalls by the extension of the main drainage system and the growth of London, that the capacity of the storage reservoirs was too limited, and the sewage had to be discharged over longer and longer periods until the discharge was continuous at all times of the tide, with the result that accumulations took place at low water when there was an insufficient quantity of aërated water in the river, and putrefaction and nuisance followed in due course. This was remedied by the chemical precipitation of the grosser solid matters and their removal to sea, when the aërobic influences in the river were again able to exert their beneficent action, whilst the effect of depositing some forty millions of tons of sludge in a sufficient quantity of aërated sea water in the Barrow Deep in the estuary of the Thames has been to dispose of it without the slightest sign of anaërobic action either at or about the point of discharge.

This experience on such an enormous scale clearly indicates the fallacy of the theory of necessary anaërobic action, a point which is more fully discussed later on. Hence we may safely turn our attention to the most efficient and economical method of purification on wholly aërobic lines as being not only the most wholesome and sweet, but efficient method.

The following facts will still further accentuate the aërobic position.

The Decomposition of Cellulose by Aërobic Micro-organisms.

(Proc. K. Akad. Wetensch. Amsterdam. 1903, 5. 685—703. Abstracted from the Journal of the Chemical Society, August, 1903, Part II.)

"The decomposition of cellulose by denitrifying bacteria has been "studied by G. van Iterson, jun. The experiments were carried out "with Swedish filter paper. The cellulose is broken down by the action "of denitrifying, non-spore forming, aërobic bacteria, provided that "there is a limited supply of air. If nitrates are present in the nutritive "medium, only nitrogen and carbon dioxide are evolved during the "decomposition. In the self-purification of waters and soil and in "biological treatment, the combined actions of nitrification and denitri-"fication play an important part in causing the disappearance of the "cellulose."

"Amongst the aërobic non-spore forming bacteria which attack "cellulose the brown pigment bacterium, Bacillus ferrugineus, is "predominant."

"In nutrient media, inoculated with ditch mud or garden soil, in "which cellulose is being destroyed by aërobic bacteria, rich spirillae "cultures are obtained, and probably the distribution of spirillae in "nature is governed by cellulose. A chief cause of the brown colour of "humus is a pigment formed from cellulose by bacteria or moulds. "Most moulds attack cellulose, and the action is due to a specific "enzyme for which the author suggests the name *cellulase*. The aërobic "destruction of cellulose accounts for the fact that wood or rope partly "immersed in water becomes weak at the point of contact with water "and air."

The well-known manner in which the posts of a wooden fence are disintegrated forms another admirable instance of the aërobic destruction of cellulose under natural conditions. This is in striking contrast to the failure of the anaërobies to destroy the woody tissues in the ground at such a depth as to preclude material aërobic conditions.

Before proceeding to the consideration of the means available for effecting aërobic bacterial action, it will be advisable to consider two points which have been little understood, viz.: first, the action of water in absorbing oxygen from the atmosphere, and thereby filling the function of a "carrier" of that gas for the service of the organisms existing in the water; and, second, the action of so-called filtration.

Dissolved Oxygen in Water.

The rate at which water will re-absorb oxygen from the atmosphere is necessarily a measure of the degree of rapidity with which aërobic bacteria can multiply and work, and beyond that point it will be useless to expect results without incurring the risk of putrefaction by the agency of the anaërobic organisms. In the course of a series of experiments instituted some years back in connection with the work of purifying the River Thames, I ascertained that still water, containing no oxygen dissolved therein, will absorb in one hour 10 per cent. of the total possible quantity which it can take at ordinary temperatures and pressures, this total quantity being equal to 2·0 cubic inches per gallon under normal conditions. In two hours water will take up 20 per cent. In three hours this quantity will be increased to 26 per cent.; in four hours to 32 per cent.; in five hours to 36 per cent.; in six hours to 40 per cent.; in seven hours to 43 per cent.; and so on, until ten hours are required for it to absorb only one-half its total quantity, or 50 per cent. of the 1·8 cubic inches per gallon. As showing the practical bearing of these results upon the water of the River Thames, we may consider their effect on the tidal portion of the river from Teddington to the Nore. The following table shows the average percentage quantity of oxygen dissolved in the water at fifteen different points at and between these places from July, 1893, to March, 1894, as determined by daily analyses at high and low tides at each place during that period:—

Average percentage quantity of oxygen dissolved in the water of the River Thames from Teddington to the Nore:—

(Saturation = 100 per cent. = 2·0 cubic inches per gallon.)

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

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

Woolwich it is only about 26 per cent., when it rises again until it is 90 per cent. at the Nore. In other words, the water as it flows over Teddington Weir is well aërated, and is able to deal with all polluting matters contained in it without suffering any material reduction in aëration, *i.e.* the rate of absorption from the atmosphere (actual aëration being 85 per cent.) is equal to the rate of consumption by the microbes feeding on the organic matter. Further down the river this process abstracts more oxygen than can be supplied at the former slow rate at the higher degree of aëration, and accordingly the degree of aëration falls, which fall is accompanied by a corresponding increase in the rate of absorption from the atmosphere, as shown by the experiments above quoted. When the rate is again equal to the necessities of the increased number of organisms feeding on the larger quantity of organic impurities, the balance is once more established, and the aëration remains constant at the lower rate.

From these observations it is evident that at Teddington, where the degree of aëration is 80 per cent., the rate of absorption of atmospheric oxygen will be 3·6 tons per 100 million cubic feet of water per day, and as the sectional volume of the river between that point and Chiswick at *high* water may be taken at about 250 million cubic feet, it follows that this reach of water will absorb 9 tons of oxygen in twenty-four hours, or 4½ tons on the assumption that the mean water capacity is one-half of that at high water. In like manner each section of the river may be tabulated as follows :—

Section.	Rate of absorption. Tons per 100 million cubic feet per day.	Tons of oxygen dissolved by the water in section per 24 hours.
Teddington to Chiswick	3·6	4½
Chiswick to St. Paul's Pier	12·7	43
St. Paul's Pier to Deptford	21·4	69
Deptford to Woolwich	43·8	240½
Woolwich to Barking Creek	43·8	105
Barking Creek to Crossness	29·2	131
Crossness to Erith	21·9	126½
Erith to Gravesend	21·9	716
Gravesend to Southend	5·5	949
Total		2384½

These considerations show the enormous forces at work in purifying our streams and rivers, and constitute the real secret of Nature's method in effecting the destruction of effete matters wherever they may be. A few years ago it was denied that rivers had the power of purifying themselves. At that time, however, the above facts had not been brought to light, nor had the equally important fact of the action of myriads of bacteria and other organisms in utilising the oxygen so absorbed been realised, nor the bearing of these factors upon the complex problem of sewage purification been even so much as dreamed of.

Filtration.

The action of a filter in removing matters in solution in a water may be considered as twofold in character. First, the action of gravity brings about the adherence of the molecules to the sides of the solid matter of which the filter is composed, just as it causes a chip of wood floating in water to adhere to the sides of a larger fragment or a boat. Secondly, a process of chemical change brought about either by the life processes of bacteria, or a process of "catalysis," resulting in slow oxidation under favourable conditions. The law of gravity teaches us that both the larger and smaller particles are attracted, and actually move one to the other; but as the movement of the greater mass is slower in proportion to its bulk, so the movement of the mass of a filter towards a molecule of matter dissolved in the water will be only practically a mathematical expression, whilst the molecule will move with appreciable rapidity. Let this be tried by placing two pieces of wood in still water, the larger piece being, say, 3 inches or 4 inches square, and the smaller only a splinter. Place them half an inch apart, and watch. The mathematician will tell us that both will move towards each other; but, to our vision, the movement of the larger will be imperceptible, whilst gradually the smaller will move towards the larger, increasing its pace until it finally rushes towards it, and clings with no little force. This action is, to my mind, precisely that which takes place in a filter. If the rapidity of the stream of water passing through the pores of the filter is not too great, the minute particles of matter in the water will adhere by the action of gravity to the walls of the cells in the filter, and will be retained there until they are destroyed, either by the life-action of the bacteria which will abound in the filter, or by a process of slow oxidation in certain cases. If the substances thus removed from the water are mineral in character, and therefore not capable of being destroyed by either of these agencies, they will gradually accumulate until the cells are filled with them, and the filter will be in the condition known as "choked" or "sludged up."

This description of the action, which it is only reasonable to presume takes place in the case of the solid matters suspended in a water, may be used as a guide to that which occurs when colloid and other matters dissolved in the water are removed therefrom by the process of filtration.

The following experiments which I carried out in 1878 will help to illustrate the point. A solution of acetate of lead was prepared, of such strength that it contained metallic lead in the proportion of one grain per gallon. This was slowly filtered through a 5½-inch carbon-block filter, when the filtrate was found to contain no lead, the whole having been retained in the pores of the filter. A second solution of similar strength was next filtered rather more rapidly, when the first portions of the filtrate contained two-tenths of a grain of lead per gallon, and the last portions three-tenths of a grain per gallon. A third gallon of lead solution of similar strength was then passed through the filter, when the first portions of filtrate were found to contain two-tenths of a grain of lead per gallon, and the last portions as much as six-tenths of a grain per gallon. A fourth gallon of lead solution was then passed through the filter, when the filtrate was found to contain five-tenths of a grain per gallon. Thus the filter gradually lost its power to either (a) take up lead from solution, or (b) to retain that which it had previously absorbed. If we consider the molecules of lead dissolved in the water as synonymous with the minute splinter of wood above referred to, we can follow the action. At first the cell walls of the filter are free from lead, and the molecules of that substance adhere to them by *the action of gravity* or "*mass-action*."

After a certain quantity of lead had been taken up, and the rate of passage of the water was slightly increased, the filter failed to retain the whole of the lead, which failure may be compared to that of a large piece of wood failing to retain small chips when the current of water is strong enough to wash them away from its side; or it may be that after the big piece is surrounded by a number of chips, more chips will not adhere. Doubtless, as it appears to me, some of the molecules of lead became attached to the cell walls, whilst others more loosely adhering were washed free again by the force of the current, whilst others again passed through certain cellular passages at such a pace that their momentum was greater than the gravitational attraction to the cell walls, and hence they passed through the filter. Similar results were obtained with solutions of quinine and morphia. At first, the filter removed the whole or nearly the whole of the alkaloid from solution, and then only a portion, whilst subsequently water passed through the filter was found to contain alkaloids.

These considerations explain why a finely divided material makes a better filter than a coarser material, because the smaller the cells of the filter the better chance is there for the contact action induced by gravity to have full play, and also why a slower rate of filtration always ensures a better filtrate, as too rapid passage of the water washes away the "chips" from the "block." It will further be easily understood why the nature of the substance of which the filter is composed is of less importance than the size of the cells of which the filter is made up. There has been much misconception upon this point.

Bacteria or "Contact" Beds.

From the work which has been done in the past it is perfectly clear that there is no difficulty in obtaining effluents of excellent quality by the final treatment of partially purified sewage on either bacteria beds, or "contact beds" as some prefer to call them, or on trickling filters, on which the liquid is distributed by one of the various forms of rotating sprinklers. By either method, or by various modifications of these, the final work may be equally well accomplished. The great desideratum is an equally simple and effective method of primary treatment of the raw sewage in such a manner as will effectually and economically meet the sludge difficulty.

When the original bacterial installation on working lines was started at the works of the London County Council at the Northern Outfall under my direction in 1892, the sludge was first removed from the sewage by preliminary treatment with lime and iron, in the proportions of about 4 grains of lime and 1 grain of ferrous sulphate to the gallon of sewage, followed by settlement in tanks.

When I introduced the "coarse bed" treatment at Sutton as a preliminary to the second or "fine" bed, it was with the object of ascertaining how far the bacterial agency was capable of disposing of the suspended organic matters and thereby avoiding the necessity for chemical treatment. The result was that the organic matters were so far destroyed or altered in character that they no longer formed the foul abomination denominated "sludge," and that the resulting effluent was, in many cases, sufficiently pure for direct treatment either on land, or for discharge into streams having a sufficient flow, whilst if passed through the second or "fine" bed the effluents were sufficiently pure to be passed direct to any inland brook.

The difficulty experienced, however, with the ordinary coarse or "first contact" bed, in those cases where the crude sewage was turned direct on to it, was that the interstices between the particles of coke or clinker, &c. became filled with the finely divided mineral matter in the sewage and the carbonaceous residuum from the bacterial action on the organic matters.

I have always felt that notwithstanding the expense entailed in turning over the material in the coarse bed from time to time, and occasionally changing it for a stand-by quantity which had been "weathering," the coarse bed system does indeed go further to solve the problem of the inoffensive disposal of the sludge than any other known method. Take a case in point. At Alton, Hants, where about 33 per cent. of the dry weather flow is brewery refuse, the filling material in the coarse beds had to be changed after three years' work. The cost for labour was 1*s.* 2*d.* per square yard, or, say, 5*d.* per yard per annum. The five beds, equal to 830 yards, had treated 160,000 gallons daily, *plus* subsoil water. This quantity is equal to over 200,000 gallons per yard, so that five yards will have treated 1,000,000 gallons, the cost for which, for renewing the material in the bed from a reserve supply, would be *5s.* 10*d.*

Dangers of Sludge Heaps.

The danger to public health from "sewer gas" is commonly referred to, but little reference is made to the danger arising from accumulations of sewage sludge either in the form of heaps of pressed "cake," or "lagoons" filled with the foul abomination collected in detritus or other tanks. This question has been brought prominently forward by the researches of Mr. John P. Lord, F.R.M.S., formerly Professor of St. Xavier's College, Calcutta, &c., which were detailed by him in a paper contributed to the Institute of Sanitary Engineers, in which the following conclusions were set out :—

"Fresh sludge may contain as many as five hundred and fifty-five million three hundred and thirty thousand (555,330,000) microbes in each grain of solid matter, which all grow at the ordinary temperature of the air. In liquid sewage the highest number recorded is eleven million two hundred and sixteen thousand per cubic centimetre (11,216,000). The concentration of bacteria in sludge is therefore very apparent.

"Instead of decreasing on exposure to air the bacteria flourish amazingly. In a gramme of weathered sludge at least a month old the average number was two thousand six hundred and forty-one million nine hundred and forty-four thousand (2,641,944,000).

"The above grow in air. In addition an average of one million two hundred thousand per gramme (1,200,000) developed in the absence of air.

"The following are the most prevalent bacilli in fresh sewage :—

"Fluorescens Liquefaciens, Proteus Vulgaris, Filamentosus, Mesentericus, Mycoides, Subtilis, and Coli Communis."

In addition to these Mr. Lord found the bacillus of typhoid fever (see block), B. Typhi Abdominalis, Ramosus, Cloacæ Superficialis, Neobacillus, Freudenreichii and Spirillum Flavenc in its three varieties.

"The anaërobic bacilli found consisted of Clostridium Fœtidum, Tetani, &c.

"The gases evolved by the anaërobes in growth were most foul smelling, the rotten egg odour of Clostridium and the bad garlic smell of the Tetanus being overpowering when the tubes were opened."

Mr. Lord then made a series of experiments to ascertain the effect of the growth of organisms on the surface of the sludge and found anthrax developed fairly rapidly, diphtheria and typhoid (Figs. 1 and 2) also, but not so readily. After a time the anthrax was entirely in a spore form, in which condition it could be blown about readily and thus cause infection.

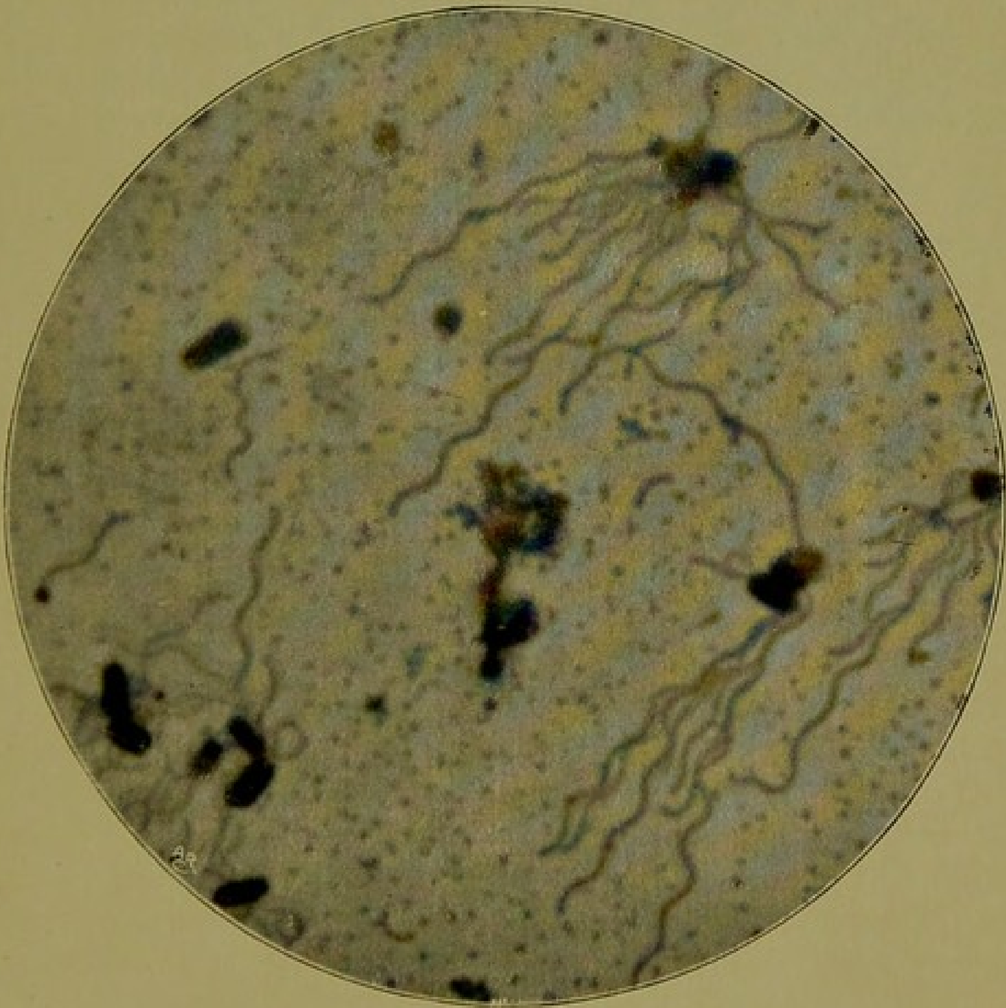


Fig. 2. Bacillus Typhosus. × 5000. *Photo as* Fig. 1.

The typhoid and diphtheria also dried up, and fresh cultures were obtained from the dry surface of the plates.

"Special experiments were made to ascertain whether some microbes were present which might kill or starve out the pathogenic bacteria, with the result that when the sludge was quite dry *cultures could be obtained from the dust on the surface of the anthrax and diphtheria plates with great readiness.*"

From these results Mr. Lord concludes that sufficient importance is not attached to the possible danger of accumulations of sludge. The surface of the heaps soon dries, and disease germs may be blown about from the dusty, bacteria-laden slabs of microbe food.

"There is yet another prolific breeding ground for bacteria to be found in the accumulations of 'grating soil' which is from time to time removed from the gratings."

Mr. Lord concludes "that, in the face of the above evidence, it seems certain that the ideal method of purifying sewage is one which prevents the formation of sludge or grating soil and which, preferably, turns the presence of the myriads of micro-organisms in sewage to good account by making them fight in the interests of sanitation instead of against it. You may obtain an excellent effluent nearly free from microbes and say your purification is perfect, ignoring the fact that you have still your accumulations of dangerous sludge to account for, and which you are either keeping on your farm to be a nuisance and a danger to the neighbourhood or are casting broadcast on the land to become a possible source of infection. Sludge is very dangerous, and the sooner the fact is recognised, and means taken to combat the evil, the better will it be for the health of the public."

Detritus and Septic Tanks.

The adoption of a grit or "detritus" tank for the purpose of intercepting the mineral matters and those of a more resistant organic character has been very successful in prolonging the effective "life" of the coarse bed, whilst the "septic" tank is undoubtedly effective in this connection. Unfortunately, however, both these contrivances still leave the alternative of a quantity of sewage sludge to be disposed of; whilst the effluent from the septic tank in some cases gives rise to most objectionable emanations, and no little evidence is forthcoming to the effect that it is better to prevent, if possible, the sewage undergoing putrefactive decomposition before passing it on to grass land, sprinkling filters, or bacteria beds. These experiences entirely support the view that I have always held, viz., that the sewage should never be allowed to *undergo putrefaction*, but should be collected and treated in as fresh a condition as possible. In fact, it would seem that the most effective work accomplished in a septic tank is that by the "aërobic" and "facultative aërobic" organisms, assisted by enzymes, or chemical ferments. Whilst the sewage is sufficiently dilute these organisms can fulfil their functions satisfactorily, but when the sewage is either too strong, or kept too long in the tank, then the purely anaërobic bacteria gain the upper hand, with resulting unpleasant consequences. The plain meaning of this view is, therefore, that the aërobic conditions are so elastic that they can exert their beneficent action under very adverse circumstances; and that when a septic tank has worked well it is due to aërobic principles, whilst nuisances have in all cases been due to anaërobic conditions. This view agrees with all the known facts, and at the same time explains many conflicting statements. As shown in the following pages a grit or detritus tank should be used to prevent only heavy mineral matters going on the beds, but not for the collection of organic matter.

Cause of Loss of Capacity in Beds.

On turning to the two admirable reports by the Corporations of Manchester and Leeds we find the question as to the causes of loss of capacity of contact beds fully discussed. Summarising these it is found that the chief causes of loss of capacity are the following:—

(a) Settling together of the material.
(b) Growth of organisms.
(c) Impaired drainage.
(d) Insoluble matter entering bed.
(e) Breaking down of material.
(f) More organic solids entering the bed than it can digest.
(g) Soluble matters being rendered insoluble by the action of the bed, as, for instance, iron salts.

After reviewing these points the Leeds report continues:—

"If, therefore, contact beds are to be used for Leeds sewage in future, the problem will be:—

1. To find material of perfectly even size not liable to degradation.
2. To reduce as far as possible the solid matters put on to the rough bed.
3. To exclude and treat separately the iron liquors.

"Another point suggests itself, whether it would be possible to construct the beds in such a way that the undigested or indigestible solids shall be expelled from the beds with the effluents."

Improved Bacteria or "Contact" Beds.

In the case of a coarse bed filled with coke, or clinker, &c., we have a number of particles of solid matter presenting only an outer surface, the interior of the particle occupying space to no purpose. On consideration, it occurred to me that this interior space could be utilised by employing a material of hollow form, so that it would present both an interior as well as an exterior surface on which the bacteria could grow, whilst the interior space would largely increase the water content or "working capacity" of the bed.

These considerations induced me to think of agricultural drain-pipes as suitable, but their cost and cleansing presented a difficulty. Then the obvious question followed, "What is a pipe but a bent plate?" Cut your pipe down its length and bend it back, and the thing is done! At once we have the interior and exterior surface, facilities for cleansing, and the working content of the bed increased as desired. (See Fig. 3.)

Tiles.

With this view, I requested Mr. Joseph Hamblet, of West Bromwich, to make me some trial tiles, having ridges on their under surface so as to separate them from each other (Fig. 4). According to the depth of these ridges so will be the water capacity of the beds. Thus, if they are one inch deep and the thickness of the tile half an inch, the water capacity will obviously be two-thirds, or 66 per cent. In the case of a new coarse coke bed, the initial water capacity will be about 50 per cent., which soon becomes reduced to about 33 per cent. by one or more of the causes mentioned above, particularly that due to the breaking down and settling of the material together, inducing impaired drainage, which would be entirely avoided by the use of suitable flat plates supported at intervals.

DEVIZES SLATE BEDS.

As an alternative to the use of tiles, an experimental bed was tried for eighteen months at Devizes in which waste slate débris was used (Figs. 5, 6 and 7). The slates varied in size from about 1 ft. to 3 ft. super., and averaged about a quarter of an inch thick. They were supported about one inch apart by means of small slate blocks. This arrangement, it will be seen, gives no less than 87 per cent. of water capacity to the beds, thereby doubling their effective working capacity as compared with coke, &c. In fact, the experimental bed at Devizes was exactly one-half the size of the fine bed into which it discharged, with the result that the cost of an installation of coarse beds is reduced by 50 per cent.

The success of eighteen months' work with this experimental bed was so satisfactory that it was decided to fill the whole of the primary beds with slate in a similar manner.

Fig. 11 shows the arrangement.

These beds were first put into action on September 12th, 1905, and have continued to work satisfactorily up to the present, dealing with the sewage *unscreened* and *unsedimented*.

The Medical Officer of Health for Devizes, Dr. Waylen, in his report for the year ending December 31st, 1906, remarked: "Sewage Works.—These works have been satisfactory throughout the year, and complaints have not been made to me of the condition of the stream into which the effluent goes." The results obtained are more fully set out in the Appendix hereto, p. 47.

TROWBRIDGE SLATE BEDS.

Following the example of Devizes, the Town Council of Trowbridge decided to institute a series of independent experiments, with the view of ascertaining how far the system of slate layers was applicable to the treatment of the effluent from the septic tank into which they proposed to pump all the sewage, more particularly for the purpose of securing a good "mixing action," in consequence of the large proportion of manufacturing waste liquors arriving at the works.

They accordingly prepared experimental beds filled with—

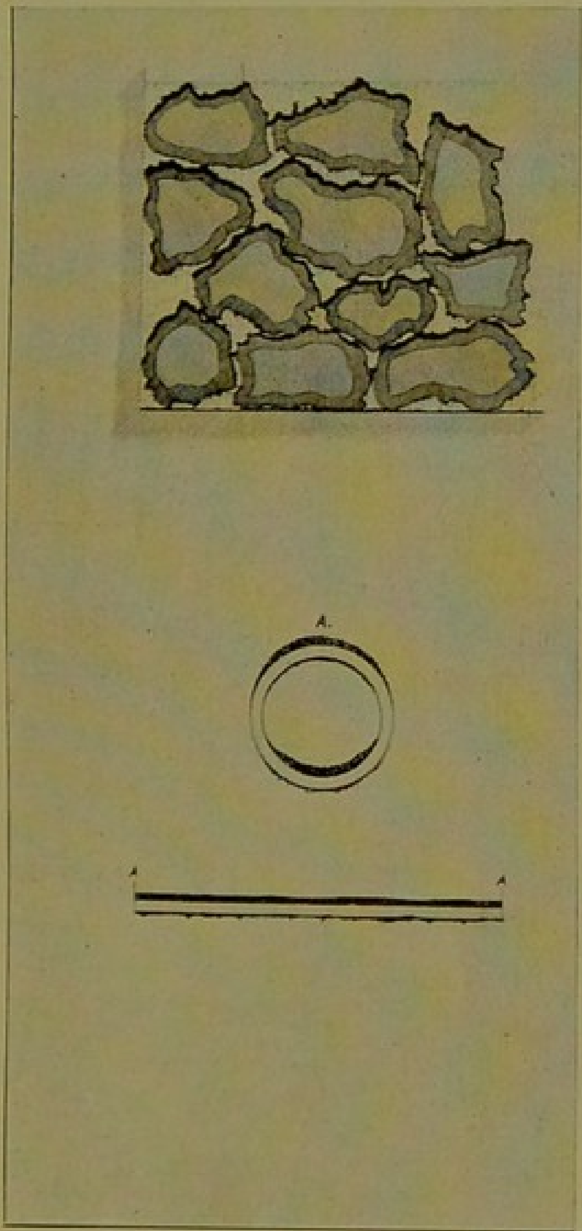
1. Slate.
2. Limestone.
3. Broken brick.
4. Empty.
5. Westbury slag.
6. Clinker.

The sewage, after twenty-four hours' rest in the septic tank, was passed on to the contact beds, and samples of the sewage and various effluents forwarded to Mr. Charles J. Waterfall, F.I.C., F.C.S., &c., of Bristol, to whom, as well as to the Corporation of Trowbridge, I am indebted for permission to quote the following results from his report thereon:—

"The result of analysis of the effluents shows the following albuminoid ammonia figures, also per cent. purification.

	Parts per 100,000 Albuminoid Ammonia.	Per cent. Purification on Septic Tank Effluent.	Corrected (arbitrary per cent.) for comparison only. Purification X Flow.
Sewage	1·00	..	..
Septic tank..........	0·82	..	..
Slate	0·51	38	60
Limestone	0·54	34	35
Brick	0·51	38	41
Slag................	0·56	32	22
Clinker	0·48	41	46

GENESIS OF THE PLATE BACTERIA BED.



Section of Coke Bed shewing waste space in centre of particles of Coke— and Deposit on surface of Coke.

Section of Pipe with Deposit on upper surfaces of exterior and interior, thus securing double working capacity and surface.

Pipe cut at A and opened out flat, forming a plate.

FIG. 3.

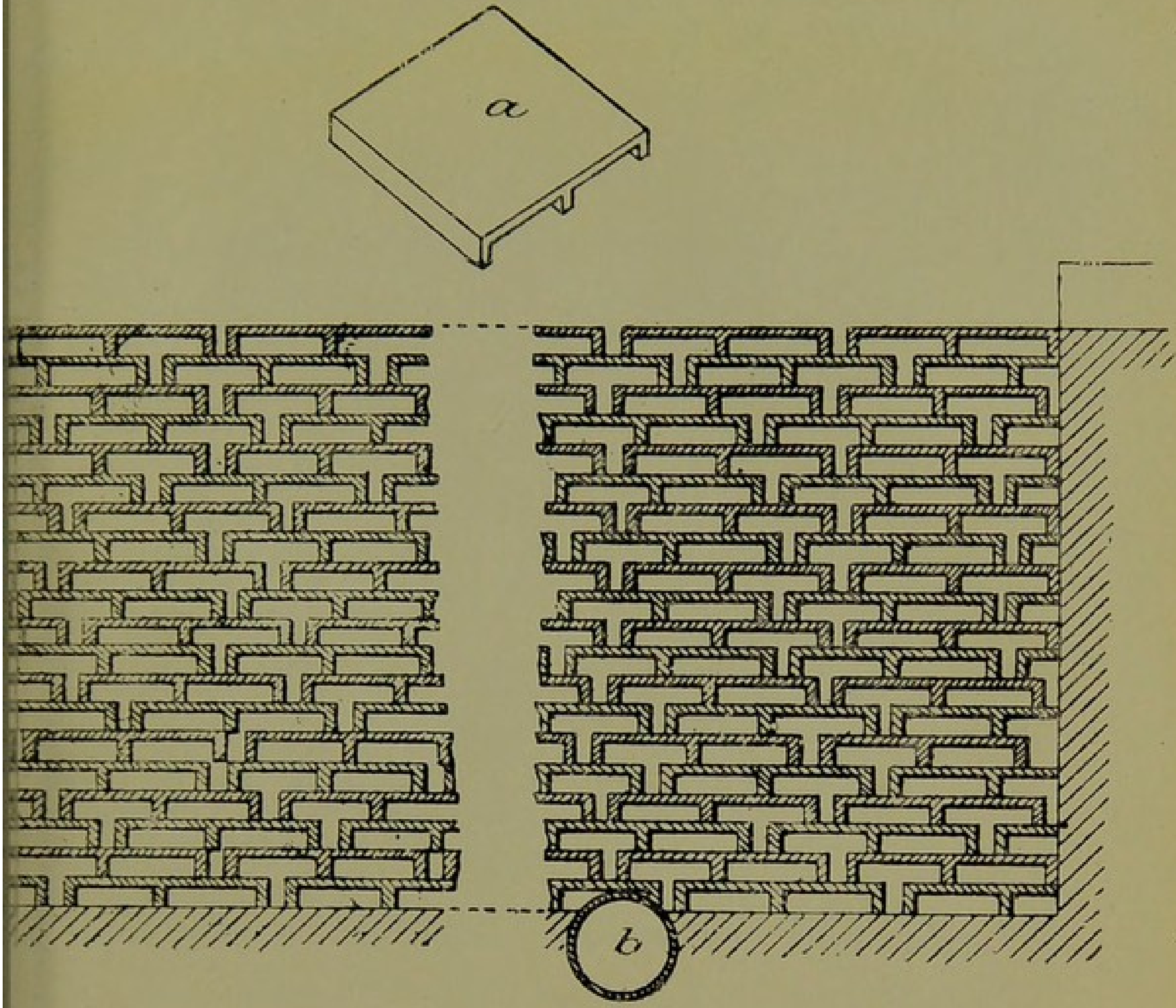


Fig. 4. Tiles.

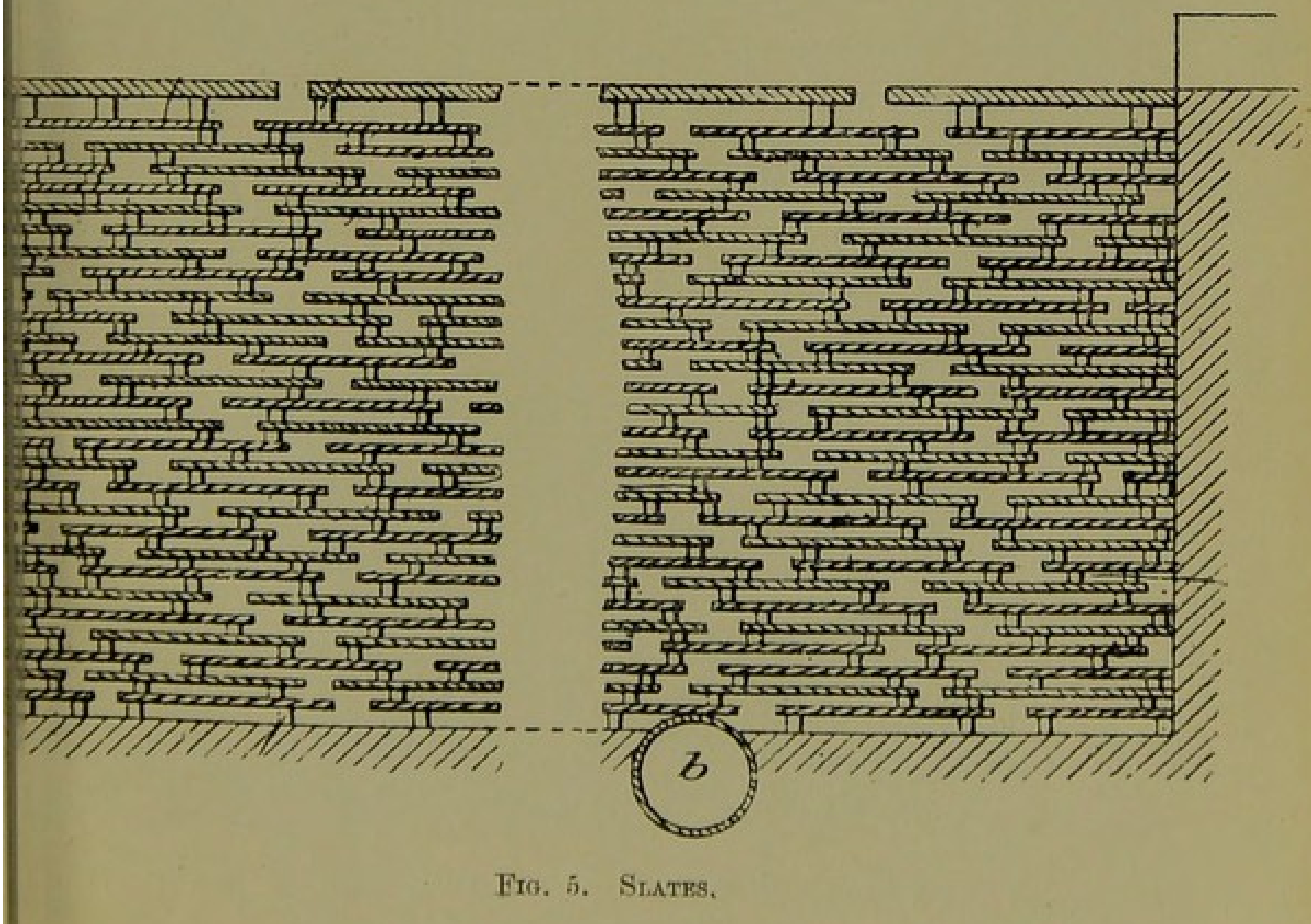


Fig. 5. Slates.

The following photograph shows the arrangement:—

FIG. 6. DEVIZES PRIMARY BED. Section showing Slate Layers. (See Fig. 8.)

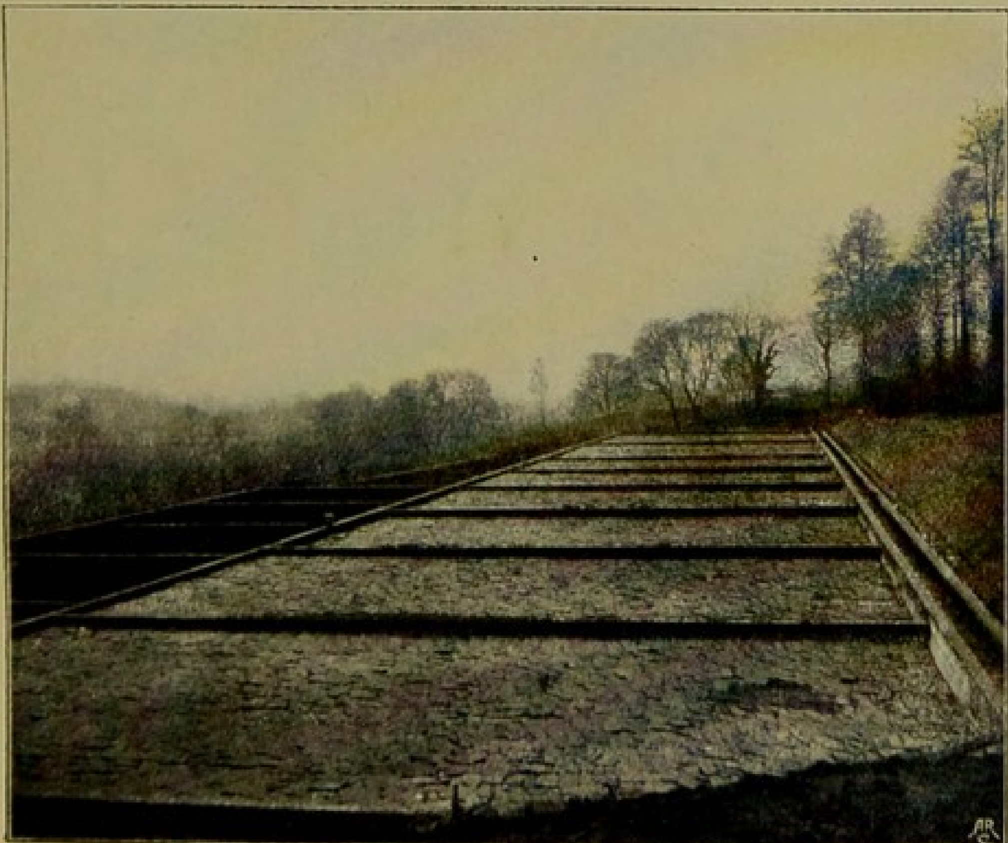


FIG. 7. DEVIZES PRIMARY BEDS FILLED WITH SLATE.

"The beds when full take the following number of inches of effluent from the septic tank—

No. 1	Slate	$6\frac{1}{2}$
,, 2	Limestone	$4\frac{1}{4}$
,, 3	Brick	$4\frac{1}{2}$
—		—
,, 5	Slag	$4\frac{1}{8}$
,, 6	Clinker	$4\frac{5}{8}$

taking the slag bed as minimum, I arrive at the above corrected figures.

"If we take the results of the last three series only, since the tanks and beds have been in good working order, we obtain somewhat different figures:—

	Per cent. Purification.	Corrected (arbitrary, for comparison only) Purification X Flow.
Slate	52 per cent.	82
Limestone	47 ,,	48
Brick	35 ,,	38
Slag	32 ,,	32
Clinker	45 ,,	50

"It will be seen that in either case slate gives the best results. And in the latter series limestone gives nearly as good results as clinker.

Slate Beds at High Wycombe.

Experience with the system has also been gained at High Wycombe, where the Borough Engineer, Mr. T. J. Rushbrooke, carefully watched two experimental beds, which gave decidedly satisfactory results, and, in conjunction with the experience gained at Devizes and Trowbridge, justified the theoretical deduction upon which, as already explained, the system is based.

A special series of analyses of samples of sewage and effluents were made by the Clinical Research Association by direction of the Corporation of High Wycombe. Each sample was the average of twelve hours' flow on the 22nd August, 1906, and those from the two slate beds show the result of two and three fillings per day respectively.

Analyses of High Wycombe Sewage and Effluents expressed in grains per gallon:—

——	1. Sewage entering Beds.	2. Effluents from Slate Bed No. 1, 3 Fillings daily.	3. Effluents from Slate Bed No. 2, 2 Fillings daily.
Appearance	Cloudy	Cloudy	Cloudy.
Odour	Distinct	Slight	Slight.
Reaction to Litmus	Alkaline	Alkaline	Alkaline.
Chlorine	2·65	3·05	2·00
Free Ammonia	1·050	1·070	0·870
Albuminoid Ammonia	0·150	0·082	0·094
Oxygen absorbed in 4 hours at 27° C.	0·481	0·342	0·270
Dissolved Solids:			
Total	29·68	28·00	25·69
Volatile	3·50	2·03	1·33
Suspended Solids:			
Total	10·22	3·64	2·66
Volatile	5·11	0·56	0·84
Odour on Incubation	The odour of the effluents is slightly increased on incubation, but no fermentative change seems to take place.		
Purification per cent. based on the Alb. Am.	..	46	38

REMARKS.—The above results show that the percentages of purification of the effluents are rather low.*

These results are exceedingly satisfactory, the effluents being non-putrescible and containing less impurity, as judged by both the albuminoid ammonia and oxygen absorbed tests, than is considered permissible in first-class effluents, whilst the volatile suspended matters are reduced to less than one grain per gallon.

It will thus be seen that, in the case of High Wycombe, the slate beds are yielding effluents up to the recognized standards of purity, thereby doing better than was anticipated, and more than justifying the claim that they take practically the whole of the suspended matters, and have a marked effect on those in solution, thereby preparing the sewage for final treatment on either land, fine contact or sprinkler beds.

It will be noticed that excellent results were obtained at even three fillings daily, so that, as the beds have a working capacity of double that of coke or clinker beds, and as the usual requirement of the Local Government Board is that such beds must be worked at only one filling

* These factors were obtained by only one treatment on primary Plate Beds, not from secondary Fine Beds as was understood to be the case by the analyst.

daily on the basis of the dry weather flow, the High Wycombe beds are doing *six times* the work of ordinary coarse coke or clinker beds when working under official conditions, and yielding by that single treatment an effluent sufficiently pure to be discharged into an ordinary stream. It will, of course, be noted that the High Wycombe sewage is largely diluted with subsoil water, but the slate beds enable this to be dealt with without the necessity for expensive works for cutting off the subsoil water, which under existing conditions exercises so beneficial an influence in flushing the sewers.

As a result of the information thus obtained the Corporation decided to adopt the slate beds for the primary treatment of the whole of the flow.

In October, 1906, the Public Works Committee presented the following Report by the Borough Surveyor, Mr. T. J. Rushbrooke, to the Town Council of High Wycombe :—

"It is well to bear in mind that the beds are primary, not secondary, and that the effluent will be treated on land afterwards. Our difficulty, as your Committee is aware, is one common to nearly all sewage works—viz., sewage sludge—and the reason for experimenting with the slate bacteria beds was that they appeared at Devizes to dispose of the sludge difficulty, and my advice in the first instance was that if the beds were laid down, and we disposed of nearly the whole of the sludge from the sewage treated without causing a nuisance, then it would be wise to adopt the slate bacteria beds, and treat the whole of the sewage in that way. It will be seen from the analysis that there are less dissolved solids in the sample from the bacteria bed No. 2 than in the sample from the old settling tanks, and less suspended solids in samples from beds Nos. 1 and 2 than in the samples from the old settling tanks; so that, supposing the whole of the sludge extracted now remained in the bacteria beds, there would be more than is extracted from the sewage by the old process; but the sludge is obviously largely destroyed in the beds, or your Committee would have seen the beds almost entirely choked with sewage sludge at the inspection made a few days since, whereas the sludge on the slates did not exceed in any case half an inch in thickness, and over a large portion of the area did not exceed one-sixteenth of an inch in thickness. It was also observable that the sludge on the slates was easily removed by flushing with water, and that it had not the objectionable appearance and smell of ordinary sewage sludge; in fact, there was only a faint smell arising from it. This point alone is of great importance, as our difficulties have in the past been greatly increased owing to the risk of nuisance incurred in removing the stinking mass of sludge from the farm in any direction. If the average thickness of the sludge on the slates is taken to be a quarter of an inch, which I consider a reasonable estimate, as judged by the portion of the beds exposed when your Committee inspected them, it would take three years to accumulate sludge to the thickness of an inch;

but in three years the destruction of the organic matter by the bacteria, worms, and other organisms would be carried on to a greater extent than in nine months only. At the end of three years* it would be desirable to cleanse the beds, as then their average capacity would be proportionately reduced; shafts are therefore formed in the slate filling, from which the slates can be washed *in situ* by means of a hose. After being washed, the beds will be just as good as new, and as they are constructed of slates are practically everlasting. The material that is washed out of the beds would be collected in a bed in the same way that the sludge is at the present time, but it would be practically without smell, and when dry could be disposed of without difficulty on the farm. . . . The result of the nine months' experiment cannot, I think, be regarded otherwise than as extremely satisfactory, and I advise your Committee to adopt slate bacteria beds."

Slate Beds at Malden.

Following these three towns, viz., Devizes, Trowbridge, and High Wycombe, the Urban District Council of The Maldens and Coombe, Surrey, made experiments with a trial slate bed for over six months, with the result that after receiving a report from their consulting bacteriologist, Mr. Lord, F.R.M.S., &c., they unanimously decided to adopt the method in place of chemical precipitation and sludge pressing. The following extracts are from Mr. Lord's report:—

"*Dec.* 17*th*, 1906.

"I have made a series of experiments on the influx to the purification beds at the sewage works of the effluent from the precipitation beds, and of the effluent coming from the experimental (slate) bacterial bed.

"The tables accompanying this will show you that even using the small experimental bed, and allowing from one and a half to two hours of contact, we get a higher rate of purification than we obtain from the precipitation tanks. The bacterial bed requires no chemicals: the precipitation tanks system is costly.

"The principal criterion is obtained from the proportion of Bacillus coli which survive after treatment, and a glance at the tables annexed will show you that whereas raw sewage contains this organism in the proportion of about one to ten, the bacterial bed reduces this to practically one to eighty or one to a hundred, but the precipitation tanks only reduce it to about one to twenty. The effective value, then, of the bacterial purification is high.

"It should be mentioned that it is proposed to pass the sewage through

* Eighteen months' experience indicates that it will be considerably more than three years before the beds will require cleansing, as the self-cleansing action is distinctly indicated.

Fig. 8. Filling the Slate Beds at Malden, Surrey.

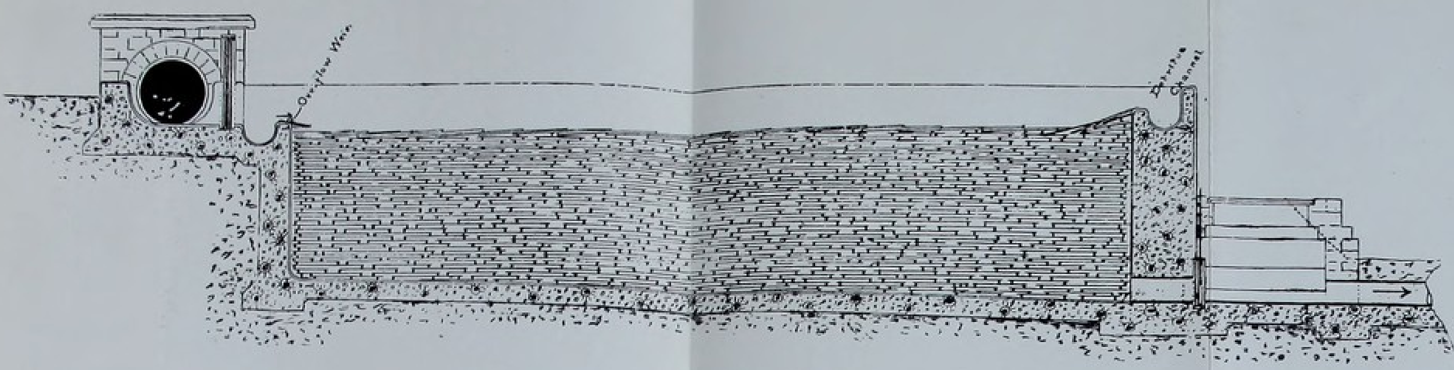


FIG. 9. SLATE BED SECTION.

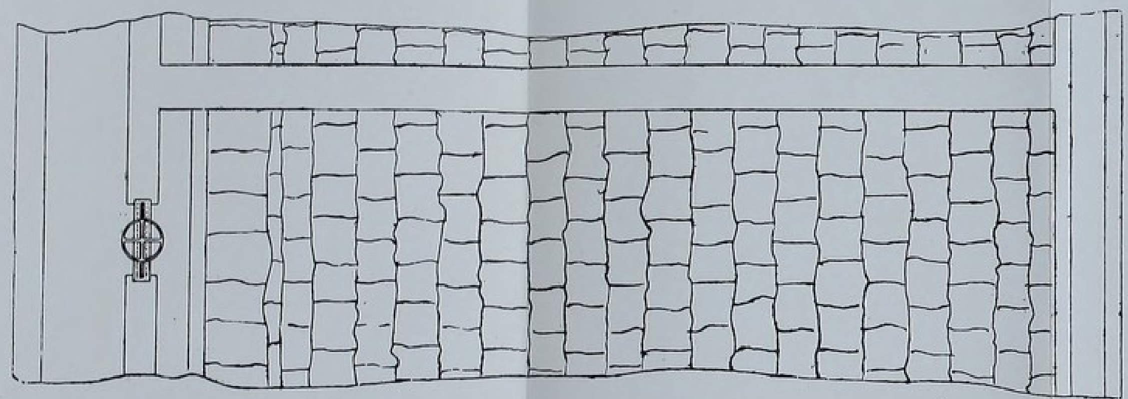


FIG. 10. SLATE BED, PLAN OF TOP LAYER.

at least two bacterial beds, and then aërate in the usual manner. A purification will thus be obtained which will fall but little short of drinking water."

THE ONLY CONCLUSION which can be drawn from these four different and independent series of experiments with sewages of widely varying quality and composition is that THE SLATE BED TREATMENT IS NOT ONLY EFFECTIVE BUT SUPERIOR TO ANY OTHER KNOWN METHOD FOR DEALING WITH THE SLUDGE PROBLEM, *and preparing the liquid portion of the sewage for secondary treatment* by one means of the several commonly practised, whether contact beds, sprinklers, land irrigation, discharge into tidal estuaries, &c.

It will now be seen that whether tiles or slates or other suitable material be used in this way, the chief causes of loss of capacity are overcome.

To take these seriatim as already set out:—

(a) The material will not settle together.

(b) The growth of organisms will take place on both surfaces of the slates or tiles, and will not choke up the spaces between as in the case of coke, &c.

(c) The drainage cannot be impaired.

(d), (f), (g) The insoluble matter (grit, &c.) can be kept off the bed by the use of a grit tank, or if it gains access, can be easily removed from such surfaces as those of slates or tiles by flushing, &c.

(e) The material will not break down.

Further, evidence is now accumulating to the effect that, to a very great extent, the slate beds are SELF-CLEANSING.

It will thus be seen that not only have we a material that will not break down, but one of even size, which can be easily cleansed when necessary by flushing with a hose, whilst the working capacity of the bed is doubled, *thereby reducing its constructional cost one-half.* In the case of a continuous tank the successive layers of slate or tiles would keep the sludge from accumulating at the bottom of the tank, and enable it to be subjected to the action of the aërobic and facultative aërobic bacteria and enzymes throughout the depth of the tank, especially when the sewage is, or can be, fairly aërated as it enters the tank, but this method cannot give as good results as alternate filling and emptying on the "contact" principle.

The accompanying diagrammatic plan and sections will show the arrangement proposed for the disposition of the slates or tiles, as the case may be. It will be seen (Fig. 10) that the top layer should be laid overlapping in such a manner that it forms an automatic screen by the junction of the edges, which will be sufficiently separated to allow the finer divided matters to pass between them to the underlying layers, the fibrous and coarser matters being retained on the surface of the slates, from which they may be removed from time to time. This will enable the particles to thoroughly drain before their removal.

The wide channel receiving the sewage will act as a grit chamber. The sewage will flow over the weir-lip of this channel on to the slates and thereby become aërated. Another point is that as the sewage gradually fills the bed, films of air will be retained on the under surface of the plates. If this layer is only one-fiftieth of an inch, and the intervals between the plates one inch, the quantity of oxygen so retained will be sufficient to thoroughly aërate the sewage. For instance: Each gallon of water will dissolve about two cubic inches of oxygen, which will be contained in ten cubic inches of air. Two cubic feet of bed-capacity of 50 per cent. will contain 6¼ gallons, which will accordingly have to be supplied with 62½ cubic inches of air.

The plates in two cubic feet of such a bed will present a total underneath area of $144 \times 24 = 3456$ inches super. If the film of air retained under this surface be of an average depth of one-fiftieth of an inch, the total volume of air so retained will be equal to 69 cubic inches.

Suspended Matters in Effluents.

Suspended matters in effluents are nearly always present, especially from continuous filters—and although the effluents may not be putrefactive when incubated with the suspended matters in it, yet when these are separated and independently incubated with distilled water putrefaction will take place. In certain cases the organic matters may be largely due to growths of organisms. Dr. Gilbert J. Fowler, Superintendent and Chemist of the Sewage Works, Manchester, in a lecture given on the 24th March, 1904, remarked in connection with this subject: "In general it may be said that the more perfect the action of the bed, the more harmless or more thoroughly oxidised will the suspended matter be, until finally it may be rightly described as organic residuum or débris. It must, however, if present in more than traces (3 grains per gallon have been suggested as a limit), be removed from the effluent by straining or settlement."

In the course of a preliminary series of laboratory experiments with layers of slate for the filling material of a primary contact bed the suspended matters in the effluent were found to be "none," *i.e.*, inappreciable.

These experiments were with a new bed and extended over six weeks.

In the first series of experiments made at Devizes, the new slate beds gave traces only of suspended matters from January 29th to April, 1904.

On May 13th, 1904, the suspended matters rose to 2·0 grains per gallon, *all organic*.

On June 20th one sample contained as much as 16·9 grains, and others from 8 to 12·6 grains per gallon. In January and March, 1905, only traces were found.

In the effluent from the new beds in September and October, 1905, only traces were found. In January, 1906, after four months' work 7·0 grains were found in one sample.*

These matters were found to undergo weathering without nuisance, and by their escape from the slates prolonged the "life" of the beds by deferring the time when they might have to be cleansed.

It is therefore evident that the *new* beds retain practically the whole of the suspended matters in the sewage, but when sufficient time has elapsed for the full growth of the organisms the humus formed from the earlier deposit escapes into the effluent, and appears in the analysis as "suspended matter," and might easily be confused under that heading with the original "suspended matter" in the untreated sewage. It is clear that with a minute exception easily coming under Dr. Fowler's definition of *traces*, the sewage suspended matters are retained whilst the "humus" and bacterial clots produced by the aërobic action on the sewage solids escape.

Careful measurements made at Devizes of the total quantity of humus, &c. which had escaped from the slate beds in eighteen months showed less than 20 cubic yards, or about 15 tons. On a daily flow of 200,000 gallons this equals about two grains per gallon, or less than a "trace."

Rate of Deposition on Slate Surfaces.

A sewage containing an average of 40 grains of dried suspended matter per gallon will contain in 1 cubic inch 0·14 grain. If the slate layers are two inches apart this equals 0·28 grain per cubic inch of surface, without allowing anything for the matters which may adhere to the under surface of the slates, or sides of the blocks. If this quantity contains 90 per cent. of water, the usual amount in settled sludge, the weight will be 2·8 grains of wet deposit, the relative volume being, on the basis of 1 cubic yard to $\frac{3}{4}$ of a ton (= 252 grains of wet mud per cubic inch), 0·011 cubic inch. Thus the average depth of the wet mud on each slate layer will be only about one-hundredth of an inch at each filling. Supposing, for the sake of illustration, that no diminution of this deposit took place either by biological action, oxidation, draining, &c., it is evident that it would require one hundred fillings to obtain a deposit equal to one inch per slate surface. At one filling daily this would happen in roughly three months, so that in a little over six months under such a supposition the whole of the beds would be full, and unable to take any further quantity of sewage.

* See "Recent Improvements in the Biological Treatment of Sewage," W. J. Dibdin, Society of Chemical Industry, May, 1906 (Appendix I., p. 47).

That such is not the case is evident from the fact that after eighteen months' work with an exceptionally strong sewage the beds take practically as much sewage at each filling as at first, whilst the measurement of the "humus" which has escaped during the whole of that period is to be measured in terms of "traces" per gallon.

The fact that the deposition of only one-hundredth of an inch takes place at each filling, enables one to understand how the organic matters are attacked by the organisms with which the underlying layers of the deposit abound. This daily increment forms but a steady fixed supply, which on digestion leaves a residue from which the major portion of the original albuminous and similar matters have been removed, whilst the original 90 per cent. of water is also largely reduced, and thus the bulk of the remainder can be but only a fragmental quantity of the original series of wet deposits.

Nature of Deposit in Beds.

The important question of deposition and analysis of sewage débris in contact beds is fully discussed in a paper read by the author before the Society of Public Analysts in April, 1907. For convenience of reference this paper is reprinted in the Appendix II. hereto (p. 55).

Construction of Bacteria Beds.

The original one-acre bed at Barking Creek and those at Sutton were constructed with merely clay banks, and have continued to work well for over ten years. One of the first complete installations carried out under my supervision was that at Worcester Park, where the sewage of Cheam and Cuddington is treated, the daily dry-weather flow being about 100,000 gallons. In this case the works were situated on a sloping clay field, and nothing more was required than to dig out shallow pits in the clay, lay the under drains, and fill up with burnt ballast, &c., a method of construction so novel for sewage works that the Local Government Board could not see its way to sanction the necessary expenditure, as they considered that it would not be permanent. Experience, however, has justified my action, and many other works have been similarly constructed, with the result that the Board now sanctions such methods. In fact, the introduction of the bacteria bed method met with more opposition than probably any other, but its own inherent merits have gradually overcome opposition, until at the present time the only alternative to the final purification of the sewage on the fine-grained beds is irrigation over suitable land or on sprinkling or "trickling" filters. In the former case irrigation of the effluent from the coarse-grained beds gives admirable results, whilst in the latter, although the results are excellent, the question of levels is often a very vexed one.

The SIMPLICITY, PERMANENCE, RELIABILITY and ECONOMY of the double contact bed method when slate is used for filling the primary beds fulfil the ideal of what a sewage works should be. The materials employed, viz., concrete (if necessary), slate and clinker, are to all intents and purposes everlasting, and simple iron valves, which will "earn their living," constitute the acme of simplicity and economy whilst dealing with the sludge difficulty in a way no other system can attempt. Nothing is left to accident, and there are no moving parts to get out of order. If, however, final treatment of the primary effluent on "sprinkling" filters is desired, treatment of the crude sewage on primary slate-filled contact beds obviates the sludge nuisance, screening and grit or "detritus" chambers, and leave the sprinklers free to deal with the non-putrefied primary effluent.

The PRIMARY SLATE BED DEALS WITH THE SLUDGE. Deal with the effluent therefrom by any suitable method. Personally I prefer fine contact beds.

Local Government Board Requirements.

Naturally, with the advance of knowledge, the requirements of the Local Government Board have been modified from time to time, and when the decision of the present Royal Commission has been finally given, further modifications may be reasonably expected. At the present time, however, the Board is taking a benevolent view of all improved methods and showing an earnest desire to foster economy, whilst securing the maximum of efficiency. Probably the most vexed question is that of the requirement of land in connection with all schemes where that safeguard is obtainable. In the case of broad irrigation, in which the crude sewage is sent on to the land direct, the Board considers that the rate of discharge should not exceed 150 persons per acre, but that in the case of a bacterial effluent the rate may be 1,000 persons or 30,000 gallons, based on the dry-weather flow, per acre.

But in those cases where it is contended that land is unnecessary, it should be clearly shown that :—

1. Land is not available.
2. That if available it is not suitable.
3. Or, that the cost of its utilisation is prohibitive.

In certain cases, such as the discharge into the sea, or a tidal river, the Board does not insist on land being employed.

The quantity of sewage which must be provided for is usually reckoned at the rate of 30 gallons per head per day.

The works for fully treating the sewage flow must be of such a capacity that it can treat double the normal flow, provided that the system of sewerage is a "separate" one. If it is a "combined" system, then the plant must be capable of treating *three times* the dry-weather flow, in addition to a special prepared area of land or storm-water beds capable of treating storm water equal to four times, or three times, as the case may be, the normal dry-weather flow, at the rate of 500 gallons per yard super. per day.

Where bacteria beds or "trickling" filters are employed in conjunction with a detritus tank, the capacity of the beds is calculated at the rate of 33 per cent. of their total cubic content, provided that there is previous treatment in tanks, or 25 per cent. if the beds are filled with crude sewage, and the number of fillings at three per day.

This requirement has been modified in view of the plate beds already described, as they give double this working capacity.

In the case of a septic tank, the Board requires this to have a cubic content equal to from twelve to twenty-four hours' flow of sewage, and that all storm water after a flow equal to twice, or three times, the normal flow shall be diverted from it on to the storm-water beds direct.

Where the beds are to be worked on the intermittent or "contact" plan, and the effluent is to receive final treatment on land, one set of beds, *i.e.*, single contact, would ordinarily be regarded as sufficient.

Where the filters are proposed to be worked on the continuous or percolating principle, and land treatment is provided, the maximum rate of filtration allowed is 56 gallons per square yard per foot in depth of filtering material per day.

Where the circumstances preclude land treatment the cubic contents of the filtering material in either case must be double that indicated above, *i.e.*, two sets of contact beds, or "double contact," must be provided in the case of beds worked on the intermittent plan, and the rate of filtration for continuous or percolating filters must not exceed 28 gallons per square yard per foot in depth of filtering material.

With regard to the question of land treatment, where a sufficient area of land of a not unsuitable character can be provided at a reasonable cost, it would be contrary to present practice to entertain a scheme which does not provide for the final purification of the sewage on land.

Mitigation of Nuisance from Septic Tanks, &c.

One of the results arising from the common practice of converting existing precipitation tanks into septic tanks is that the noxious emanations arising therefrom have been the cause of considerable nuisance at distances of half a mile or more. In such cases I have adopted the expedient of covering the tanks with peat moss, with very satisfactory results. A simple means of applying this material was tried on my suggestion at Carshalton. Stout galvanized iron wires were stretched across the tanks at close intervals and close-woven sheep hurdles laid upon them, both the wires and the hurdles having been previously well tarred. Peat moss was then teased out and spread over the hurdles to a depth of six inches, and allowed to lap over the sides of the walls. The result was most satisfactory. All complaints immediately ceased and a threatened injunction stopped. After some five years' working the moss is still effectually preventing all nuisance. The advantage of this arrangement is that no accumulation of gases can take place, as the diffusion through the moss is necessarily perfect, while it saves the enormous expense of costly covering arches, &c. over the tanks. This arrangement, however, is but a partial remedy. The best plan is to at once convert the tanks into contact beds by filling them with slate, thus obviating both the nuisance in ordinary work and all subsequent sludge troubles.

Asylums, Hospitals and Private Houses.

The advance which has been made in the much-vexed question of sewage purification has resulted in the application of the above principles to many cases where previously the sewage was disposed of only with much nuisance and expense. Whilst the bacterial principle is capable of dealing with the sewage of large towns and cities, it is also applicable for the purification of that from even the smallest cottage, and in particular the drainage from asylums, hospitals, and country mansions. The best means of applying those principles can only be determined after a careful inspection of the whole of the attendant circumstances, especially having regard to the nature of the soil, level of the ground, &c., as upon these will rest the necessity or otherwise for more or less expensive works, as the case may be. For instance, in one case where the surrounding circumstances were favourable, I was enabled to design a plant for the treatment of the whole of the sewage of a large country mansion in such a manner that for two and a half years it received *no attention whatever*, and then only the time of two labourers for one day, when it was re-started with as good results as at the first. But in other cases, unless automatic gear is employed, the work must be looked after at least once a day. The employment of automatic appliances for regulating the filling and emptying beds has given rise to many suggestions of more or less utility, but the most suitable can only be determined after all the local circumstances have been carefully considered.

Synopsis of Reports of the Royal Commission on Sewage Disposal.

The fundamental importance of the questions of land and trade effluents which are more particularly dealt with in the Reports of the Royal Commission, renders unnecessary any apology for the insertion of the following abstracts from these Reports which I made for the purpose of the third edition of my work on the "Purification of Sewage and Water." These abstracts contain such a clear and definite statement of the position that no useful purpose would be served by any further curtailment.

In consequence of the rapid development of the methods of treating sewage solely by the agency of bacteria and the increasing urgency of the sewage question generally, a Royal Commission was appointed on the 7th May, 1898, under the presidency of the Earl of Iddesleigh, to inquire and report:—

> I.—(1) What method or methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted, consistently with due regard for the requirements of the existing law, for the protection of public health, and for the economical and efficient discharge of the duties of local authorities; and
>
> (2) If more than one method may be so adopted, by what rules, in relation to the nature or volume of sewage, or the population to be served, or other varying circumstances or requirements, should the particular method of treatment and disposal to be adopted be determined; and
>
> II. To make any recommendations which may be deemed desirable with reference to the treatment and disposal of sewage.

On the 12th July, 1901, the Commissioners issued an interim report, from which the following salient features are abstracted, viz.:—

3. We have, however, arrived at conclusions on three questions which appear, for reasons hereafter given, to be of urgent importance, and we have therefore deemed it desirable to make a preliminary report and to publish the evidence already taken.

The three questions are:—

(1) Are some sorts of land unsuitable for the purification of sewage?
(2) Is it practicable uniformly 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?
(3) What means should be adopted for securing the better protection of our rivers?

5. The first Sewage Commission was appointed in the year 1857. In 1865, as a result of labours extending over eight years, they reported that:—

"The right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided."

6. In 1868 a further Commission was appointed to inquire into the best means of preventing the pollution of rivers. They made several reports, the fifth and last being made in 1874.

The opinion of this Commission on the comparative merits of the three classes of processes for the treatment of sewage—viz., chemical precipitation, intermittent filtration, and broad irrigation—may be stated thus:—(1) All these processes are to a great extent successful in removing polluting organic matter in suspension. But intermittent filtration is best, broad irrigation ranks next, and the chemical precipitation processes are less efficient. (2) But for removing organic matters in solution the processes of downward intermittent filtration and broad irrigation are greatly superior to upward filtration and chemical processes.

7. The last Commission was appointed in 1882. They were directed to inquire into and report upon the system under which sewage was discharged into the Thames by the Metropolitan Board of Works, whether any evil effects resulted therefrom, and, if so, what measures could be applied for remedying or preventing the same.

In November, 1884, they issued their final report. They found that evils did exist "imperatively demanding a prompt remedy," and that by chemical precipitation a certain part of the organic matter of the sewage would be removed. They reported, however, "that the liquid so separated would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a permanent measure. It would require further purification, and this, according to the present state of knowledge, can only be done effectually by its application to land."

Practice of Local Government Board.

8. Since the publication of the last-mentioned report it has been the practice of the Local Government Board to require, save in exceptional cases, that "any scheme of sewage disposal, for which money is to be borrowed with their sanction, should provide for the application of the sewage or effluent to an adequate area of suitable land before its discharge into a stream." There can be no doubt, in our opinion, that the Local Government Board were bound, under the circumstances, to insist upon such a rule.

Reasons for Reconsidering Position.

9. It is now contended that in many cases, especially in the great centres of manufacturing industry, 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. During recent years a variety of artificial processes, differing from those which were considered by the earlier Commissions, have been elaborated for treating sewage, and it is urged that satisfactory effluents can be obtained by such artificial processes.

Scope of Work of this Commission.

10. Having regard to the definite findings of previous Commissions, to the consequent practice of the Local Government Board in insisting on the provision of land for the purification of sewage, and to the fact that the artificial processes are still only in the experimental stage, and, as might be expected therefore, the evidence in regard to them is inconclusive on many points, it has appeared to us essential to subject

the artificial processes to sustained examination, and also carefully to test the contention that in certain cases it is not practicable to purify sewage by land treatment.

11. At the time of the investigations of the earlier Commissions, the science of bacteriology was in its infancy, and these Commissions confined themselves almost entirely to a chemical examination of sewage effluents. Since the dates of those Commissions a large amount of exact knowledge has been gained concerning the part played by bacteria in various processes of nature and operations of man, and it became our duty to study the various questions connected with sewage disposal, not only from a chemical but from a bacteriological point of view as well. This has largely increased our labours, but we trust will also largely increase their usefulness. We have had to initiate and carry out various bacteriological investigations, and, in particular, finding that the work done by earlier Commissions in regard to land treatment was not complete enough for our purposes, we have thought it necessary to include in our work a systematic investigation, bacteriological as well as chemical, of the treatment of sewage on land of various kinds. This investigation is on the point of completion.

Conclusion I.

15. We doubt if any land is entirely useless, but in the case of stiff clay and peat lands the power to purify sewage seems to depend on the depth of the top soil.

There are, of course, numerous gradations in the depths of top soil which are met with in nature, and it is not easy to draw the line between lands which contain a sufficient depth to justify their use and lands which do not.

We are, however, 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.

Further information with regard to this point will be available when our investigation of land treatment is completed.

Question II.—**Is it practicable uniformly 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?**

16. The following general classification will serve to show the nature of the artificial processes to which we refer:—

Closed septic tank and contact beds.
Open septic tank and contact beds.
*Chemical treatment, subsidence tanks and contact beds.
Subsidence tanks and contact beds.

* The expression "subsidence tanks" is intended to denote tanks which are used in such way that little or no "septic" action is produced.

Contact beds alone.
Closed septic tank followed by continuous filtration.
Open septic tank followed by continuous filtration.
Chemical treatment, subsidence tanks, and continuous filtration.
Subsidence tanks followed by continuous filtration.
Continuous filtration alone.

Conclusion II.

19. After carefully considering, however, 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.

No general rule as to what these safeguards should be can be laid down at present, and indeed it will, probably, always be necessary that each case should be considered on its own merits.

Bacteriological Qualities of Effluents. Sewage Effluents in Relation to Disease.

20. As we have already said, sewage effluents must, in accordance with present knowledge, be judged not only from a chemical but also from a bacteriological point of view. In order to safeguard public health, it is, in certain cases, at any rate, not enough to know the chemical features of an effluent, and to ascertain that it will not putrefy of itself; we must know the bacteriological features as well.

21. Several witnesses have referred to the danger of allowing pathogenic organisms to enter streams which are used for drinking purposes, and our own officers are carrying out careful prolonged investigations on this matter.

We are impressed with the great importance of the bacteriological questions which have arisen in the course of our inquiry, but we do not at present feel justified in putting forward any conclusions concerning them.

We may, however, even at this stage point out that as a result of a large number of examinations of effluents from sewage farms and from artificial processes we find that while in the case of effluents from land of a kind suitable for the purification of sewage there are fewer micro-organisms than in the effluents from most artificial processes, yet both classes of effluents usually contain large numbers of organisms, many of which appear to be of intestinal derivation, and some of which are of a kind liable, under certain circumstances, at least, to give rise to disease.

We are of opinion, therefore, that such effluents must be regarded as potentially dangerous; and we are considering whether means are available and practicable for eliminating or destroying such organisms, or, at least, those giving rise to infectious diseases.

Question III.—What means should be adopted for securing the better protection of our rivers?

22. From the evidence which we have received, from our own observation, and from information collected for us by the Local Government Board for Scotland, we are satisfied that the Rivers Pollution Prevention Act, 1876, has not resulted in the general purification of our rivers.

23. This is due largely to the reluctance of the authorities to put the Act in force, but partly also to the difficulty which a sanitary authority experiences in proving that the pollution within its district comes from the district against which, or the person against whom, action is taken. An authority wishing uniformly to enforce the Act in its own district has no security that the authorities above and below it on the stream will do the same, and it is therefore naturally disinclined to take action.

Conclusion III.

30. We consider it of the utmost importance that the simplest possible means should be provided for adequately protecting all our rivers; and we are further of opinion that it will be desirable, probably for some time to come, that scientific experiments should be carried on in order to ascertain all the real dangers of pollution, against which they should be protected.

In the present state of knowledge, and especially of bacteriology, it is difficult to estimate these dangers with any accuracy, and it seems quite possible that they should be either exaggerated or undervalued according to the predisposition of those who have to deal with them. An authority, guided by medical considerations, might not unnaturally be inclined to insist on a degree of purity which may ultimately prove in certain cases to be uncalled for, while another authority, with its mind fixed upon economy, might shrink from taking essential precautions.

31. It is, perhaps, scarcely for us to say what arrangements should be made; but we are of opinion that the general protection of our rivers is a matter of such grave concern as to demand the creation of a separate Commission, or a new department of the Local Government Board, which shall be a supreme rivers authority, dealing with matters relating to rivers and their purification, and which, when appeal is made to them, shall have power to take action in cases where the local authorities have failed to do so.

The Second Report of the Commission was dated 7th July, 1902, and formally presented, without further observation, a series of reports by their expert officers on various questions of importance, chiefly on the bacteriology of sewage and effluents, and the pollution of the River Severn in the Shrewsbury district.

The Third Report of the Commissioners was dated the 2nd March, 1903, from which the following clauses are abstracted :—

We find that sewage containing trade effluents is generally more difficult to purify than ordinary sewage, and that the following are the chief causes of difficulty :—

1. The trade effluents may be turned into the sewer at irregular intervals, so that the composition of the sewage as it arrives at the sewage works varies considerably throughout the day.
2. The trade effluents may contain large quantities of solids in suspension which tend to choke the purification plant.
3. The trade effluents may be very acid or very alkaline, or otherwise chemically injurious.

The general opinion of these witnesses, however, is that it is practicable, in the great majority of cases, to purify mixtures of sewage and trade effluents if the manufacturers adopt reasonable means for removing the solids, equalizing the discharge, and, when necessary, neutralizing the trade effluent.

Moreover, there is some evidence to indicate that even if the manufacturers do not adopt such means the purification of the mixture of sewage and trade effluents is still practicable, though the difficulties and cost are much greater.

But the evidence clearly shows that wherever practicable the manufacturer should adopt means for removing the bulk of the solids in suspension from his effluent, for neutralizing it, and for delivering it into the sewer in a fairly uniform manner. And further, it would seem probable that in some cases the cost to the manufacturer of adopting these preliminary measures would be less than the additional cost which would be thrown on the local authority if the measures were not adopted. Indeed, there is evidence to show that occasionally the removal of the solids has been a source of profit to the manufacturer.

We have examined a large number of effluents from works where sewage containing trade refuse is being treated, and our results fully support the view that it is practicable in the great majority of cases to purify mixtures of sewage and trade effluents if the manufacturers adopt reasonable preliminary measures.

Separate Purification of Trade Effluents by Manufacturer.

18. We have not yet examined in detail the methods available for the purification of trade effluents, but from an inspection of some manufactories where considerable sums have been expended on purification plant which is inefficient, and also from the evidence, we are satisfied that in some cases at least the purification of the trade effluent by itself would be very difficult to accomplish.

Moreover, the evidence shows that the separate purification of trade effluents is generally more difficult and more costly than their purification when mixed with the ordinary sewage of the locality.

And it has been proved by the evidence and by our own inspection of manufactories that there are many cases, especially in towns, where the manufacturer has not sufficient space on which to erect purification works.

20. The position therefore is as follows:—

Purification of trade effluents by the local authority is in the great majority of cases practicable; purification by the manufacturer is in some cases difficult, if not impracticable; while purification by the manufacturer would generally be more costly than purification by the local authority. It also appears that the local authorities as well as the manufacturers are of opinion that there should be laid on the local authority a distinct obligation to receive trade effluents.

21. Further advantages which would follow from such a change in the law would be that the average standard of purification which would be reached throughout the country would be higher than if each manufacturer separately attempted to purify his own trade effluent, and also that the work of preventing the pollution of rivers would be greatly assisted in that the number of purification works to be kept under observation would be diminished.

Alteration of Law.

22. We are therefore of opinion that the law should be altered so as to make it the duty of the local authority to provide such sewers as are necessary to carry trade effluents as well as domestic sewage, and that the manufacturer should be given the right, subject to the observance of certain safeguards, to discharge trade effluents into the sewers of the local authority if he wishes to do so.

We do not think it possible to provide by direct enactment what these safeguards should be. In each district it would probably be desirable that the local authority should frame regulations which should be subject to confirmation by a central authority. In most cases, however, these regulations could provide definite standards for the different manufacturers as regards preliminary treatment, and it appears from the evidence that manufacturers would much prefer to have standards to work to.

Power to vary the standards or to dispense with them altogether in special cases would be necessary.

23. Although the duty of receiving trade effluents should, we think, be imposed on the local authority, cases may arise in which they should be wholly or partially relieved of it.

For example, we find that in some instances the effluent discharged from the manufactory is of a composite character, the greater part of which might with advantage be easily dealt with by the manufacturer if it were kept separate. In such cases we think the manufacturer would generally be willing to adopt this course, but provision is necessary for those cases in which the local authority and manufacturer could not agree.

Further, although we have received no conclusive evidence to show that there are trade effluents which could not be purified by the local authority, we do not deny the possibility of such cases arising.

And it is possible that in some cases—as, for example, of a large manufactory being newly established in a small district—it might be necessary to relieve the authority of the obligation to treat the trade effluent or to enable them to exact some special contribution from the manufacturer not only for the cost of treatment, but also towards capital expenditure.

24. It is obvious, therefore, that some tribunal will be required for settling differences between the local authority and the manufacturer, and for relieving the local authority in exceptional cases either wholly or

partially of their obligation to provide sewers and disposal works of sufficient capacity for trade effluents as well as ordinary sewage.

We shall explain in a later section the plan which we think should be adopted.

Riparian Rights.

25. In many cases a part or the whole of the water which the manufacturer uses in his business is obtained from a stream, and must therefore be returned to the stream.

We do not propose that the manufacturer should by statute be relieved of this liability. If he is able to relieve himself from the obligation by obtaining the necessary consents from other riparian owners or by providing compensation water, then he might discharge his effluent into the sewer, but the responsibility must rest entirely on the manufacturer: the local authority should be expressly exempted from any liability for the infringement of riparian rights by the discharge into the sewer of water obtained from a stream.

Special Charge on Manufacturer.

26. We have taken a considerable amount of evidence on the question whether the manufacturer who discharges his trade effluent into the sewer should be required to pay something beyond his ordinary rates, and, as might be expected, the views expressed are divergent.

It appears that in some few cases manufacturers have by agreement with the local authority purchased the right to discharge crude trade effluents into the sewer.

27. The chief argument which has been used against a special charge being made is that a manufacturer who is heavily rated in respect of his premises is therefore entitled to the free use of the sewer.

This argument raises a general question of rating into which we do not propose to enter, but we may observe that other manufacturers producing little or no trade effluent are rated equally, and that, speaking generally, the amount of the trade effluent is not proportional to the rateable value of the premises.

29. Having regard to these considerations, we are of opinion that generally no special charge should be made on the manufacturer in those cases in which the regulations as to preliminary treatment are complied with.

As we have already stated, it is desirable that wherever practicable, some preliminary treatment should be carried out by the manufacturer.

But where the manufacturer is unable to comply with these regulations we consider that the local authority should be empowered to make a special charge.

Power should also be granted to make a special charge, even when preliminary treatment is adopted, where there are exceptional circumstances as regards volume, quality or otherwise.

30. We should leave the actual amount of the charges to be fixed by agreement between the manufacturer and the local authority.

In default of agreement the amount should be settled by a superior authority in the manner hereinafter explained.

31. In those cases in which a manufacturer is precluded from discharging his effluent into the sewer by reason of the fact that the water which

he uses is obtained from a stream, and must therefore be returned to the stream, the duty of purification will still rest with him.

But we do not consider that this will be a serious grievance, as he obtains his water without charge, and this advantage may be set against the cost of purification.

Moreover it would be open to him to acquire the right to use the sewer by getting his water from some other source or by obtaining the necessary consents of riparian owners below him on the stream.

II. THE NEED OF SETTING UP A CENTRAL AUTHORITY.

The Settlement of Differences between Local Authorities and Manufacturers.

40. In an earlier section of this Report we have referred to the necessity of providing machinery for the settlement of differences between local authorities and manufacturers.

The chief questions upon which differences may arise are the following—

1. The refusal of a local authority to allow a particular trade effluent to enter their sewers.
2. The refusal of a local authority to construct or enlarge sewers for the purpose of a particular manufactory.
3. The question of varying general regulations as to preliminary treatment by the manufacturer.
4. The amount of the special charge to be imposed on the manufacturer.
5. The removal of sludge.

Central Department Essential.

44. In our opinion a properly equipped central authority is essential, and we unhesitatingly recommend the creation of such an authority.

In the interests of river purification as well as of the trade of the country we consider it is of the highest importance that the changes in the law which we have recommended should be made. But these changes would not in our opinion be of much use apart from the creation of a central authority for the determination of differences between the local authority and the manufacturer.

If the settlement of these differences be left to the ordinary Courts, differential treatment of manufacturers, with all the objections to it, will be certain to continue.

45. The central authority should have the following permanent chief officers:—

1. An administrative head.
2. A bacteriologist having special knowledge of the bacteriology of sewage, trade effluents and water supply.
3. A chemist having special knowledge of the chemistry of sewage, trade effluents and water supply.
4. An engineer having a special knowledge of geology and water supply.

It should also be provided with a laboratory.

46. The officers of the central authority must be clothed with the necessary powers to conduct inquiries, to call witnesses, to enter premises to take samples of the trade effluent, and generally to do such acts as are necessary for the proper performance of their duties.

47. At any inquiries which may be held neither counsel nor expert witnesses should be heard except with the special permission of the central authority.

48. The work of the central authority will be so intimately connected with the work of the Local Government Board that it will be desirable to make it a new department under the Local Government Board rather than an entirely separate department.

The Pollution of Rivers and the Protection of Sources of Water Supply.

60. At an early stage of our investigation we were struck by the fact that in many parts of England the pollution of rivers goes on unchecked, notwithstanding the fact that the Rivers Pollution Prevention Act has been on the Statute Book for over a quarter of a century, and in our Interim Report we deemed it necessary to state that the protection of our rivers is a matter of such grave concern as to demand the creation of a Supreme Rivers Authority.

General Position of our Inquiry.

77. In conclusion, we think it may be desirable briefly to explain the position of our investigations.

78. At the commencement of our inquiry we devoted considerable attention to general questions relating to the chemical and bacteriological analysis of sewage and sewage effluents.

The methods of bacteriological analysis which we have adopted are explained in a paper by Dr. Houston, which we presented with our Second Report.

A paper is now in preparation by Dr. McGowan in regard to chemical analysis, which will contain a detailed account of the work which has been done under our direction, with a view of settling the value of different methods of analysing sewage effluents.

79. We have completed a systematic investigation of the land treatment of sewage on farms of different kinds of soil.

This investigation has extended over a period of two years, and has embraced the bacteriological, chemical and engineering aspects of this method of disposing of sewage.

80. We are now making a similar investigation of artificial processes of various kinds at about thirty distinct places. This investigation will, we hope, be completed in about a year.

In addition certain authorities are, in conjunction with us, making similar systematic observations in regard to a number of artificial processes.

When these results have been collected, we shall endeavour, in compliance with the instructions contained in the second part of our Terms of Reference, to report on the different methods of treating sewage in the same and in dissimilar sets of circumstances.

81. In the meantime, we are taking evidence as to the discharge of sewage, sewage effluents, and manufacturing effluents into tidal waters. The importance of this subject as regards the contamination of shellfish

has recently come into prominence. It is indeed a matter of great importance from the point of view both of public health and the fishing industries.

82. We are also continuing the investigations which we referred to in our Interim Report, for the purpose of ascertaining whether it is practicable to destroy those micro-organisms which are common to sewage effluents, and which may be dangerous, if the effluent flows into a river from which water for drinking is obtained, and we are generally considering what measures may be desirable to lessen dangers so arising.

83. Subsequently we propose to consider the methods available for the satisfactory disposal of manufacturing effluents when not mixed with ordinary sewage.

The Pollution of Water Supplies.

The inference to be drawn from the presence of the Bacillus Coli Communis and its allied forms in normal domestic water supplies, is a subject of the greatest interest and importance. The relation of the question to the character of sewage effluents necessitates a careful review of the question, and with a view to elucidate some of the points involved, the following *résumé* of the question may appropriately conclude a discussion of one of the vexed questions of the day in connection with sanitary science and practice:—

Bacillus Coli Communis in Potable Water.

The subject may be divided under several heads—

1. The nature and source of the Bacillus Coli Communis.
2. The means by which it may gain access to water supplies.
3. The pathogenic character, if any, of this organism.
4. The deduction to be drawn from the presence of the Bacillus Coli Communis and Coli-like organism in various numbers in a given quantity of water.
5. The presence of the Bacillus Coli Communis in ordinary articles of diet consumed in an uncooked state, and on ordinary articles frequently handled.

Dealing with these several points *seriatim*, the results of numerous investigations have shown that—

1. The Bacillus Coli Communis is a minute organism resembling a very short rod, with rounded ends, of such a size that about one thousand millions would be required to cover a surface of one square inch. It possesses from one to three flagella or whip-like processes attached to its extremities.

It was first obtained by Emmerich, in 1885, from the blood, various organs, and alvine discharges of cholera patients at Naples; afterwards by Weisser, in 1886, from normal and abnormal human fæces, from the air and from putrefying infusions; by Escherich from the fæces of healthy children; and has since been shown to be constantly present in the alvine discharges from healthy men and the lower animals.

This latter point was fully discussed in the *Lancet*, March 5th, 1904, by Dr. J. W. H. Eyre, of the Bacteriological Laboratories, Guy's Hospital, who showed that the Bacillus Coli was present in the fæces of the mouse, rat, guinea-pig, rabbit, cat, dog, sheep, goat, horse, cow, fowl, duck, pigeon, sparrow, and sea-birds. Also in fish caught two miles from land, viz.:—sprat, smelt, mullet, dab, sole, plaice, john dory, dog-fish, and skate. Dr. Eyre concluded a very valuable contribution to the question by observing, "Without going so far as to say that these results point to the presence of the Bacillus Coli as a normal inhabitant of the intestinal canal of fish in general—such a contention is neither warranted nor justified by these few observations—I would point to the necessity for further experiments in the direction I have indicated before assuming that the presence of Bacilli Coli is synonymous with *sewage contamination*."

The following reactions are specifically indicative of the organism or organisms which are known under this name. If these are not obtained, the organism isolated is not classified as Coli Communis or typical Bacillus Coli:—

Preliminary—

Bile-salt Glucose media. (MacConkey.) Reaction—Acid and Gas.

Secondary—

Litmus Lactose Agar, or Nutrose serum Agar.	(surface).	Reaction—Typical acid producing colonies.

Confirmatory—

Motile Small Bacillus. Length 1 to 4 times its breadth.

Reactions—

Always.	Litmus Lactose media (Durham tubes) ..	Acid and Gas.
	,, Milk media	Acid and clotting.
	Surface gelatine	Thin, smooth, non-liquefying growth.
	Stab gelatine	Growth well developed to bottom of stab.
	Shake gelatine	Irregular flat bubbles.
Usually.	Peptone broth or water	Indol reaction.
	Neutral red broth	Fluorescence and turbidity.

The neutral red reaction is not insisted on, but failure to obtain the indol reaction raises a suspicion as to the identity of the bacillus.

The American practice, according to Dr. Kinnicut, is to add ten separate quantities of one c.c. each to ten MacConkey tubes, and incubate at 37 deg. Cent. Unless more than two of these tubes show acid and gas, no further action is taken; if more than two give that reaction, the sample is regarded with suspicion, and sub-cultured.

2. The means by which the Bacillus Coli may gain access to ordinary water supplies are necessarily variable. In the case of waters drawn from rivers, this may be by discharges of sewage and sewage effluents from sewage works, surface drainage from manured lands, roads, farms, &c., conveying ordinary animal excreta.

In the case of underground water supplies the nature of the soil will affect the question considerably, especially in regard to the depth at which the water is collected. Supplies from gravel soils especially are open to suspicion; but in the case of deep wells in the chalk the water must percolate through immense masses of chalk, and thereby receive a degree of filtration which practically precludes contamination. The presence of fissures in the chalk will, when unduly present, affect this point.

Variations will occur according as the climatic conditions affect the level of the water in the soil. During dry weather the subsoil water level will fall, and the water percolating downwards through the chalk will have a greater degree of filtration than in wet weather, when the water level is higher. Thus the effect of the drainage from the surface of cultivated land, &c., bringing with it a larger proportion of the unoxidised organic matters, will be more in evidence. Should this effect be marked the ordinary analytical results will indicate it, but if it is only of such a slight nature that a few bacteria find their way into the area of supply, then the bacteriological result may point to the presence of such organisms, a result, however, which by no means is to be held as indicating "recent sewage contamination," especially if one particular organism having no known pathogenic effect is selected for the purpose of supporting the statement, quite regardless of the fact that other organisms which are known to be invariably present in all sewage-contaminated waters are conspicuous by their absence.

Dr. Klein stated in evidence before the Court of Arbitration *re* London Water Supply (p. 571) that if he went to the Welsh or Scotch hills, where there was nothing but sheep, we should find the Bacillus Coli in the water.

3. The pathogenic character of the Bacillus Coli Communis has not been demonstrated. Dr. Klein, at the inquiry mentioned above, stated that "The Bacillus Coli that is typical for sewage, although of intestinal origin, is not necessarily a dangerous type of bacteria. In one case it was found to be so." . . . "The Bacillus Coli taken in by the mouth may produce serious results." . . . "It was found that in the majority of cases

the organism was not pathogenic when introduced subcutaneously into the guinea-pig."

In answer to Sir Edward Fry (Q. 4076): "Taking all the experiments you have made and the number of these Bacilli Coli which you have found, are there any of them which you can be sure would be pathogenic if taken into the digestive system of man?"

Dr. Klein said: "I could not be sure of that. I can give you instances where organisms of that type have produced disease, belonging to the Coli group."

(Q. 4077): "I can understand that, but none of these you could lay your hand on?"

Dr. Klein: "I could not."

In their evidence before the Royal Commission on Water Supply, 1893, Drs. Odling, Ray Lankester, and Sims Woodhead all agreed that a small dose of even pathogenic organisms cannot produce disease.

4. The deduction to be drawn from the fact of the presence of the Bacillus Coli Communis and Coli-like organisms in various numbers in a given quantity of water has been discussed by many authorities.

Tabulating various determinations made by Dr. Houston, the numbers of Bacilli Coli Communis in sewage, &c., are as follows:—

London Sewage	Average 600,000 per c.c.
,, ,, Sludge from	From 1,000,000 to 10,000,000,000 per c.c.
Thames Water, Barking Creek	From 100 to 1,000 per c.c.
,, ,, Purfleet	About 100 per c.c.
,, ,, Grays	Over 100, but less than 1,000 per c.c.
,, ,, Mucking	About 10 per c.c.
,, ,, Chapman	,, 1 in 5 c.c.
,, ,, Barrow Deep	,, 1 in 5 c.c.
,, ,, Sunbury and Hampton	,, 40 per c.c.
,, ,, Twickenham	,, 100 per c.c.
London Filtered Water	One or less per c.c.
Pure Sea Water	None

Other results obtained by myself are:—

	Maximum.	*Minimum.*
Chalk Wells	Present in 0·1 c.c.	Not present in 100 c.c.
Filtered River	,, ,, 1·0 c.c.	,, ,, 100 c.c.
Moorland Water	,, ,, 1·0 c.c.	,, ,, 100 c.c.
Chalk and Greensand, Deep wells	Not in 100 c.c.	,, ,, 100 c.c.
Shallow Wells	Present in 1/50 c.c.	—

In connection with the discussion of the absence of the Bacillus Coli from sea-water Dr. Houston remarks (p. 182, Royal Commission, 4th Report, Vol. 3, 1904):—" It is indisputable that the presence of birds and fish, and also of drainage from manured land, may, as regard water samples, affect bacteriological results. But practically speaking this consideration does no more than suggest the prudence of not pushing an extremely delicate test too far, and of not laying undue significance on the mere presence of Bacilli Coli."

On p. 103 of the same report Dr. Houston further remarks *apropos* of the question of standards, " Those having most reason to speak authoritatively on these matters admit the paucity of our knowledge of water-borne epidemics and the existence of controlling factors in relation to the spread of disease by water concerning which our knowledge is practically *nil*."

On p. 104 of the same report Dr. Houston states with great force, " Further, a Bacilli Coli pollution of, say, 1 per c.c., due to the dejecta of an enteric fever patient, would be of the greatest consequence, but if such a Bacilli Coli pollution were known to be derived from a non-specific source it would be, relatively speaking, unobjectionable."

In his summarised conclusions, Dr. Houston, on p. 109, on the classification of waters by the Coli test, states :—" That this division of waters into classes does not involve necessarily the difficult question of absolute standards, but it may be convenient to condemn or object to a water of the fourth class, *i.e.* (+ 1 – 0·1 c.c.); regard with some degree of suspicion a water of the third class, *i.e.* (+ 10 – 1·0 c.c.); consider not wholly free from evidence of probably objectionable pollution a water of the second class, *i.e.* (+ 100 – 10 c.c.); and unconditionally on the basis of results approve a water of the first class, *i.e.* (– 100 c.c.)."

Drs. Thresh and Sowden, in their paper before the Incorporated Society of Medical Officers of Health, said that "to regard a water with two bacilli in the same quantity as unpolluted, and one with three bacilli in the same quantity as polluted, is utterly absurd. We must confess that in our opinion little stress can be laid upon the detection of the Bacillus Coli alone; to be of definite significance it must be associated with other organisms of intestinal type, and especially with some organism fairly easily recognizable. We regard the Bacillus Enteritidis Sporogenes of Klein as being such an organism, and our scheme of examination involves :—(1) The detection of the presence of organisms of intestinal type; (2) The isolation and detection of the Bacillus Coli Communis; (3) The detection of the spores of the Bacillus Enteritidis Sporogenes. We believe that this is the minimum amount which will enable anyone to say positively that a water is fæcally contaminated."

In their classification Drs. Thresh and Sowden state :—

" 1. Waters showing the absence of organisms capable of fermenting glucose, and of the Bacillus Enteritidis Sporogenes.

" These are regarded as being free from any evidence of pollution.

"7. Waters containing organisms of the Coli Group other than the Bacillus Coli Communis, but no spores of the Bacillus Enteritidis Sporogenes.

"These we do not regard as dangerously polluted but as probably coming from a source such as that referred to under 6—*i.e.*, manurial matter probably used on the collecting area.

"9. Waters containing the true Bacillus Coli Communis, but no spores of the Enteritidis Sporogenes.

"Such waters are occasionally met with. No opinion can be expressed without an intimate knowledge of the source. We have had such water from a source absolutely free from the possibility of contamination, but usually subsequent examination has revealed the presence of B. Enteritidis Sporogenes. The proximity of manured soil is strongly indicated."

Finally, these authorities say:—"The correct interpretation of the results of a bacteriological examination requires more than a knowledge of bacteriology. The most expert bacteriologist cannot hope to give an opinion worth having unless he has made a study of the characters of waters from the most diverse sources."

Dr. Klein, F.R.S., in his article in the *British Medical Journal*, February 21st, 1903, on the "Bacterioscopic Diagnosis of Sewage Pollution of Shellfish," remarks, on p. 6:—"2. The fact that a microbe owing to insufficient response to certain presented tests can only be described as a Coli-like microbe is at present of indeterminate value in making a definite diagnosis of sewage or other pollution.

"3. B. Coli Communis is a microbe which has its habitat in bowel discharges—that is, excremental matters—and is contained therein in enormous numbers; its presence, therefore, in any material in appreciable and relatively large amounts is highly suggestive of sewage and excremental pollution."

The American experience on this question is well expressed in the following extracts from a paper by Samuel C. Prescott, Instructor in Bacteriology in the Bacteriological Laboratories, Massachusetts, "On certain precautions required in making and interpreting the so-called 'Colon test' for potable waters." On p. 6 he remarks:—"My results in any event do not invalidate the Colon test, but simply make plain the necessity for special care and judgment in its application and in the interpretation of results. They strongly support the statement made by Dr. Theobald Smith in 1892, and later by Freudenreich and a few other investigators, that it is the *number* of Colon Bacilli present in a water, rather than the *presence* of this organism, which should be considered in deciding whether or not recent sewage pollution of the water has taken place. Judging from the results obtained by my friend and colleague, Mr. C.-E. A. Winslow, who has carefully studied a large number of polluted and unpolluted waters in Massachusetts, and whose paper on that subject will be shortly published, the presence of B. Coli in 1 c.c. of the suspected water in a large proportion of cases is required in order to establish reasonable proof of sewage pollution. It may be necessary to modify this standard somewhat for other and more agricultural parts of the country, but the important point is that if the Colon Bacillus is found only rarely, or only in large samples of water, its presence has no great sanitary significance."

In *Technology Quarterly*, Vol. XVI., No. 3, September, 1903, Messrs. C.-E. A. Winslow and C. P. Nibecker, of the Biological Laboratories of the Massachusetts Institute of Technology, published the results of their investigations on "The Significance of Bacteriological Methods in Sanitary Water Analysis." On p. 230 *et seq.* they remark :—"Bacillus Coli has frequently been found in large samples of waters of fair sanitary quality. Prescott has shown the identity of this organism with certain lactic-acid bacteria found upon grain and other cereals. Whipple remarks that 'Bacillus Coli, if not widely distributed in nature, resembles certain common bacteria in all points covered by the usual tests'; but it by no means follows, as he states, that 'this throws doubt upon the use of this organism as a conclusive test for fæcal contamination.' Many German bacteriologists, particularly the pupils of Kruse, at Bonn, have indeed concluded, because they could isolate Colon Bacilli from good waters by the examination of a series of litre samples, that the test was valueless. It is essentially, however, a question of less or more. Colon Bacilli are either wanting in good waters or are so rare as not to be found in the examination of samples of 1 c.c.; they are found in a majority of 1 c.c. samples of water so polluted as to be dangerous for drinking. Between these two extremes their numbers vary with the amount of the pollution. Klein and Houston in England, Jordon and Winslow and Hunnewill in America, and very recently Petruschky and Pusch in Germany, have exhaustively studied the distribution of the Colon Bacillus with uniform results. That the absence of this organism demonstrates the harmlessness of a water, as far as bacteriology can prove it, no one would probably hesitate to acknowledge; and that, when present, its numbers form a trustworthy measure of its sanitary condition the observers above quoted have proved beyond reasonable cavil."

G. C. Whipple, writing in *Technology Quarterly*, Vol. XVI., 1903, p. 18, considers that a water giving a positive presumptive test of the presence of B. Coli in 1 c.c. is questionable, and in one-tenth of a cubic centimetre as probably unsafe; and this view, in the opinion of Messrs. Winslow and Nibecker, seems justified by all the evidence at hand.

Nevertheless, Messrs. Winslow and Nibecker, in their summary of bacteriological methods, p. 236, consider that the full bacteriological examination of the future will include an examination for Streptococci in addition to the B. Coli. In this view they are at one with my own practice and that of Drs. Thresh and Sowden, who maintain that corroborative evidence is required before condemning a water as polluted, but Winslow and Nibecker select the Streptococcus, whilst Thresh and Sowden prefer the indications afforded by the Bacillus Enteritidis Sporogenes. This difference is practically immaterial, the main point being the admission of the desirability of corroborative tests by the detection of sewage organisms other than the B. Coli.

Many other authorities could be quoted on this point, but the above will serve to indicate with sufficient clearness the points at issue.

5. The significance to be attached to the presence of B. Coli in potable waters must be considered in the light of common sense as well as theoretical deduction. So far the whole of the argument appears to circle round the question as to whether a water is to be considered as more or less dangerously polluted by the mere fact that it contains a certain number of organisms of a definite type, no evidence being adduced whether these organisms are really pathogenic or not, especially in the attenuated degree in which they are present. The upholders of the pollution theory argue that as the B. Coli are present in excrementitious matter of all kinds *à priori* the water containing them must, or may, to that extent equally contain other objectionable and possibly dangerous bacteria which may cause disease, and this, apart from the fact that before disease can be conveyed an enormously greater proportion of the bacteria in question must be present to have any effect. (See evidence of Drs. Odling, Ray Lankester, and Sims Woodhead, 1893, already referred to above.)

As shown above, Dr. Klein could not be sure that any of the B. Coli would be pathogenic if taken into the digestive system of man, and it is clear that the carefully guarded statements of Dr. Houston and others as to the inference to be drawn from the presence of B. Coli are fully justified.

There can be no question as to the presence of B. Coli in uncooked foods, especially after exposure for sale in shops, &c., nor as to their presence on clothing. I have detected the presence of B. Coli Communis on lettuces, even after washing, as well as on tomatoes, which are frequently consumed uncooked, unwashed and unskinned. I have also found gas-forming organisms in an active state in cooked whitebait served in a public restaurant. It is, therefore, obvious that enormous numbers of organisms of the Coli group are habitually taken into the system without specific deleterious results.

Winslow and Hunnewill, in their paper on "Streptococci Characteristic of Sewage and Sewage-polluted Waters apparently not hitherto Reported in America," published in *Science* (U.S.), Vol. XV., No. 386, May 23rd, 1902, state: "We first isolated the sewage Streptococci of Houston in the Spring of 1901, in a study of the bacteria occurring on the hands, chiefly of students and school-children, where they were found in two out of some hundred specimens of wash-water examined in both cases in conjunction with the Bacillus Coli," and they expressed themselves as convinced that record of the presence or absence of the Streptococci of Houston should be made in any sanitary bacteriological water analysis, thereby again confirming the view of other experimentalists that the deduction to be drawn from the presence of Coli alone should be confirmed by a search for other typical organisms.

Another frequent means of distributing B. Coli is atmospheric dust. It has been shown that this organism is present in the excreta from horses and other animals, and I have found it in numbers in ordinary street débris. The effect in dry weather in much-frequented thoroughfares is that they are largely present in the atmosphere of our streets, and that, in windy weather especially, we may be subject to the effect of more Coli by breathing than by drinking water containing one or more of those organisms per cubic centimetre.

To condemn a water, therefore, which contains no sign of contamination other than a few B. Coli, but gives negative reactions to all the tests for other objectionable bacteria, such as B. Enteritidis Sporogenes, Streptococci, &c., and also fails to respond to the most delicate chemical and microscopical tests for those substances which are known to be present in sewage-polluted waters, but which, on the contrary, exhibits all the characteristics of an exceedingly pure water, is rash in the extreme, and may be the cause of unnecessary alarm tending to do more harm than good, as nervously-constituted people who have no knowledge of the true facts of the case are easily affected by the spectre of an unknown danger.

It should be clearly borne in mind that all natural waters are liable to contain such an omnipresent organism as the B. Coli Communis and its allies, and that before it can be said that any particular water is polluted with excrementitious matter confirmatory evidence should be obtained as to the presence of other organisms of a sewage-derived nature; and, further, that the sample examined is collected in such a manner as to absolutely preclude the possibility of contamination after leaving the original source of supply. In the absence of such confirmation we may safely conclude, when all other evidence is of a satisfactory nature and the source of the water is known, that no undue stress need be laid on the fact that a particular organism which is ever present in our daily surroundings happens to have gained access in extremely limited numbers to such a supply.

APPENDIX I.

RECENT IMPROVEMENTS IN THE BIOLOGICAL TREATMENT OF SEWAGE.*

In February, 1904, I had the honour of placing before the Society certain suggestions with reference to the use of horizontal layers of slates, tiles or other suitable material for the purpose of facilitating the destruction of the matters held in suspension in sewage, and thus "effectually meet the sludge difficulty."

I now propose to submit for the consideration of the members the results of actual work accomplished on the lines then laid down. In the previous paper referred to, a series of results were given showing the effect on the organic matters in solution when the layers of slate were placed at intervals of 2 ins. apart. For the purpose of testing the question as to whether satisfactory results could be obtained when the layers were placed at greater or less intervals, I am permitted to quote from the results given by Dr. David Sommerville of the State Medicine Laboratories, King's College, London, in a paper which was published in *Public Health*, September, 1904, viz. :—

"The immediate object of the experiments to be described was to determine the degree of purification, as measured by decrease in albuminoid ammonia, corresponding with definite spaces between the slabs of slate, with the view of establishing, if possible, an optimum space.

"Crude sewage, obtained through the kindness of Dr. Clowes from the London outfall, was used throughout. Operations were carried out in two laboratory tanks of different sizes, containing horizontal rows of slate slabs, arranged at distances apart, varying from 1 in. to 12 ins. Care was taken that the conditions of temperature, time given to filling and emptying the tank, time of contact of sewage with slates, &c., were as nearly as may be constant. The temperature was maintained at 16° C. to 18° C. Half an hour was allowed for filling a tank, half an hour for emptying, and two hours for undisturbed contact. Five hours were allowed for rest.

* A paper read by the Author before the Society of Chemical Industry, April 9th, 1906.

"The optimum vertical space between the rows of slabs, as indicated by the experiments, appears to be about 4 ins. A few examples selected from a large number of results will serve to make this manifest":—

No. of experiment.	Distance between rows of slab.	Percentage reduction of alb. ammonia.
	In.	
5	1	25
7	2	31
11	2	30
17	3	50
19	3	52
23	4	56
29	6	45
35	12	18
37	12	17

The Corporation of Devizes, having decided to make a series of experiments with the view of ascertaining how far the method of filling the primary contact beds with slate would answer for the sewage of that town, instructed their surveyor, Mr. F. G. Billingham, to construct a pair of experimental beds (Fig. 11), the first to be filled with slate placed at from 2 ins. to 3 ins. apart and having an initial gross capacity of 12½ cb. yds., and the second having an initial gross capacity of 25 cb. yds. and filled with breeze. This arrangement was intended to test the relative working powers as to quantity of sewage treated. If the preliminary experiments held good in practice the reduction in the size of the primary beds would be warranted. The results entirely confirmed the suggestion that this reduction in first cost would be justified.

The beds were first started at work in January, 1904, and were continued at work for eighteen months, when they were put out of use, as the whole of the sewage was then treated on the new beds which had been constructed to replace the old system of chemical precipitation and sludge pressing.

[The results of analyses made from time to time of the sewage, slate bed effluents and breeze bed effluents will be found in Table (First Series) on page 49.]

These results were so far satisfactory in that they showed that the work of treating unscreened and unsettled sewage on the slates could be accomplished without nuisance from accumulated sludge and with the production of an effluent which was ready for final treatment on suitable fine beds. The effluents from the breeze beds, however, were not up to the standard, and a careful examination was made as to the cause, when it was found that a large proportion of the material was too coarse, much

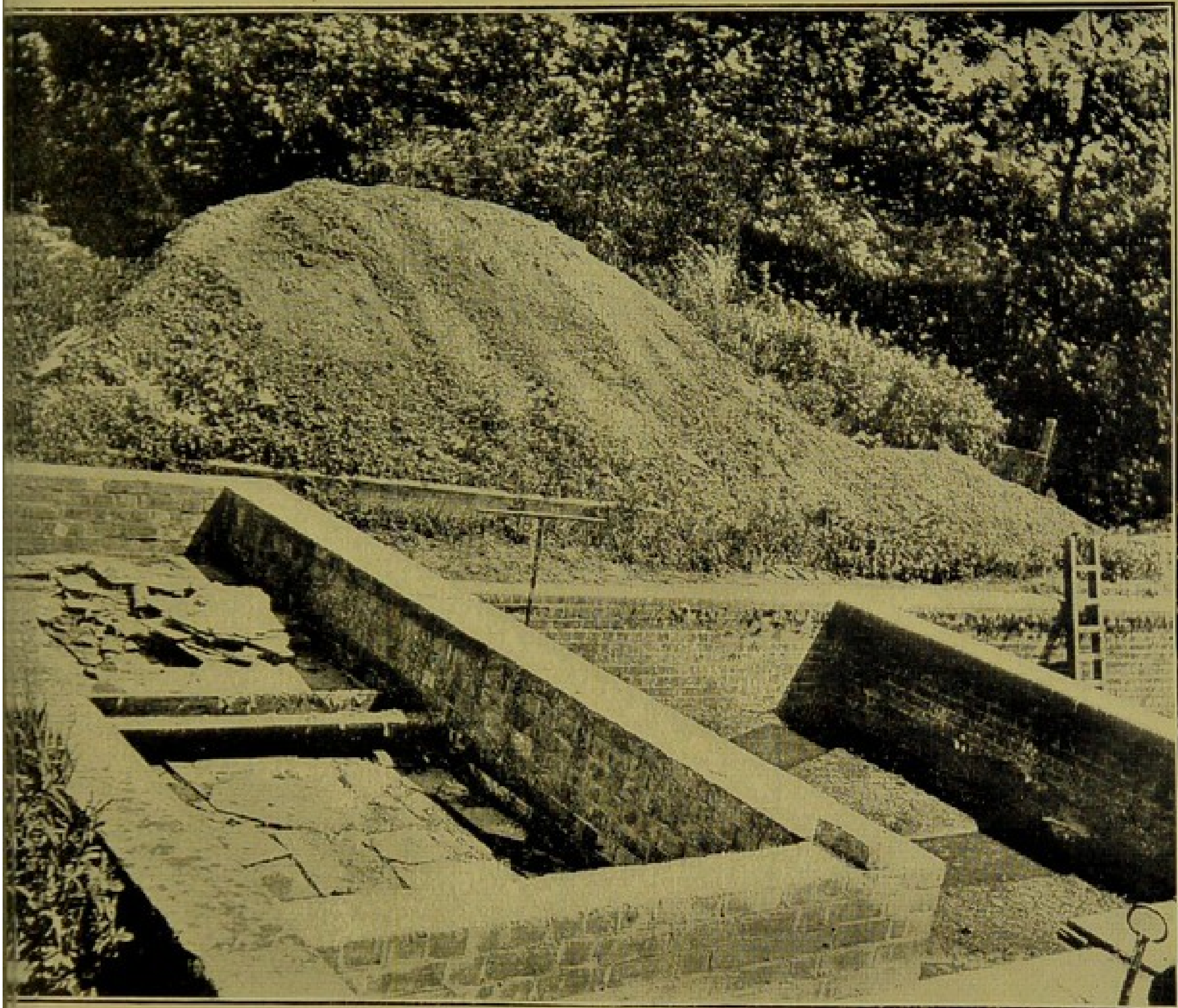


Fig. 11. Experimental Beds at Devizes.

First Series.

Table of Results of Analysis of Samples of Sewage and Effluents from the Experimental Slate and Breeze Bacteria Beds at Devizes, Wiltshire.

Date of collection. 1904.	Sewage.			Slate Bed Effluent.						Coke Breeze Bed Effluent.				
	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Purification per cent.		Suspended matters.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Purification per cent.	
	Free.	Albuminoid.	In 4 hours.	Free.	Albuminoid.	In 4 hours.	Alb. NH_3.	Oxygen absorbed 4 hours.		Free.	Albuminoid.	In 4 hours.	Alb. NH_3.	Oxygen absorbed 4 hours.
Jan. 29 ..	2·42	0·815	6·20	1·09	0·535	2·32	33	62	Traces	2·09	0·465	4·37	42	29
Feb. 3 ..	7·20	1·701	6·56	5·66	1·263	8·10	26	+	,,	5·34	0·602	5 85	64	11
,, 10 ..	0·82	0·462	7·76	1·23	0·448	7·67	3	1	,,	3·76	0·483	5·60	+	28
,, 11 ..	3·29	1·029	8·85	4·42	0·558	5·43	46	38	,,	1·36	0.396	3·00	61	66
,, 20 ..	8·19	0·990	5·92	8·50	1·015	6·59	+	+	,,	7·05	0·994	4·08	+	31
,, 24 ..	7·52	1·086	7·00	7·51	1·086	7·00	0	0	,,	6·42	0·959	4·20	12	40
,, 27 ..	4·28	1·200	6·40	Br	oken	—	—	—	,,	4·56	0·959	5·04	19	21
March 3 ..	6·46	1·554	8·82	5·56	1·204	6·53	22	26	,,	5·90	0·976	3·77	37	57
,, 11 ..	3·50	1 099	8·99	3·45	0·381	5·82	65	35	,,	3·58	0·144	3·04	86	66
,, 28 ..	6·41	1·428	20·00	6·02	0·843	3·50	41	33	,,	6·02	0·749	5·30	48	73
April 5 ..	5 27	0·689	4·34	5·62	0·568	3·64	17	16	,,	—	—	—	—	—
,, 14 ..	7·37	0·680	8·70	6·80	0 572	7·86	16	11	,,	3·97	0·335	3.60	50	58
,, 20 ..	10·31	1·470	9·55	9·66	1·050	8·25	28	13	,,	7·68	0·420	6·38	71	33
,, 20 ..	4·23	1·045	9·30	3·00	0·525	8·38	50	10	,,	2·50	0·332	6·02	68	35

of it running to 1—2 ins. in diameter. The bed was then refilled with suitable fine material, averaging from a quarter of an inch to one thirty-second of an inch. This was satisfactory.

[The analytical results obtained are given in Table (Second Series) on page 53.]

It was noticed that at the end of the discharge from the slate beds a small quantity of semi-black matter flowed out from the bed. This was retained on the surface of the fine bed and there underwent disintegration, and on being removed and thrown out on the surface of the adjoining ground dried up into a condition resembling ordinary mould, no offensive odours being emitted in the process. This was so far satisfactory in that it meant that there was a self-cleansing action going on by which the capacity of the beds would be retained for a longer period than would otherwise be the case. A sample of this matter was collected and submitted to careful chemical and bacteriological examination with the following results, viz. :—

	Per cent.
Water	38·6
Organic matter	25·2
Mineral matter	36·2
	100·0

The organic matter was found to consist almost entirely of the zoogloea masses of bacteria, the appearance under the microscope being comparable to an ordinary gelatin culture. A sample of the deposit on the top of the slate at about 18 in. below the surface of the beds was then collected, as also one from the under surface of the slates in the same position. The following are the results of the examination :—

Sept. 15, 1904.	Deposit from top of slate 18 ins. below surface.	Deposit from under side of slate 18 ins. below surface of bed.
	Per cent.	Per cent.
Moisture	75·3	65·7
Organic matter	9·5	12·7
Mineral matter	15·2	21·6
	100·0	100·0
	Per cent.	Per cent.
Organic matter in the dry material	38·4	37·2
Nitrogen in the dry material	1·94	5·1
Bacteria per grain of wet material	=199,000,000	207,000,000

The microscopical examination of the matter from the upper surface of the slate revealed the presence of mineral débris, grit, &c. Spiral vessels, human hairs, leptothrix, anguillulæ, vorticellæ, various starch cells, &c.

The matter from the under surface of the slate contained diatomacæ, infusoria, starch cells, spiral vessels, monadina, spores of fungi, confervæ, hairs, muscular fibre, fragments of insects, &c.

On March 10th, 1905, further samples of the black "humus" discharged from the slate bed were collected and examined when fresh and after weathering, with the following results:—

	Fresh material.	Weathered material.
Appearance.	Black and smooth spreading.	Like ordinary mould.
Odour.	Sewage.	None.
	Per cent.	Per cent.
Organic matter in dry material....	40·5	32·5
Mineral matter in dry material....	59·5	67·5
	100·0	100·0
Nitrogen per cent. on organic matter	8·42	7·62

The high nitrogen in the black "humus" from the slate bed was doubtless due to the large number of living organisms it contained. The experiment on the "weathering" is of the highest importance as showing the manner in which the solid matters of the sewage can be disposed of without nuisance, especially when it is remembered that these beds received the sewage without being either screened or settled.

After the beds had been at work for fourteen months, being charged on an average twice a day, the capacity of the slate bed was measured, when it was found to hold 50 per cent. of the original gross cubic content of the tank up to the level of the slate filling. It was then roughly flushed out, when the capacity rose to 64 per cent. Some of the slates at the sides were then removed, in order to allow the remainder of the slates to be flushed with a hose, which so thoroughly cleansed the slates that the water capacity rose to 82 per cent., which was the cubic content of the bed when newly filled with the slates, thus showing that by this simple method the beds can be restored, when required, to the condition of a new bed. This particular bed, being the first constructed on a working scale, was not laid with the same skill as is now obtainable, nor were the slates as well split, especially the supporting blocks between the different layers of slate. As now arranged, the water capacity of a new bed is about 87 per cent. of the total cubic content of the tank up to the level of the top layer of slate.

The whole of the sewage of the town was turned on to the new installation on September 12th, 1905, with the results of entirely confirming the above experiences with the experimental beds.

[The analytical results obtained will be seen in Table (Third Series) on next page.]

The effluent from the fine bed is then discharged on to land.

The deposit from the slate beds has been allowed to flow on to the surface of the fine beds and there collected in channels, from whence it is removed and thrown up in heaps on the surface of the fine beds to undergo weathering after which it is again spread out on the surface of the bed. In future installations arrangements will be made for this matter being discharged on to a special area of ashes or similar material, so as to keep the surface of the fine beds as open as possible.

Experimental trials of the use of the slate have also been made by the Corporation of Trowbridge, who, however, placed the effluent from a septic tank upon them as well as on beds filled with granite, sandstone, coke and other material. The analyses of the respective effluents were made by Mr. Waterfall, F.I.C., &c., of Bristol, who reported that "in either case slate gave the best results," and as a result the Corporation are filling one half of the primary beds with that material.

Slate beds are also in operation at the works at High Wycombe for the purpose of eliminating the sludge difficulty, the effluent from these being discharged direct on to the land with satisfactory results.

From these various results it is evident that the suggestion to use beds filled with layers of slate divided by distance pieces has been justified, and that the method, although doubtless subject to improvement, deals effectually with the sludge difficulty, and renders the sewage fit for the further process of purification on either contact beds, sprinkling beds or on land when such is obtainable of suitable quality and quantity.

With regard to the discharge of sewage direct into the sea, it is evident that the preliminary breaking up of the solid matters by inoffensive digestion on a slate bed would be an immense improvement over the common custom of sending it in with all the solid matters, which float along the coast and form offensive deposits on the shore, as I found to be the case in one instance where the whole of the foreshore for a considerable distance at low water was reeking with sulphuretted hydrogen, and the stones and rocks and many of the seaweeds coated with *Beggiatoa alba*, the well-known "sewage fungus," whilst *Bacillus coli communis* was abundant in all the samples collected. Such a state of things could not arise if the sewage before its discharge had been subjected to preliminary aërobic action on such beds as described above.

Table of results of analysis of samples of Sewage and Effluents from the Experimental Slate and Breeze Beds at Devizes, Wiltshire.

Quantities stated in grains per gallon.

Date of Collection.	SEWAGE.								SLATE BED.										NEW BREEZE BED WITH FINER MATERIAL.									
	Chlorine.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Suspended matters.		Dissolved solids.		Chlorine.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Purification per cent.		Suspended matters.		Dissolved solids.		Chlorine.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Purification per cent.		N as NO_3.	Suspended matters.	Dissolved solids.	
1904.		Free.	Albuminoid.	In 4 hours.	Total.	Volatile.	Total.	Volatile.		Free.	Albuminoid.	In 4 hours.	Alb. NH_3.	Oxgn absorbd 4 hours.	Total.	Volatile.	Total.	Volatile.		Free.	Albuminoid.	In 4 hours.	Alb. NH_3.	Oxgn absorbd 4 hours.		Total.	Total.	Volatile.
April 28..	—	8·26	0·875	10·80	—	—	—	—	—	8·03	0·497	9·58	45	11	—	—	—	—	—	5·26	0·049	11·17	94	?	—	—	—	—
May 13..	8·0	4·82	1·166	7·11	35·3	31·0	89·5	30·0	7·25	4·80	0·693	5·85	40	18	2·0	2·0	80·0	28·6	7·2	4·77	0·052	1·94	96	73	—	*Nil*	128·6	20·1
June 1..	7·0	5·18	0·860	3·89	69·3	32·7	54·1	14·3	7·26	5·08	0·542	3·69	37	5	4·6	2·1	57·6	16·1	8·6	3·13	0·130	0·81	91	79	0·368	,,	120·3	16·2
,, 20..	12·4	10·11	1·020	7·70	47·8	23·5	82·6	15·1	11·62	11·60	0·696	6·30	31	18	16·9	2·6	58·6	13·2	12·7	2·43	0·121	1·06	88	86	1·068	,,	144·4	20·4
July 4..	8·1	8·25	9·030	4·92	30·5	11·6	63·9	16·2	8·33	9·69	0·606	4·92	33	0	8·1	3·8	66·6	18·3	8·3	2·75	0·168	1·02	81	79	0·936	,,	107·6	11·2
Aug. 9..	25·6	5·78	0·787	4·24	40·2	9·6	100·4	20·0	24·60	5·73	0·569	4·30	27	—	37·0	8·4	92·0	20·0	19·4	5·51	0·263	1·49	66	65	Tr.	Tr.	121·3	5·5
Sept. 5..	20·3	7·72	1·060	4·85	61·8	52·4	90·2	15·8	20·30	7·30	0·787	4·35	26	10	12·6	6·8	84·4	16·8	19·8	2·84	0·357	3·05	67	37	*Nil*	,,	88·6	13·6
,, 26..	8·4	8·89	0·606	5·11		lost			9·01	9·39	0·455	3·76	24	26		lost			7·1	3·57	0·130	1·26	78	76	1·117	,,	lost	
1905.																												
Jan. 1..	6·0	7·26	0·899	5·37	71·0	41·0	49·8	6·8	7·55	7·03	0·892	5·48	1	0	Traces		62·6	24·0	9·0	2·12	0·402	2·42	55	55	1·240	*Nil*	80·0	14·0
March 6..	17·1	1·59	1·179	5·70	74·4	52·9	79·4	13·0	9·60	1·43	0·481	5·01	59	11		,,	63·0	10·8	11·6	1·06	0·234	0·79	80	86	0·250	,,	82·7	9·2

These effluents did not putrify on incubation.

THIRD SERIES.

Table of results of analysis of samples of Sewage and Effluents from the Devizes Reorganised Works, treating the whole of the Sewage of the Town.

Quantities stated in grains per gallon.

Date of collection.	SEWAGE.								SLATE BED EFFLUENT.										FINE BED EFFLUENT.											
	Chlorine.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Suspended matters.		Dissolved solids.		Chlorine.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Percentage purification.		Suspended matters.		Dissolved solids.		Chlorine.	Ammonia.		Oxygen absorbed from permanganate at 80° F.	Purification per cent.		Nitrogen as.		Suspended matters.		Dissolved solids.	
1905		Free.	Albuminoid.	In 4 hours.	Total.	Volatile.	Total.	Volatile.		Free.	Albuminoid.	In 4 hours.	Alb. NH_3.	Oxgn absorbd 4 hours.	Total.	Volatile.	Total.	Volatile.		Free.	Albuminoid.	In 4 hours.	Alb. NH_3.	Oxgn absorbd 4 hours.	Nitrites.	Nitrates.	Total.	Volatile.	Total.	Volatile.
Sept. 12 ..	Sewage turned on to new works.																													
,, 17 ..	9·1	7·45	0·47	4·58	?	?			11·3	4·42	0·446	4·99	6	0	Traces		—	—	12·0	2·60	0·210	2·31	55	50	0	0	*Nil*		—	—*
Oct. 20 ..	12·5	8·27	1·86	12·15	499·9	220·6	118·2	34·2	15·2	4·58	1·344	4·84	29	60	,,		107·2	20·2	14·1	4·32	0·108	0·72	94	94	0	0	*Nil*		92·3	20·5*
1906.																														
Jan. 9 ..	12·6	7·29	1·10	8·36	32·5	15·S	97·5	31·5	10·2	5·31	1·020	6·02	7	28	7·0	5·8	73·5	1·0	7·7	3·23	0·021	0·56	92	93	0·60		Traces		—	—*

*Did not putrify on incubation.

In reply to the discussion, the author observed that he was glad to find that there was now a general agreement as to the aërobic principle being the correct one. He (Mr. Dibdin) had been fighting this battle for years, and congratulated himself that at last the point was being conceded in all directions. Even the strongest supporters of the anaërobic theory admitted that it was quite possible to "over septicise" the crude sewage, which was a convenient phrase to intimate that putrefaction was a blunder. In due time they would admit that the action took place to the best advantage when the sludge was laid out in thin layers on a well-drained surface in the presence of air, as in land treatment under the best conditions. This was precisely the principle and practice of the slate bed, which thus came nearer to nature's method than any artificial treatment which had been proposed.

APPENDIX II.

THE DISPOSITION AND ANALYSIS OF SEWAGE DÉBRIS IN CONTACT BEDS.*

PREVIOUS to the recognition of the efficacy of biological action on the refuse matters deposited from sewage, it was generally considered sufficient to estimate the mineral and organic matters by simple combustion, and to determine the percentage of nitrogen in the organic matter, and sometimes the phosphoric acid, in order to obtain the requisite data on which to form an opinion as to the origin and existing condition of the matters in question. In some instances the organic carbon was determined in addition to the above factors. For instance, the late Sir Edward Frankland, in the course of a lengthy investigation as to the origin of the deposits in the bed of the River Thames, drew up the following table, and used it as a guide in forming his conclusions:—

THAMES MUD INQUIRY, 1879-80, p. 495.

—	Ratio of N : C.			N per Cent. on Organic Matter.		
	Minimum.	Maximum.	Mean.	Minimum.	Maximum.	Mean.
Mud from sewers	1 : 5·4	1 : 8·7	1 : 6·8	4·8	7·4	5·9
Polluted muds	1 : 4·6	1 : 7·6	1 : 5·7	3·6	6·3	4·9
Unpolluted muds	1 : 8·8	1 : 9·6	1 : 9·1	1·8	3·0	2·3
Fæces	—	—	—	—	—	7·7

The nitrogen per cent. on the organic matter has been calculated from Frankland's figures, and the last factor added for further comparison.

Whilst these general results are of undoubted value when used with discretion, they yet leave much unsaid, and may entirely mislead under

* A paper read by the Author before the Society of Public Analysts, March, 1907.

certain conditions which were not contemplated at the time. For instance, when examining the deposit on the slates in the biological beds at Devizes, I obtained the following results:—

—	Deposit from top of Slates 18 inches below surface, September 15, 1904.	Deposit from under side of Slates 18 inches below surface, September 15, 1904.	Fresh Humus discharged from Slate Bed, March 10, 1905.	Weathered Humus from Slate Bed, March 3, 1905.
Nitrogen per cent. in the organic matter	5·10	13·80	8·42	7·62

If judged by the simple percentage of nitrogen in the organic matter, the obvious conclusion would be that three out of the four samples were more impure than the strongest sewage. Further investigation, however, showed that these high nitrogen values were due to the presence of enormous numbers of living organisms of various types, including worms, &c. Cultures on nutrient gelatine gave the following results:—

—	Deposit on top of Slates 18 inches below surface.	Deposit on under surface of Slates 18 inches below surface.
Moisture in mud, per cent.	75·3	65·7
Colonies developed on nutrient gelatine per gram of wet mud	3,044,000,000	3,167,000,000

It is therefore clear that the "nitrogen per cent." factor when taken alone is unreliable, as the influence of the presence of living tissues is sufficient to entirely vitiate the conclusion. This point has been generally hitherto recognized, but the extent to which it affects the problem in certain cases has probably not been fully appreciated in its modern bearings.

With the view of obtaining a further insight into the question, I collected two series of samples of the deposit on the slate biological beds —one from those at Devizes after they had been at work for fourteen months, and another from those at High Wycombe after about nine months' work. These two series are of special interest, as those from Devizes are from sewage of an exceptionally foul character, whilst that of

High Wycombe is probably one of the weakest in England, and the two series may be taken as fairly representing the extremes in this respect. It must not be overlooked, however, that sewage débris is of about the same general character whether the volume of water is more or less, the strength of the sewage affecting the character of the effluent to a greater extent than that of the deposit.

In each series three samples were collected in such a manner as to follow the variations which had taken place with the increasing age of the deposit—viz.: Sample No. 1 was carefully scraped from the surface of the deposit, and may be taken as representing the most recently deposited débris, with its adhering bacterial gelatinous film, &c.; sample No. 2 was collected as nearly as possible at about half-depth; and sample No. 3 was taken from the under portion next to the slates. It was noticed that in each case large numbers of minute worms, monadina, anguillulæ, and other organisms were present, the worms especially indicating the aërobic conditions which prevailed. The following are the results of the respective examinations:—

Sewage Mud from Slate Beds at Devizes, November 13th, 1906.

——	Surface of Deposit on Slates.	Half-depth of Deposit on Slates.	Bottom layer of Deposit on Slates.	Average.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	80·00	80·50	79·70	80·07
Mineral matter	9·05	8·76	8·53	8·78
Organic matter	10·95	10·74	11·77	11·15
	100·00	100·00	100·00	100·00
On Dried Mud.				
Mineral matter	45·25	45·00	42·00	44·08
Organic matter	54·75	55·00	58·00	55·92
CO_2	5·8	7·0	4·0	5·6
Ether extract (fat, &c.)	9·62	5·9	7·7	7·41
Organic carbon	20·19	20·09	17·86	19·38
Organic nitrogen	5·98	3·12	3·71	4·30
Ratio N : C	1 : 3·4	1 : 6·4	1 : 4·7	1 : 4·83
Nitrogen on dry organic matter	10·8	5·65	4·70	7·05
On Wet Mud.				
Free ammonia	0·028	0·013	0·023	0·021
Albuminoid ammonia	0·112	0·135	0·045	0·098
Bacteria, per gram	725,000,000	495,000,000	240,000,000	480,000,000

Microscopical Examination.—Large numbers of worms, monadina and other infusoria, anguillulæ, bacteria, both free and in the zooglœa condition, and usual sewage débris.

SEWAGE MUD FROM SLATE BEDS AT HIGH WYCOMBE, SEPTEMBER 28TH, 1906.

——	Surface of Deposit on Slates.	Half-depth of Deposit on Slates.	Bottom layer of Deposit on Slates.	Average.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	83·68	84·31	84·86	84·28
Mineral matter........	7·95	7·75	7·46	7·72
Organic matter........	8·37	7·94	7·68	8·00
	100·00	100·00	100·00	100·00
On Dried Mud.				
Mineral matter........	48·66	49·40	49·27	49·11
Organic matter........	51·34	50·60	50·73	50·89
CO_2	1·84	3.88	3·24	2·97
Ether extract (fat, &c.)	5·13	7·12	6·89	6·38
Organic carbon........	17·31	25·07	23·15	21·88
Organic nitrogen	3·46	4·64	3·73	3·94
Ratio N : C	1 : 5.0	1 : 5·4	1 : 6·2	1 : 5·5
Nitrogen on dried organic matter	6·6	9·2	7·3	7·7
On Wet Mud.				
Free ammonia	0·065	0·065	0·060	0·063
Albuminoid ammonia ..	0·270	0·250	0·235	0·252
Bacteria, per gram	160,000,000	190,000,000	50,000,000	133,000,000

Microscopical Examination.—Usual sewage débris, with large numbers of small worms, monadina and other infusoria, anguillulæ, bacteria, both free and in the zooglœa condition.

In each case the deposits were without offensive odour, such as would have been evolved from an ordinary sewage sludge. In the bulk the odour was described by Dr. G. J. Fowler as slightly resembling that of seaweed. When kept for a time in closed bottles an extremely offensive odour was evolved, due to the decomposition of the organisms which freely flourished under normal aërobic conditions. When the deposits were exposed to the air and allowed to "weather," as it is generally termed, the mass became friable and odourless.

An important point brought out in the two series is that the collection of a mass of the deposit, without differentiating the respective layers, may yield entirely misleading results. For instance, the bulk would be that represented by the middle and bottom layers. In the case of Devizes, the mean of these two would be 5·17 per cent. of nitrogen on the organic matter, which, according to Frankland's table, would indicate merely a polluted mud as opposed to a sewage mud; but in the immediate surface layer we find 10·8 per cent., which would indicate a deposit more foul than fæces.

Again, the ratios of nitrogen to carbon, in the case of the Devizes samples, show variations from 1 : 3·4 to 1 : 6·4. In the first layer we have thus a more highly nitrogenous body than that in the strongest sewage, as indicated by the percentage of nitrogen on the organic matter.

Similar differences are indicated by the percentage of fat, &c., extracted by ether, and clearly show the necessity of differentiating the respective layers as representing the various ages of the deposit.

I am kindly permitted by Dr. G. J. Fowler, Consulting Chemist to the Rivers Committee of the Corporation of Manchester, to quote the following results, obtained by him in collaboration with Mr. J. Clifford. In the following table are given the results of analyses of material from the Devizes experimental slate beds. These form part of a research at present in progress, and are preliminary only. The Society will, nevertheless, I am sure, be indebted to those gentlemen for their permission to include them in the present paper for the purpose of discussion.

SAMPLES OF UNWEATHERED AND WEATHERED DEPOSIT FROM THE EXPERIMENTAL SLATE BEDS AT DEVIZES—COLLECTED JULY 8TH, 1905.

	Unweathered 1 mm.	Weathered 1 mm.	Unweathered ¼ mm.	Weathered ¼ mm.
	Per cent.	Per cent.	Per cent.	Per cent.
Organic matter........	56·5	45·0	57·0	40·1
Carbon in dried substance, 100°	29·10 29·32	17·14 16·86	30·05 30·19	24·21 23·96
Average......	29·21	17·00	30·07	24·07
Hydrogen in dried substance, 100°	4·03 4·13	2·47 2·52	4·26 4·22	2·37 2·52
Average......	4·08	2·50	4·24	2·44
Nitrogen in dried substance, 100°	3·80	1·99	3·31	1·83
Carbon on organic matter	51·7	37·7	52·7	60·2
Hydrogen ,, ,,	7·2	5·5	7·4	6·1
Nitrogen ,, ,,	6·7	4·4	5·8	4·5
Ratio N : C.	1 : 7·7	1 : 8·5	1 : 9·0	1 : 13·0

On turning to the averages in Frankland's table, we find that the lowest carbon ratio for unpolluted mud is 8·8, varying up to 9·6, so that the carbon ratio in the weathered samples is even greater than that in an unpolluted mud, and clearly points to the complete degree of purification effected.

Facilities for carrying out a bacteriological examination of the deposit on the Devizes and High Wycombe beds were kindly furnished by Professor Delépine, the work being done by Dr. Sellers under his supervision. The results are given in the following table, which also gives Dr. Fowler's results of the examination of the same deposit. It is interesting to note the apparent correspondence of the oxidation test with the bacteriological results. This test consisted in passing equal volumes of moist air over known weights of the samples, thence into standard baryta-water, and titrating the residual baryta with oxalic acid.

The production of carbon dioxide increases with the number of bacteria present; but other factors, such as worms, must not be overlooked.

Description.	Loss on Ignition.	Ether Extract.		Oxidation Test.
		On Dry Material.	On Loss on Ignition.	
Sample scraped from middle layer of deposit on slates. Devizes, November 21st, 1906.	54·52	6·00	11·0	1 gram dry material $=24{\cdot}6$ c.c. $\frac{N}{10}$ oxalic $=108{\cdot}4$ mgms. CO_2 $=198{\cdot}4$ mgms. CO_2 on organic matter.
Sample scraped from bottom layer of deposit next slates. Devizes, November 21st, 1906.	43·65	8·75	20·0	1 gram dry material $=7{\cdot}7$ c.c. $\frac{N}{10}$ oxalic $=33{\cdot}8$ mgms. CO_2 $=77{\cdot}4$ mgms. CO_2 on organic matter.
Sample taken from drying beds thoroughly weathered. Devizes, November 21st, 1906.	37·09	2·16	5·8	1 gram dry material $=0{\cdot}1$ c.c. $\frac{N}{10}$ oxalic $=0{\cdot}044$ mgm. CO_2 $=1{\cdot}14$ mgms. CO_2 on organic matter.

——	Bacteria, per Gram.	Prevailing Type.
Devizes: Top layer ..	6,200,000	White, non-liquefying; coli-like; few moulds.
,, Middle layer	200,000,000	Many moulds; yellow, liquefying; few coli-like.
,, Bottom layer	250,000,000	White, non-liquefying; numerous coli-like; moulds not numerous.
,, Thoroughly weathered from drying-beds.	4,500,000	White, non-liquefying; many liquefying; moulds numerous.

From an examination of these results it will be seen that the samples from the middle layer of the deposit, which contained 200 millions of bacteria per gram, yielded 198·4 mgms. of carbon dioxide per gram of organic matter; whilst a sample of the thoroughly weathered material from the drying-beds, containing only four and a half millions of bacteria per gramme, yielded only 1·14 mgms. carbon dioxide per gram of organic matter. This is a result which might have been anticipated in the light of the experiments made by F. Hatton (*Chem. Soc. Trans.*, 1881, 247), but the experimental demonstration of the oxidation of the carbon afforded by Dr. Fowler's results is, nevertheless, of the greatest importance, and, taken in conjunction with the reduction of the extractive matters, clearly indicates the inoffensive breaking down of the sludge, with elimination of nitrogenous, carbonaceous, and fatty matters.

An interesting point arises in comparing the results of the analyses of the Devizes and High Wycombe samples by myself and of those by Dr. Fowler and his colleagues. In my results the surface layer at Devizes contained the highest number of bacteria, whilst at High Wycombe the intermediate layer contained the highest number. In Dr. Sellers' results the middle and bottom layers contained the highest numbers. Dr. Fowler suggests that these differences may depend upon the surface layer consisting of fresh sewage, or upon weathered sewage, which was possibly the case in his samples. It is therefore advisable to carefully note whether the sample is taken just after filling a bed or following a period of rest.

In making the bacteriological examination the following method was adopted by Dr. Sellers: In each instance 10 grams of the deposit were weighed in a sterilized glass capsule and transferred to a sterile Winchester containing 990 c.c. of sterile water. After shaking for thirty minutes in a shaking machine the contents were allowed to settle for ten minutes. At the end of that time 1 c.c. was taken at a depth of about 5 mm. from the surface for preparing the various dilutions for making gelatine plates. The medium used was peptone bouillon gelatine, containing 10 per cent. of gelatine, and having a reaction slightly more acid than usual (+15). In the case of Nos. 1 and 2 control plates were made with ordinary gelatine, as used in the laboratory, but the results obtained with the two media showed no appreciable difference. The plates were incubated at 20° C. and counted on the fifth day.

In the examination of similar samples by myself, 1 gram of the deposit was first carefully broken up in a watch-glass with a glass rod, so as to carefully disintegrate all lumpy particles, thus doubtless more effectually breaking up the zooglœa masses.

The disintegrated matter was then diffused in a litre of water and thoroughly shaken to secure equal distribution. One c.c. of this litre was then taken *at once* and diffused in a second litre of water, which was again well shaken, and, without allowing any time for settlement, 0·2 c.c.

was withdrawn and used to inoculate an ordinary nutrient gelatine plate, a check test with 0·5 c.c. being made at the same time. The average colonies counted on the two plates after incubation at 22° C. was taken as representing the total number of bacteria. The variations in the two methods, especially in regard to the preliminary breaking up of the zooglœa masses and collecting the test quantities before allowing settlement to take place, doubtless accounts for the higher results obtained by me.

The main point brought out, however, is that, instead of the few millions per gram formerly supposed to be present in a sewage deposit in an active state of fermentation, there is now ample evidence that, under favourable conditions, the total number is far greater, and explains the remarkable power of living organisms, such as bacteria, in conjunction with those of a higher type, to effect the inoffensive decomposition of sewage matters on superposed surfaces when acting under ærobic conditions.

I have to express my sincere thanks to Professor Delépine, Dr. Gilbert J. Fowler, Dr. Sellers, and Mr. Clifford for so kindly permitting me to include in this paper the results of their valuable work in elucidation of some of the problems underlying this important question.

DISCUSSION.

The PRESIDENT having invited discussion,

Dr. FOWLER said Mr. Clifford and himself had analysed a large number of deposits from the Manchester Sewage Works, beginning with the original sludge, the sludge after septic tank treatment, then the humus washed out from the beds, and finally the matter deposited from the effluent, with the object of ascertaining the stages in the oxidation which took place. The carbon was determined by moist combustion with strong sulphuric acid and potassium bichromate. In many cases that process worked well, but some deposits which contained peaty matters and refractory cellulose were not oxidised completely. In Calcutta, where the deposits mainly consisted of an easily broken up form of cellulose, it was quite easy to oxidize them completely by this mixture. This suggested a possible means of differentiating between classes of organic matter by using different oxidizing agents and finding out the limits of their action. The complete analysis and investigation of a sewage deposit was really a small research in itself. In addition to ultimate analysis, air should be passed over the fresh sample and the amount of carbonic acid produced determined. Further, the fats should be estimated by ether extraction, and also the amount of cellulose. There was one point of importance in the aeration test—more carbonic acid was given off from the middle layer as compared with the others. By passing air over some samples of sludge from Davyhulme for a long time, only about 3 per cent. (on the organic matter) of carbonic acid was obtained, whereas in the examples given in the author's paper there was about 10 per cent. after a couple of days. The sludge they had worked upon at Davyhulme was free from worms, which were abundant in the deposits referred to by the author, and this, he thought, accounted for the varying results. This difference showed how easily a wrong conclusion might be drawn. In the instance cited he had been inclined to think that very little destruction of organic matter was taking place in the beds, whereas, if the sludge had been examined when it was fresher and contained the higher organisms, probably a good deal more carbonic acid would have been evolved. It might, perhaps, be of interest in reference to the question of the presence of higher organisms, to mention that occasionally a curious biological sequence was met with. In addition to worms, which were present in countless numbers in many of these beds, there were occasionally quite a large number of leeches, which apparently fed in their turn on the worms. There was little doubt that other organisms than bacteria played their part in the destruction of sewage matter.

Mr. SEYLER said the chemical or bacteriological examination of material like these deposits could have only a very rough value. Indeed, the determination of carbon, nitrogen, &c., in a material containing worms and leeches seemed to him to be a very unscientific proceeding. Of course, the mere number of bacteria found would depend very largely upon how completely the zooglœa was broken up, and also upon the extent to which the different organisms flourished in the gelatine.

Mr. JULIAN L. BAKER said it was a matter of considerable importance to dispose of brewery and distillery effluents containing large quantities of yeast; he would ask how the author thought the principle which had been described would apply to such abnormal sewage.

Mr. J. H. JOHNSTON asked how long the different layers of the deposits examined had been in the beds. It was important to know this in studying the changes taking place in the sludge. He supposed the bottom layers represented the oldest deposit, and the top layers fresh sludge; it would, however, be desirable to know the age of each layer. As the bacteriological examinations were made on the moist samples, had the numbers of bacteria found been calculated to a common percentage of water?

Mr. DIBDIN, in reply, said sewage sludge, after being weathered, ceased to be sewage, and reached a condition almost approaching that of garden mould. The deposit in a slate bed certainly contained a considerable quantity of water, but when washed out and dried on a drainage bed it became like powder. Of course only an approximate estimate could be made of the biological contents of the sludge. Indeed, as Dr. Fowler had said, a single sample would afford material for a research in itself, but questions of time and expense would not, as a rule, allow of this.

The great point to remember was that a high percentage of nitrogen in the sludge did not necessarily indicate bad condition. The nitrogen was probably derived from living tissues, and not from what were commonly called sewage matters. He was afraid that he could not at present say anything about the treatment of undiluted brewery effluents. It was a difficult question, and one which opened up a large field for discussion. He had recently undertaken to make certain experiments on the subject, but would rather not say anything about them now. With regard to Mr. Johnston's remarks, these examinations were, roughly speaking, made after the deposits had been in the beds something over twelve months. The point was to watch the gradation of the changes as far as possible, and to avoid such mistakes as might be made by taking up a mass of deposit and mixing it together. A very interesting physical characteristic of these deposits had been observed; the matter at the top was fairly homogeneous, but if a piece were cut off and turned over, the under-side would be found to have a cellular structure. Dr. Fowler had suggested that this was probably due to the generation of gas by the living organisms, which puffed out the fibrous part of the stuff after the more digestible matters had been eaten away. This showed the gradual change that took place from the upper layers of freshly-deposited mud down to the lower layers, which were full of these air-spaces. As would be seen from the table, the quantity of water in the deposits was about 80 to 85 per cent., and did not vary very much. It was interesting to note that the organic matter was generally only about 8 to 11 per cent.

The proportion of dye-works refuse in the Devizes sewage was comparatively small; it was largely composed of refuse from slaughter-houses, breweries, gasworks, and milk-factories.

APPENDIX III.

DOUBLE CONTACT TREATMENT.

Tables for Finding the Capacity and approximate Cost of Slate and Fine Beds required for Treating Sewage, on the Basis of the Local Government Board's Requirements.

THESE tables have been compiled for ready reference. The daily dry-weather flow of the sewage being ascertained, preferably by actual gaugings, the tables at once show the total cubic contents of the beds necessary for treating the whole of the sewage on the basis of either two volumes being treated as sewage and a further four volumes as storm-water, as permitted in those cases where a perfect separate system is in use—Table I.; or on the basis of three volumes being treated as sewage and three volumes as storm-water, as is necessary where a combined system of sewers exists—Table II.

The total combined capacity of the primary beds, which should preferably be eight in number, is calculated upon the fact that when these beds are filled with slate in superposed layers, separated by distance pieces, the working capacity of the beds may safely be taken as double that of the ordinary coke beds. In fact, when new, they have an actual working capacity of about 85 per cent. of the total cubic contents of the tank.

The fine-grained secondary beds are based upon the usual practice of assuming these in ordinary working condition to have a working capacity of 33 per cent.

The areas of storm-water beds, or suitable land, is based upon the rate of 500 gallons per superficial yard.

To facilitate the calculations of the designer, the number of tons of slate which would be required to fill the slate beds is given in column 5.

Columns 6, 7, and 8 give the approximate cost of an installation on the assumption of three different prices per cube yard of work, including filling material. In certain cases, where the beds can be made by simply excavating the solid clay, as at Sutton and Worcester Park, Harrow, &c., the cost may be largely reduced, and the factors in column 6 will serve as a guide. In other instances, where more or less concrete work, foundations, &c. are necessary, columns 7 and 8 may be used at the judgment of the designer of the scheme.

These tables are not to be assumed as giving absolute cost, but are merely intended to serve as rough guides in the preliminary consideration of a scheme, and it is hoped that they will be of some assistance in that respect, as saving much unnecessary "brain-fag" in working out suggestions.

It will be observed that the cost of the storm-water beds, if such are to be provided, or the alternative of prepared land, cannot be conveniently given, as circumstances vary so enormously. Suitable land may be available, and require but little cost in preparing it, whilst in other instances specially constructed beds will have to be prepared, and if the foundations are bad the cost will necessarily be much greater than under more favourable conditions.

No estimate is included for preliminary detritus tanks or screens, as by the use of the slate these are rendered unnecessary in the majority of cases where the separate system of sewers exists and the sewage is fairly free from manufacturing refuse containing much mineral débris. The surface of the slate bed itself acts as a screen of the most perfect kind, as it permits the thorough drainage of the detritus before its removal, thereby lessening the work very considerably, whilst indigestible matters which find their way into the beds will not interfere with their action, and in due time, when the slates are flushed down, these matters will be readily removed with the remainder of the mineral and carbonaceous refuse, and mix with the "mould" which results from the inoffensive "weathering" of these matters. Continued experience with the slate beds, however, indicate that, if not entirely self-cleansing, they are so to a very much greater extent than at first anticipated, and will necessitate flushing at only *very prolonged intervals*. Certainly both at Devizes and High Wycombe, after nearly two years' work, they show no sign of requiring cleansing, but apparently clear themselves of the *humus* automatically.

If sprinkler beds are preferred to fine contact beds for secondary treatment, the cost of the primary slate beds may be deduced from column 2.

TABLE I.

Capacity and Cost of Beds required for Double Contact Treatment of Sewage on the basis of :—

2 volumes to be treated as sewage, and

4 volumes to be treated as storm water.

Dry weather flow.	Cubic yards of beds required.			Tons of slate required for primary beds.	Cost of slate beds *plus* fine beds at*		
Gallons.	Slate beds at 66 per cent. capacity.	Fine beds at 33 per cent. capacity.	Storm water beds or land at 500 gallons per yard super.		15*s.* per cubic yard over all.	20*s.* per cubic yard over all.	25*s.* per cubic yard over all.
					£	£	£
2,000	12	24	16	4	26	35	44
4,000	23	46	32	8	53	70	88
10,000	59	117	80	20	132	176	220
20,000	117	235	160	39	264	352	440
30,000	176	352	240	59	396	528	660
40,000	235	469	320	78	528	704	880
50,000	293	587	400	98	657	876	1,095
60,000	352	704	480	117	792	1,056	1,320
70,000	411	821	560	137	924	1,232	1,540
80,000	469	939	640	156	1,056	1,408	1,760
90,000	528	1,056	720	176	1,188	1,584	1,980
100,000	587	1,173	800	196	1,320	1,760	2,200
120,000	704	1,408	960	235	1,584	2,112	2,640
140,000	821	1,643	1,120	273	1,848	2,464	3,080
160,000	939	1,877	1,280	313	2,112	2,816	3,520
180,000	1,056	2,112	1,440	352	2,376	3,168	3,960
200,000	1,173	2,347	1,600	391	2,640	3,520	4,400
400,000	2,347	4,693	3,200	782	5,280	7,040	8,800
600,000	3,520	7,040	4,800	1,173	7,920	10,560	13,200
800,000	4,693	9,386	6,400	1,564	10,560	14,080	17,600
1,000,000	5,867	11,733	8,000	1,956	13,200	17,600	22,000
1,200,000	7,040	14,080	9,600	2,347	15,840	21,120	26,400
1,400,000	8,213	16,426	11,200	2,738	18,477	24,639	30,798
1,600,000	9,386	18,773	12,800	3,129	21,118	28,159	35,198
1,800,000	10,560	21,119	14,400	3,520	23,759	31,679	39,599
2,000,000	11,733	23,466	16,000	3,911	26,400	35,200	44,000

* Note.—The cost of the storm water beds or land area, as the case may be, must be added to the above, which is for slate beds *plus* fine beds only.

TABLE II.

Capacity and Cost of Beds required for Double Contact Treatment of Sewage on the basis of:—

3 volumes to be treated as sewage, and

3 volumes to be treated as storm water.

Dry weather flow. Gallons.	Cubic yards of beds required. Slate beds at 66 per cent. capacity.	Fine beds at 33 per cent. capacity.	Storm-water beds or land at 500 gallons per yard super.	Tons of slate required for primary beds.	Cost of slate beds *plus* fine beds at* 15*s.* per cubic yard over all.	20*s.*	25*s.*
					£	£	£
2,000	18	36	12	6	41	54	68
4,000	36	72	24	12	81	108	135
10,000	90	180	60	30	203	270	338
20,000	180	359	120	60	404	539	674
30,000	269	539	180	90	606	808	1,010
40,000	359	718	240	120	808	1,077	1,346
50,000	449	898	300	150	1,000	1,347	1,674
60,000	539	1,078	360	180	1,213	1,617	2,021
70,000	629	1,257	420	310	1,415	1,886	2,358
80,000	718	1,437	480	240	1,616	2,155	2,694
90,000	808	1,616	540	270	1,818	2,424	3,030
100,000	898	1,796	600	300	2,021	2,694	3,368
120,000	1,077	2,158	720	360	2,426	3,235	4,044
140,000	1,257	2,514	840	419	2,828	3,771	4,714
160,000	1,437	2,873	960	479	3,225	4,310	5,385
180,000	1,616	3,232	1,080	539	3,636	4,848	6,060
200,000	1,796	3,592	1,200	599	4,041	5,388	6,735
400,000	3,592	7,183	2,400	1,197	8,081	10,775	13,469
600,000	5,387	10,775	3,600	1,796	12,122	16,163	20,204
800,000	7,183	14,366	4,800	2,394	16,162	21,549	26,936
1,000,000	8,979	17,958	6,000	2,993	20,203	26,937	33,671
1,200,000	10,775	21,550	7,200	3,592	24,244	32,325	40,406
1,400,000	12,571	25,141	8,400	4,190	28,284	37,712	47,140
1,600,000	14,370	28,740	9,600	4,790	32,333	43,110	53,888
1,800,000	16,160	32,320	10,800	5,387	36,360	48,480	60,600
2,000,000	17,960	35,920	12,000	5,987	40,410	53,880	67,350

* Note.—The cost of the storm-water beds or land area, as the case may be, must be added to the above, which is for slate beds *plus* fine beds only.

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