The experimental bacterial treatment of London sewage : being an account of the experiments carried out by the London County Council between the years 1892 and 1903 / by Frank Clowes and A.C. Houston.

London County Council.
Clowes, Frank, 1848-1923.

London, 1904]

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London County Council.

THE EXPERIMENTAL BACTERIAL TREATMENT

OF

LONDON SEWAGE,

BEING AN ACCOUNT OF THE EXPERIMENTS CARRIED OUT
BY THE LONDON COUNTY COUNCIL BETWEEN THE YEARS
1892 AND 1903,

BY

PROFESSOR FRANK CLOWES, D.SC.(LOND.), F.I.C.,
Chemist to the Council,

AND

A. C. HOUSTON, M.B., D.SC.

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[1904]

DIVISION I.

CHEMICAL AND GENERAL.

BY

PROFESSOR FRANK CLOWES, D.Sc. (LOND.), F.I.C.,

Chemist to the Council.

ERRATA (p. 210.)

Second paragraph and third line, for 141,600.000 read 126,500,000. Table 3, line May 4, in the first column of figures, for 195,000,000 read 119,500,000, and for the average in the same column read 126.500,000 instead of 141,600,000.

ADDENDA (p. 210.)

TABLE 3A. *Number of bacteria in sewage sludge produced at the Southern Outfall Works.*

Date.	Number of organisms in one cubic centimetre of sludge.		
	Total number of bacteria.	Number of B. coli.	Number of spores of B. enteritidis sporogenes.
June 8th, 1903	118,000,000	At least 1,000,000	At least 10,000, but not 100,000
" 9th "	57,000,000	At least 100,000, but not 1,000,000	"
" 10th "	149,000,000	At least 1,000,000	"
" 11th "	163,000,000	"	"
" 12th "	132,000,000	"	"
" 13th "	177,000,000	"	"
Average	132,666.666		
Average for both Outfalls	129,583,333		

TABLE 3B. *Average number of bacteria in sewage effluent.*

Date, Outfall, and number of samples.	Number of organisms in one cubic centimetre of effluent.		
	Total number of bacteria.	Bacteria which grow at 37° C. (blood heat).	Aërobic spores.
Barking, March, 1903 (seven)	8,585,714	5,100,000	234
Crossness, June, 1903 (six) ...	6,300,000	—	—
Average	7,442,857	—	—

Charts following p. 222.

All details furnished in these charts apply to mud and sand samples dredged from the bottom, and not to water samples.

ERRATA.

Page 3, line 12, for "milk of lime" read "lime water."

Page 63, three lines from bottom, for "6 feet" read "13 feet."

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INTRODUCTION TO DIVISION I.

THE disposal of the sewage of London has been placed under the charge of the London County Council. Originally the discharge of the crude sewage into the river Thames at various points in the vicinity of the City gave rise, especially in summer time, to very serious and widespread nuisance. This was obviated, for the time, by intercepting the discharges and taking the whole of the sewage by main sewers some fifteen or sixteen miles down river. The whole of the sewage of London, north of the river, was thus collected for discharge at Beckton or Barking, and this was known as the Northern Outfall. The whole of the sewage of London, south of the Thames, was collected at Crossness, and this constituted the Southern Outfall.

Before the sewage was discharged from these Outfalls into the river, it was decided that it should be freed from its suspended matter, which had undoubtedly been the principal source of nuisance. This matter had settled on the foreshores of the river as black mud, which at low water evolved foul odours; it had also floated, in summer time, as thick black masses on the surface of the river, and these, when agitated by the navigation or by natural means, had given rise to most offensive emanations. It was anticipated that the interception of this suspended matter would produce a great improvement in the condition of the river. This has been the case, and the foreshores have now become clean and sweet, while the river surface is no longer a source of foul odour from floating offensive masses of scum.

The removal of the suspended matter has been effected by passing the crude sewage slowly through a series of settling channels, the process of sedimentation being facilitated and hastened by the admixture of the sewage, before it reaches these channels, with solutions of lime and of sulphate of iron. The addition of these solutions, even in small proportion, was found not only to promote rapid sedimentation, but also to retard the foul condition both in the settled matter and in the effluent.

The effluent from this sedimentation passes direct into the river continuously at all states of the tide; it is almost free from suspended matter, and the small amount which it contains cannot lead to the formation of sediment on the river-bed. The sediment or "sludge" is removed from the settling channels into tank steamers, which take it far out into the estuary and discharge it on a falling tide. By this process of treatment the sludge is finally disposed of without giving rise to nuisance.

It has always been anticipated, however, that the effluent, as its volume increases with increase of population, would require further purification in order to avoid all risk of causing occasional offence. Treatment on land was found to be out of the question owing to the marshy nature of the low-lying land by the river. But when the results of experiments on bacteria-bed treatment were made known, the London County Council at once commenced the experimental treatment of a small portion of the London sewage by this method.

In the early stages the effluent, before it passed into the river, was experimented upon, and with most encouraging results. Then the crude unsettled sewage was passed into the bacteria-beds, and although an entirely satisfactory purification was attained the bacteria-beds were soon thrown out of action by being choked with the suspended matter of the sewage.

In the latest stages of the experimental treatment, the crude sewage was, therefore, subjected to sedimentation in a tank, and the effluent from this tank was passed into the bacteria-beds. By this means the choking of the beds by suspended matter was entirely arrested, although the time of passage of the sewage through the settling tank was restricted to a period of five hours only. It was found that the coke bacteria-beds underwent a loss of capacity, which was apparently due to the formation of bacterial growths upon the surfaces of the coke fragments, but that, when these growths had fully formed, an almost unchanging capacity remained, equal to about 30 per cent. of the empty space which had been filled with coke.

A further advantage resulted from this preliminary sedimentation. It was found that, if the sediment in the tank was left undisturbed, it underwent considerable reduction in amount, partly by conversion into gaseous matter (mainly methane) and partly by being changed into soluble or liquid substances. Over 60 per cent. of the sediment disappeared in this way, and it was evident that if the mineral road grit had been allowed to settle separately, the percentage reduction of the organic matter by this bacterial resolution would have been much greater.

Hence by working on the large scale with tanks for the sedimentation of the grit, which would be in duplicate and would be frequently emptied; and by letting these be followed by settling tanks of greater capacity for the slower passage of the sewage and the sedimentation of the organic suspended matters, the sludge might be obtained in two portions: (*a*) the mineral deposit, which could be thrown out upon the land without causing offence: (*b*) the organic deposit, which would be largely or possibly wholly disposed of by the resolving action of bacteria.

The effluent, resulting from these sedimentation processes, would finally be subjected to intermittent treatment in the bacteria-beds, and would after this treatment pass away in a condition in which even at summer heat it would never become offensive, and in which it could maintain indefinitely the life of fish.

Such are, briefly, the practical conclusions arrived at from the experimental bacterial treatment, and they have been fully confirmed when the proposed treatment has been applied at other places than the London Sewage Outfalls.

During the earlier part of this investigation the Council retained the services of an experienced bacteriologist, who has detailed the results of his observations in the second part of this book. His results embrace those obtained by the bacterial examination of crude London sewage, of the present effluent from sedimentation, and of the effluent from the earlier stages of the experimental bacterial treatment.

During the later stages of the experimental treatment, subsequent to the introduction of the preliminary sedimentation, which were finally carried out on a plant erected at Christ's Hospital, Horsham, the bacterial examination was made by the Council's chemical staff. The results indicated that a reduction in the bacterial content of the sewage resulted from its passage through the settling-tanks, and that a still further reduction took place in the coke-beds. The bacterial examination of the river water below the Council's Outfalls, by the chemical staff, also showed that the bacteria which were introduced into the river by the present effluent, underwent rapid reduction in numbers as they passed down the river. A similar rapid reduction in number of these bacteria derived from the sludge, occurred in the water of the estuary: the number remaining in the water of the lower river and of the estuary not exceeding those frequently found in drinking water supplies.

It has been thought by the County Council, that the results of the lengthened and systematic experimental bacterial treatment of London sewage, which they have maintained, should now be placed at the disposal of those who are interested in dealing satisfactorily with the treatment of sewage. The experiments have been suggested and controlled by men of scientific training, with the view of furnishing information as to the desirability of their being adopted on the larger and practical scale. It appears that the experiments have now arrived at a stage when their practical application could be simply carried out on the large scale, and that the probability of success is so great as to make the scheme of bacterial treatment of the sewage of the greatest city in the world worthy of careful consideration. The Council's experimental work has been made known to the public from time to time in a series of reports. These reports have rapidly passed out of print, and the great demand for them has encouraged the Council to reissue the reports in the present connected and somewhat abridged form, for the benefit of sanitary authorities and of those generally who have to deal with the disposal of sewage.

The chemical work and the bacterial work included in the appendix have been carried out by Mr. J. W. H. Biggs and Mr. E. B. Pike, assistant chemists at the Outfall Works, and the successful carrying out of the investigation has been largely due to these gentlemen. The co-operation of Messrs. E. J. Beal and H. Stokoe, superintendents at the Outfall Works, who, with the consent of the Chief Engineer of the Council, have done their utmost to facilitate the work, has also been of the greatest value. I wish also to acknowledge the assistance rendered to me by Mr. E. J. Jackman in collating and preparing the matter which had already appeared in the Council's published reports.

The publication of the book has been delayed by the inclusion of the matter contained in the appendix. The series of investigations, the results of which are stated in the appendix, were only commenced after the other portion of the book was already in type; and it was felt that the information thus obtained would be of interest to those who are concerned with the bacterial treatment of sewage.

Since the matter for this book was set up in type, the Fourth Report of the Royal Commission on Sewage Disposal has been made public. This Report deals amongst other things with the possible pollution of shell-fish by the London sewage, and it will be seen that the conclusions arrived at from Dr. Houston's investigations bear out the opinions expressed in the appendix of this book.

F. C.

January, 1904.

THE BACTERIAL TREATMENT OF SEWAGE.

DIVISION I.—CHEMICAL.

A.—NORTHERN OUTFALL.

I. Series of Experiments on the bacterial treatment of sewage effluent and of raw sewage, together with a description of the tanks and beds used in connection therewith, at the Northern Outfall Works (Barking).

Description of tanks and beds.

The first bacterial experiments in connection with the treatment of sewage at the Northern Outfall Works were commenced in the latter part of May, 1892, under the direction of Mr. W. J. Dibdin. For the purpose of these experiments, four wooden tanks, each about 5 feet deep and having an area of 24·2 square yards, were erected near the main culvert into which the effluent from the settling channels discharged. One of these tanks was divided into two parts, one of which was twice the size of the other. The beds formed in these tanks were used only for the bacterial treatment (or "filtration," as it was then termed) of the effluent from the chemically treated and subsequently sedimented sewage. The effluent was pumped from the main culvert, by a portable engine, into the coke-beds.

The next experiments in the bacterial treatment of sewage effluent at the Northern Outfall Works were carried out in a coke-bed 5,067 square yards in area and 3 feet in depth; the depth was afterwards increased to 6 feet. This bed was constructed on an irregular piece of waste ground at the Outfall Works, which was levelled and embanked where necessary. Perforated drains were laid on the ground, meeting in a common trunk for the discharge of the effluent. The filtering material consisted of 3 feet of unsifted coke-breeze, covered with 3 inches of gravel.

Early in 1898 another 3 feet of coke was placed on the bed, thus making the depth of the bed 6 feet. This coke was freed from dust, and the size of the fragments varied between that which would pass through a 1-inch mesh and be rejected by a ½-inch mesh.

This coke-bed has been in use since its construction, with but few interruptions, and has almost invariably dealt with the effluent from the chemically treated and subsequently sedimented sewage. The bed is supplied from the main effluent culvert, which runs at the end of the precipitation channels, by means of wooden troughs which are branched over the bed in order to secure the even distribution of the liquid.

This coke-bed is known as the "one-acre coke-bed," and is still at work.

On the 22nd of September, 1898, Dr. Clowes started the experimental bacterial treatment of screened crude sewage. For these experiments four galvanised iron tanks 4 feet square and 6 feet deep were erected near the liming station at the Northern Outfall Works. This site was selected in order that the tanks might be near the point where the sewage entered the works, and thus obviate the necessity of conveying the raw sewage any great distance to the coke-beds. During May and June, 1899, the depth of these iron tanks was increased to 10 feet by the addition of 4 feet of iron superstructure, which was bolted to the tanks, the joints being caulked and made watertight.

These tanks were arranged at two levels, so that the effluent drawn from the bottom of two of them on the higher level could flow by gravitation upon the top of the material in the two lower tanks.

List of Experiments on the bacterial treatment of sewage effluent and of raw sewage, carried out at the Northern Outfall Works (Barking).

Date.	Tank used.	Name of bed.	Description of Experiment.
May, 1892, to Aug., 1892	Four wooden tanks each of 24·2 square yards superficial area	Filter No. 1. Burnt ballast " No. 2. Pea ballast " No. 3. Coke-breeze " No. 4*a*. Sand " No. 4*b*. Proprietary	These experiments were conducted with a view to gaining information as to the best material for use as a bacteria-bed.
28 Sept., 1893, to date	... ...	One-acre coke-bed... ...	Various experiments were at first carried out in this bed, but of late years it has been used constantly in dealing with a portion of the effluent from the "chemical" treatment.
22 Sept., 1898, to 15 Apl., 1899	Upper iron tanks, 6 feet deep Lower iron tanks, 6 feet deep	Primary Kentish ragstone-bed Primary coke-bed Secondary Kentish ragstone-bed Secondary coke-bed	(Series I.) This was the first series of experiments in the bacterial treatment of raw sewage.
4 July, 1899, to 19 May, 1900	Upper iron tanks, 10 feet deep Lower iron tanks, 10 feet deep	Primary coarse coke-bed A Primary coarse coke-bed B Secondary coarse coke-bed A 1 Secondary fine coke-bed B 1	(Series II.) These experiments were conducted with a view to obtaining information as to the efficiency of a bed 10 feet deep and as to the comparative results of a fine and of a coarse secondary bed.
7 Nov., 1900 to 10 Aug., 1901	Upper iron tanks Lower iron tanks	Settling tank A Settling tank B Single coarse coke-bed A Single fine coke-bed B	(Series III.) In this series of experiments the sewage underwent sedimentation before treatment in coke-beds.

II. PRELIMINARY EXPERIMENTS AT THE NORTHERN OUTFALL WORKS (BARKING).

On the 10th of March, 1891, the Main Drainage Committee of the London County Council ordered that a series of experiments should be made at the Northern Outfall Works to ascertain the value of the treatment of sewage effluent in bacteria-beds, or "filters," as they were then called.

The sewage effluent which was treated in these beds and in the one-acre coke-bed, described in section III., pp. 5 to 9, unless otherwise stated, was the effluent obtained by subjecting the sewage on the north side of the Thames to the usual treatment. This treatment consists in the addition of about 4 grains of lime as milk of lime and of about 1 grain of sulphate of iron in solution to each gallon of raw sewage; this is followed by sedimentation in brick channels approximately 1,000 feet in length. The chemicals are added to the raw sewage at some distance from the penstocks of the settling channels, in order that an opportunity may be afforded of their becoming thoroughly mixed with the sewage before it undergoes sedimentation. On arriving at the channels the sewage is allowed to flow continuously through them at the rate of about 6 feet per minute, and at the further end the effluent flows over a weir wall into a common effluent-culvert and thence into the river. A unit of sewage occupies about 2¾ hours in traversing the length of the channel during sedimentation.

For the purpose of carrying out these experiments, four wooden tanks were constructed, each of which was equal in area to $\frac{1}{200}$th part of an acre. The beds in these tanks were composed of the following materials.

"Filter" No. 1 was composed of burnt ballast. This material was obtained by burning clay which had been taken from the marsh land adjoining the Outfall Works. The tank was filled with the burnt ballast to a depth of 4 feet, the larger pieces being placed at the bottom, and the remaining unsifted portion being placed on the top.

"Filter" No. 2 was composed of pea ballast. The material was Lowestoft shingle of pea size, and the tank was filled with it to a depth of 4 feet.

"Filter" No. 3 was composed of coke-breeze. The tank was filled with the coke-breeze to a depth of 4 feet, and 3 inches of gravel were placed on the top to prevent the coke from floating.

"Filter" No. 4*a* was composed of gravel and sand. One of the tanks was divided into two portions by a wooden partition. One of the portions, occupying two-thirds of the area of the entire tank, was used for No. 4*a* "filter," and was filled with a bottom layer, 5 inches in depth, of walnut-size gravel and successive layers of 2½ inches of bean-size gravel, 1½ inches of pea-size gravel and on the top 10 inches of sand.

"Filter" No. 4*b*. The remaining portion of the tank, which occupied one-third of the area of the entire tank, contained "filter" No. 4*b*, which was composed of a bottom layer of 3 inches of walnut-size gravel and successive layers of 2 inches of bean-size gravel, 1½ inches of pea-size gravel, 1 inch of sand and 12 inches of a proprietary material. This "filter" was supplied with perforated pipes leading to the surface for aëration purposes.

"Filter" No. 4*b* was fed with the effluent from "filter" No. 4*a*; accordingly 4*a* and 4*b* together count as one "filter."

The main object in conducting the experiments in the above described beds was to obtain information as to the best material for use in bacteria-beds. All four beds were worked at the same rate and during the same time.

During the first six weeks sewage effluent was passed through at the rate of 500 gallons per square yard per day, whilst from the middle of July, 1892, to the end of August, 1892, the rate was reduced to one-half, or 250 gallons per square yard in 24 hours. The treatment was intermittently continuous, the "filters" passing effluent constantly for 8 hours daily and resting during the remaining 16 hours, being allowed to run dry at the end of each day's work. During the 8 hours working period of the "filters" the outlet valve was closed just sufficiently to keep the "filters" full, the effluent being level with the surface of the material of which the "filters" were composed.

These beds were worked during June, July and August, 1892.

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

Burnt ballast	1
Coke-breeze	1
Pea ballast	1¾
Sand (1st portion of compound "filter") ...	2¼
Proprietary article (2nd portion of compound "filter" after sand)...	2½

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

TABLE I. *The four small bacteria-beds, or "filters," at the Northern Outfall Works. Figures relating to the quality of liquid dealt with, and to the purification effected by the beds, during June, July, and August,* 1892.

Name of bacteria-bed.	Average amount of Oxygen absorbed from permanganate in 4 hours at 80° Fahr. by the		Percentage purification effected by the bed as measured by the removal of dissolved putrescible matter.	Average amount of Albuminoid Nitrogen estimated in the		Percentage purification effected by the bed as measured by the reduction in the amount of Albuminoid Ammonia.	Quantity of sewage effluent dealt with by the bed during the whole course of the experiments.	Number of hours during which the experiment lasted.	Number of hours during which the beds were being worked.	Numb of gallo per ac per 2 hour dealt with l the be
	dissolved putrescible matter in the liquid as supplied to the bacteria-bed.	dissolved putrescible matter in the effluent from the bacteria-bed.		clear liquid as supplied to the bacteria-bed.	clear effluent from the bacteria-bed.					
							Gallons.			
"Filter" No. 1 ...	2·010	1·158	42·4	0·264	0·130	50·7	185,000	2,160	484	411,
"Filter" No. 2 ...	2·010	0·902	55·1	0·264	0·133	49·5	185,000	2,160	484	411,
"Filter" No. 3 ...	2·010	0·723	64·0	0·273	0·112	59·0	185,000	2,160	484	411,
"Filter" No. 4*a* ...	1·931	1·054	45·4	0·268	0·130	51·5	123,333	2,160	484	411,
"Filter" No. 4*b* ...	1·054	0·703	33·3	0·130	0·084	35·8	61,666	2,160	484	411,
Filters No. 4 *a* & *b*	1·931	0·703	63·6	0·268	0·084	68·9				

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

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

III. The one-acre coke-bed at the Northern Outfall Works (Barking).

In consequence of the more satisfactory results obtained from the coke-breeze in the previous series of experiments, the Main Drainage Committee of the London County Council gave instructions on the 24th of November, 1892, for the construction at the Northern Outfall Works of an experimental coke-bed, one acre in area.

The coke-bed was started on the 28th of September, 1893, and has been in use ever since with but little intermission. The following is a list of the various experiments which have been conducted in this bed and of the periods during which the bed was in use.

Date.	Nature of Experiment.
28 September, 1893	To find the rate at which the bed could deal with sewage effluent.
24 December, 1893	Resting.
2 April, 1894	To find the maximum purification effected by the bed.
10 June, 1894	Resting. Feeding trough to bed being increased in size.
30 July, 1894	Increased quantity of effluent supplied to bed.
17 November, 1894	Resting. Emptying arrangements being supplemented by a pump.

Date.	Nature of Experiment.
3 January, 1895	Work resumed.
8 March, 1895	Resting.
1 April, 1895	Work resumed.
3 August, 1895	Resting, owing to holiday arrangements.
12 August, 1895	Work resumed.
29 September, 1895	Resting. Experiments discontinued by order of Committee.
16 March, 1896	Work resumed.
26 March, 1896	Resting.
13 April, 1896	Work resumed.
4 October, 1896	Resting.
6 November, 1896	Work resumed.
21 November, 1896	Resting. Surface of bed being dug over.
22 December, 1896	Work resumed.
10 January, 1897	Resting.
15 March, 1897	Naturally sedimented sewage being dealt with.
31 May, 1897	Sewage treated with 1 grain of $FeSO_4$ only, being dealt with.
13 June, 1897	Ordinary "chemical" effluent being dealt with.
19 September, 1897	Resting. Bed being deepened.
16 May, 1898	Work resumed.
31 July, 1898	Resting.
8 November, 1898	Work resumed.
1 March, 1899	Resting.
6 March, 1899	Work resumed.
12 March, 1899	Resting.
8 May, 1899	Work resumed.
26 August, 1900	Resting.
3 September, 1900	Work resumed.
15 September, 1901	Resting.
22 September, 1901	Work resumed.

Averages of the results obtained by the chemical examination of the "chemical" effluent as supplied to the coke-bed and of the effluent from the coke-bed will be found in Table II. on p. 10.

The numbers at the commencement of the paragraphs in this section refer to the different periods in the working of the one-acre coke-bed for which averages are given in the table.

1. The first experiments with the one-acre coke-bed were instituted for the purpose of ascertaining the rate at which it was possible to pass effluent through the coke-bed, without attempting to produce the best results. The coke-bed, however, speedily became clogged with sludge, and after the sixth week the coke-bed effluent was putrid. The daily quantity that could be passed fell rapidly until at the end of twelve weeks the coke-bed was quite useless, being putrid throughout. Valuable information was thus gained, for it was shown that rest and aëration were vital, and also that in order to obtain the best work from a bacteria-bed, the quantity poured on it must be augmented very gradually, in order to permit of the proper biological condition being reached. The rate of working varied from close on one million to a quarter of a million gallons per diem. The filling was, during several weeks, continued until the water stood 6 inches above the surface; when the coke-bed was emptied this portion ran through without having time for purification, and this fact doubtless aided largely in reducing the efficiency of the coke-bed during this set of experiments.

2. The first series of experiments on biological lines, conducted with the same coke-bed as the preceding, was then commenced. The surface was raked, and the bed was allowed to rest during three and a half months. For fully three months of that time a putrid odour was observable when the coke-bed was disturbed, but this gradually disappeared and during the last fortnight the coke-breeze was perfectly sweet. From the second of April, 1894, until June the 9th of the same year the coke-bed was in continuous use.

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

After the coke-bed had been at work for over two months, it was found necessary to discontinue its use while alterations were made to the troughs which conveyed the liquid to the bed.

3. The alterations made in the arrangements for filling the coke-bed consisted in doubling the size of the feeding trough.

The daily quantity was increased to over 600,000 gallons, and the analytical results continued to be highly satisfactory.

4. Towards the end of 1894 the emptying arrangements were supplemented by a pump, and later the resting time was shortened, until finally the coke-bed passed 1⅛ million gallons daily for six days, resting empty from 10 p.m. on Saturdays until 6 a.m. on Mondays. The method adopted was to fill the coke-bed to the surface of the coke as quickly as possible, allow it to remain standing full for one hour, and then to draw off the effluent with the least possible delay. Working in this way the coke-bed passed an average of one million gallons a day, including all times of rest, during a period of eight weeks; the effluent was clean and sweet and a purification of 78 per cent. was effected. Nitrification proceeded satisfactorily, and the coke-bed was apparently capable of continuing its action for an indefinite time.

A point of the greatest importance is the fact that the coke-bed was able to do its work satisfactorily during the exceptionally severe weather in January and February, 1895. A thin coat of ice was formed on the surface, but the treatment proceeded without intermission, the only noticeable change being a decrease in the amount of nitrification.

5. After the coke-bed had been successfully dealing with one million gallons daily for about eight weeks, a large quantity of sludge, amounting to at least 10 tons, passed upon it accidentally. This occurred during the week ending 23rd February, 1895. The result was an immediate falling off in the quality of the effluent; a putrescent odour was observed, and finally the coke-bed had to be thrown out of work. Remarkable

evidence of the recuperative power of the coke-breeze was however obtained, as after 20 days' rest it was quite sweet again, nothing objectionable being observed on digging down to a depth of about 2 feet. The coke had only the odour of ordinary earth when moist, and it emitted whilst it was being burnt no objectionable smell.

On resuming work, after 28 days resting, satisfactory results were obtained and the coke-bed was kept in constant work until the end of September, 1895, except during one week in August. This brought the preliminary experiments to a close.

The experiments taken as a whole showed that sewage especially if previously clarified by precipitation, might be purified to any desired degree, the actual amount of purification depending upon (1) the length of time during which the effluent is allowed to remain in contact with the bacteria-bed, and (2) the length of time allowed for aëration of the surface of the coke fragments. If a reduction by 75 per cent. in the amount of the oxidisable organic matters in solution is considered as sufficient, the quantity that could be treated per diem on one acre of coke-breeze would be one million gallons, in a coke-bed 3 feet deep.

The coke-bed was restarted during March, 1896, and continued to work with a few interruptions until the 9th of January, 1897. The method of dealing with the bed was similar to that adopted during the period April to September, 1895.

6. On the 15th of March, 1897, the bed was again started and worked for two and a half months with the effluent from sewage which had undergone previous settlement without the aid of chemicals.

In the table on page 10 the average results of the chemical analysis of the settled sewage and of the coke-bed effluent and of the purification effected during this period are set forth.

7. From the 30th of May, 1897, the coke-bed dealt with the effluent from sewage which had been treated with 1 grain of sulphate of iron only per gallon and then subjected to sedimentation.

After this experiment the coke-bed continued until the 18th of September, 1897, to deal with "chemical" effluent as before. It was thrown out of work on the 19th of September until the 15th of May, 1898. During this interval the bed was increased in depth to 6 feet by placing upon the top of the old bed, 3 feet of sifted and graded coke fragments. On the 16th of May, 1898, work was resumed and has been continued up to the present time with about half-a-dozen breaks of varying duration in the continuity of the work.

8. The work of this bed has been uniform in character during the last few years and is no longer of an experimental nature. The results of the analysis of the "chemical" effluent and of the coke-bed effluent, since the bed was deepened and matured, have been very concordant; only the averages for the years 1900 and 1901 are therefore given in the tables on p. 10 and on pp. 50-1.

It was discovered some time after the bed had been deepened that the lower 3 feet of the bed, which consisted of unsifted "fine pan breeze," had become very much consolidated, and that the effluent drained away from it very slowly; the effective portion of the bed was, therefore, the upper 3 feet which consisted of sifted coke. It was evident, therefore, that unsifted coke was quite unsuitable for the purpose of making a coke-bed, and that the coke must not only be freed from dust, but could also with great advantage be composed of particles of similar dimensions

The average quantity of effluent dealt with by the bed at each filling, during the years 1900-1 was 344,969 gallons, whereas during the period from May 12th, 1898, to December 30th, 1899, the average quantity per filling was 519,367 gallons. This difference is probably due to—

i. The continued consolidation of the lower 3 feet of the material composing the bed.

ii. The difference in the average number of hours during which the bed was allowed to drain throughout the two periods. From May 12th, 1898, to December 30th, 1899, the average number of fillings per day was 1·05, whereas during the two years 1900-1, the average number of fillings per day was 1·55.

The time for filling the bed was generally so selected that the effluent could be discharged into the river at low water; this was done in order to avoid the expense of pumping. Under this arrangement two fillings per 24 hours were usually made. The time-table for the bed was as follows—

Time occupied in filling	1½ hours
Time occupied in standing full (contact period) ...	2 ,,
Time occupied in emptying	2½ ,,
Time occupied in standing empty (aëration period)	6 ,,

The high efficiency of the bed has been very well maintained, but it should be borne in mind that this bed has been dealing only with the effluent from chemically precipitated sewage, and has therefore had a much smaller amount of purification to effect than the beds which have dealt with crude or with "septicised" sewage.

The average purification of the crude sewage which was effected during the two years 1900–1 by the bacterial action of the bed in conjunction with the previous chemical treatment and sedimentation was 91·2 per cent, as measured by the relative quantities of oxygen absorbed from permanganate by the total putrescible matter (both suspended and dissolved) in the crude sewage and in the coke-bed effluent. The average purification effected on the "chemical" effluent by the coke-bed treatment, when estimated in a similar manner, was 85·6 per cent., whereas it was only 81 8 per cent. during previous periods when these estimations were made, namely, from November 8th, 1898, to January 21st, 1899, and from October 18th to December 31st, 1899.

The treatment of effluent from the chemically treated and sedimented sewage is being continued in this bed.

TABLE II. *Averages of the chemical estimations of the effluent from the chemically treated and subsequently sedimented sewage as supplied to the one-acre coke-bed at the Northern Outfall Works, and of the effluent from the one-acre coke-bed, during the various periods referred to in the foregoing pages. All quantities, except where otherwise stated are expressed in parts per* 100,000.

Date.	Oxygen absorbed from permanganate in four hours at 80° Fahr. by the clear liquid (dissolved putrescible matter) of the		Albuminoid nitrogen in the		Nitric nitrogen in the		Percentage purification effected by the coke-bed on the "chemical" effluent, as measured by the removal of dissolved putrescible matter.
	"chemical" effluent. 2	coke-bed effluent. 3	"chemical" effluent. 4	coke-bed effluent. 5	"chemical" effluent. 6	coke-bed effluent. 7	8
1. 28 Sep. to 23 Dec. 1893	5·867	1·704	0·479	0·136	0·1577	0·1883	71·0
2. 2 Apr. to 9 June, 1894 ...	5·852	1·223	0·490	0·112	0·1829	0·3398	79·1
3. 30 July to 9 Nov., 1894..	5·154	1·043	0·466	0·133	0·0319	0·2020	79·8
4. 3 Jan. to 7 Mar., 1895 ...	6·148	1·406	0·479	0·143	0·5382	0·9727	77·1
5. 1 Apr. to 28 Sep. 1895 ...	4·602	0·926	0·403	0·129	0·2004	0·7602	79·9
*6. 15 Mar. to 29 May 1897 ..	3·860	0·713	0·385	0·105	0·0283	0·3769	81·5
7. 31 May to 12 June, 1897	3·140	0·617	0·301	0·086	0·0556	0·4149	80·4
8. 1900–1901	5·497	0·880	not estimated		0·0425	0·9971	84·0

* For " 'chemical' effluent" in columns 2, 4, 6, and 8 read "settled sewage," for this series of averages only.

IV. THE TREATMENT OF CRUDE SEWAGE IN PRIMARY AND SECONDARY BEDS FIVE FEET DEEP, OF KENTISH RAGSTONE AND OF COKE, AT THE NORTHERN OUTFALL WORKS (BARKING). SERIES I.

These experiments, which were commenced on the 22nd of September, 1898, were the first carried out at the Northern Outfall Works in the systematic treatment of crude sewage in bacteria-beds. The experiments, which were conveniently divided into three series, were conducted in four iron tanks, each 4 feet square.

For the experiments of Series I. the tanks were used at their original depth of 6 feet. Two of the tanks were fixed on supports at a higher level than the other two, in order that any liquid could be discharged from the bottom of the higher tanks or primary beds at a level above the top of the lower tanks or secondary beds.

The crude sewage applied to the beds was obtained from a large pipe conveying sewage to an overhead lime-tank, and was raised by means of a portable auxiliary pump. This pump was stopped for a few days periodically for cleaning, and on these occasions the bacteria-beds could not be filled.

The material employed in the two primary beds was coke and ragstone respectively, and was of such a size that the pieces would pass a 4-inch mesh and be rejected by a ½-inch mesh. The material in the two secondary beds was also coke and ragstone respectively, and was of such a size that it would pass a ½-inch mesh and be rejected by a $\frac{1}{16}$-inch mesh.

The reason for employing Kentish ragstone was that it seemed probable that the calcium carbonate in the ragstone would be found to promote the bacterial action.

The method of working the beds was as follows :—

The two coarse primary beds were filled with crude sewage simultaneously and as quickly as possible to a level with the top of the solid material; the beds were allowed to remain full for two hours, and were then drained into the fine secondary beds. These remained full for two hours, and were then drained off.

The effluent from the coarse primary Kentish ragstone-bed was always discharged into the fine secondary Kentish ragstone-bed, and that from the coarse coke-bed into the fine coke-bed.

During the outflow of the effluent from each bed samples were taken every few minutes. These samples were mixed, and the average liquid thus obtained was subjected to analysis. The crude sewage with which the primary beds were filled was sampled and examined in a similar manner.

The following table gives particulars as to the number of times the coarse beds were filled, and as to the quantity of crude sewage dealt with by them.

TABLE III.

Date.	Number of days.	Number of days on which each bed was filled.	Number of fillings of each bed per day.	Average quantity of crude sewage dealt with by each bed per day. Expressed in terms of an acre.			
				During the whole period.		During the days on which the beds were working.	
				Coke-bed.	Ragstone-bed.	Coke-bed.	Ragstone-bed.
1898 1899				Gallons.	Gallons.	Gallons.	Gallons.
22 Sept. to 9 Jan. ...	110	83	1	519,750	415,800	688,825	551,060
1899 11 Jan. to 15 April ...	95	73	2	626,576	601,128	815,407	782,290

The capacity of the two coarse beds was estimated at various times with the following results :—

TABLE IV.

Date.	Capacity of the		Capacity of the bed stated as a percentage of the volume of the empty tank.		Corresponding capacity per acre of bed.		Average weekly percentage reduction in the capacity of the	
	coke-bed.	ragstone-bed.	Coke-bed.	Ragstone bed.	Coke-bed.	Ragstone-bed.	coke-bed.	ragstone-bed.
	Gallons.				Gallons.			
29 Sept., 1898 ...	250	200	50·0	40·0	680,625	544,500	...	...
11 Jan., 1899 ...	195	183	39·0	36·6	530,887	498,217	0·73	0·23
9 Mar., 1899 ...	168	174	33·6	34·8	457,380	473,715	0·68	0·22

The "original capacity" (September 29) was taken about 10 days after the experiments had been started; it is probably below the total capacity, since it was taken while the beds were being emptied, and the drainings of the beds were therefore not included. No doubt a more trustworthy method of estimating capacity consists in filling the bed after it has drained for a definite time, which should be the same in all processes of taking capacities. It might be well that a standard "drainage period" should be recognised generally, since the wetness of the bed-material must affect the so-called capacity considerably. Thus a bed which had been draining for one hour only would require less liquid to fill it than one which had been draining for ten hours. In the case of the one-acre bed at Barking, it is known that the effluent will continue to drain away for several days.

It should be stated that the raw sewage which was supplied to the beds was of the heaviest kind. It was drawn from a level about a foot from the bottom of the sewer, and passed through a ½-inch screen to the beds without any previous sedimentation.

On January 20th, 1899, an attempt was made to estimate the free oxygen in solution in the effluents from the four beds, and the following results were obtained—

Ragstone, coarse bed	nil.
Coke "	nil.
Ragstone, fine bed	18·0 per cent.
Coke "	19·1 "

Complete saturation with oxygen was taken as 100.

The effluents from the primary beds killed gold and silver fish in a few hours, but those from the secondary beds sustained fish life as readily as fresh tap-water does.

The averages of the results of the chemical examination of the crude sewage as supplied to the bacteria-beds, and of the effluents from the beds, together with the amount of purification effected by each bed, are shown in the table on pp. 50 and 51.

Early in January, 1899, it was considered that the beds, with one filling daily, had reached their maximum power for purifying the sewage. It was therefore decided to fill them twice daily. It will be observed that generally two fillings a day gave a rather better result than was obtained with one filling per day, showing that although the purifying power of the beds, owing probably to the large size of the material, was in itself low and unsatisfactory, still the beds were not being over-worked.

The effluent obtained from the primary beds did not show as high a purification as had been expected; it is probable that the large size of the material had the effect of presenting an insufficient surface of contact with the sewage; the putrescible matter in the sewage was not therefore thoroughly dealt with by the bacteria. This conclusion has since been confirmed by a higher percentage of purification having been obtained in primary and single beds composed of coke fragments smaller than those used in the experiments of Series I.

It will also be seen that coke gives better results than ragstone in the removal of organic matters in solution; the results are slightly better on the primary treatment, and considerably better on the secondary treatment.

Abnormal amounts of nitrate were found in the first effluent from the fine ragstone bed after the bed had rested at Easter, from March 29th until April 5th, 1899, and it appeared probable that nitrates had been formed in the bed during the rest and had then been washed out by the first filling with sewage. A similar result was not found in any of the other beds.

The points upon which information was gained by these experiments were:—

a. The use of Kentish ragstone is not so suitable for bacteria-beds as coke is.

b. The size of the fragments of the material of which a bacteria-bed is composed must be carefully adjusted so as to obtain the maximum of superficial area or coke surface for the bacteria to cover, without reducing the size of the fragments of the material to such an extent as to cause the bed to become choked.

V. THE TREATMENT OF CRUDE SEWAGE IN DOUBLE COKE-BEDS TEN FEET DEEP, AT THE NORTHERN OUTFALL WORKS (BARKING). SERIES II.

From the results of the experiments of Series I, it was decided to conduct experiments in beds of increased depth, in order to ascertain whether the depth of a bacteria-bed has any effect on its purifying action.

For the purpose of these experiments, iron superstructures 4 feet in height were bolted to the existing tanks, and the joints were caulked and made watertight. Thus the depth of the tanks was increased to 10 feet. The tanks were then filled to a depth of 9 feet 9 inches with coke, and were worked in two series as follows—

Series A—
(1.) A primary coarse bed. (A.)
(2.) A secondary coarse bed. (A1.)
Series B—
(1.) A primary coarse bed. (B.)
(2.) A secondary fine bed. (B1.)

The three coarse beds were composed of coke of such a size that it would pass a 2-inch mesh and be rejected by a $\frac{1}{2}$-inch mesh.

The fine bed was composed of coke of a size which would pass a $\frac{1}{2}$-inch and be rejected by a $\frac{1}{16}$-inch mesh. In this instance the coke which had been in use in the previous experiments, and was thus in good bacterial condition, was mixed with two-fifths of its bulk of new material in forming the deeper bed. The arrangement of the tanks allowed the effluent from the primary beds to drain completely into their respective secondary beds.

The sewage supplied to the beds was obtained from the same source as during the previous experiments, and was thus of the strongest nature; it contained sand and other suspended mineral and vegetable matters which should not be allowed to reach the bed, and which a short period of sedimentation would, in a very great measure, remove. It speaks well for the beds that they were able to cope so satisfactorily with the heavy work which was thrown upon them.

In series B the depth of the primary coarse bed was reduced to 9 feet 6 inches, in order that its liquid contents should not overflow when they passed into the secondary fine bed, whose capacity was somewhat smaller owing to its being made of finer material.

The procedure was precisely similar to that adopted in the previous experiment. The two primary beds were filled simultaneously, and were allowed to remain full for two hours; they were then drained into the secondary beds, and the effluent was allowed to remain for a further period of two hours in contact with the coke. The crude sewage and each of the effluents were separately sampled and subjected to examination.

This series of experiments lasted from the 4th of July, 1899 to the 19th of May, 1900.

The beds were charged by means of a fixed syphon made of 1-inch pipe, from an overhead water-tank, which was kept constantly full. The volume delivered by this syphon per minute was ascertained, and the capacity was then determined by the length of time required for filling each bed.

The following figures indicate the capacity of the various beds expressed as percentages of the total tank volume, also the weekly percentage loss of capacity during the number of weeks stated in the last column of the table.

TABLE V.

Date.	Capacity of the bed stated as a percentage of the volume of the empty tank.				Average weekly percentage reduction in the capacity of the				Number of weeks during which the reduction occurred.
	Primary coarse bed A.	Secondary coarse bed A1.	Primary coarse bed B.	Secondary fine bed B1.	primary coarse bed A.	secondary coarse bed A1.	primary coarse bed B.	secondary fine bed B1.	
1899									
29 May ...	68·7	61·7	70·3	53·1	...	...	...	...	...
20 Sept. ...	41·9	56·8	33·3	48·1	1·67	0·31	2·31	0·31	16
27 Oct. ...	32·3	54·9	32·7	46·9	1·92	0·38	0·12	0·24	5
6 Dec. ...	31·3	53·1	27·6	48·1	0·17	0·30	0·85	0·20 (increase)	6
1900									
4 Jan. ...	26·8	50·6	24·7	47·0	1·12	0·62	0·72	0·27	4
7 Feb. ...	21·8	50·6	21·2	44·4	1·00	nil	0·70	0·52	5
15 Mar. ...	20·3	50·6	17·9	44·4	0·30	nil	0·66	nil	5

The progressive decrease in the capacity of the beds shows that they were choking. This cannot be wondered at, considering that the very worst of the sewage was being dealt with, and that sand and other solid matter was being admitted to the beds. Latterly, trouble had been experienced in filling the primary beds, owing to the accumulated mass of undissolved matters on the upper part of the beds. These beds, however, were doing very satisfactory purifying work, and were removing from 40 to 50 per cent. of the dissolved putrescible matters.

It was noticed that after seven months' work the coarse bed B had sunk to the extent of 6 inches. On 20th February, 1900, 9 inches of new coke, similar to that originally used, was placed on the top of this bed, and the depth of the bed was thus brought up to 9 feet 9 inches, as in the case of the other three tanks, the capacity of the bed having fallen sufficiently to prevent its contents from overflowing the secondary fine bed.

During this series of experiments both the crude sewage as supplied to the beds and the effluents from the various beds were regularly sampled and subjected to chemical examination. In the tables on pp. 52-3 the average results of these estimations are set forth, together with the percentage of purification effected by the coke-beds as measured by the relative quantities of oxygen absorbed by the putrescible matter.

It will be seen that the sewage arrived at the works, containing an average amount of 0·1617 part per 100,000 of nitric nitrogen, which shows that it was fairly fresh. It contained, as a rule, no nitrous nitrogen.

Comparing the amounts of oxidation of nitrogen produced in the various beds, the amount of nitrous oxidation effected in the primary beds was increased by 6·4 per cent. in the secondary coarse bed, but it was decreased by 26·6 per cent. in the secondary fine bed. On the other hand the amount of nitric oxidation effected in the primary beds was increased by 125·8 per cent. in the secondary coarse bed and by 425·9 per cent. in the secondary fine bed.

During this series of experiments, records of the temperature of the atmosphere and of the sewage and effluents were kept. The averages of a series of twenty estimations made during December, 1899, were as follows :—

Temperatures in degrees Fahrenheit.

Air.	Crude sewage.	Air.	Effluent from primary bed A.	Effluent from primary bed B.	Air.	Effluent from secondary bed A1.	Effluent from secondary bed B1.
38·5	53·0	38·0	46·0	44·5	37·5	44·0	42·5

From a general consideration of these averages it appears that when the atmosphere was at a temperature of 38·5° Fahr. the sewage flowed into the primary beds at a temperature of 53° Fahr.; and that, after it had remained in the primary beds for two hours, it flowed into the secondary beds at a temperature of 46° from bed A and of 44·5° from bed B, the air temperature at that time being 38·0°. After the sewage had remained in the secondary beds for two hours, it was drawn off, and showed a temperature of 44° from bed A1, and 42·5° from bed B1, the air temperature at the time being 37·5°. It will be observed that the average temperature of the outside air fell during the whole process 1° Fahr., and that the sewage fell 7° while it remained for two hours in the primary bed A, and a further 2° while it remained another two hours in the secondary bed A1, or 9 degrees out of a possible 15·5 degrees fall during the whole process. In series B the sewage fell in temperature 8·5° after two hours' rest in the primary bed and a further 2° after another two hours in the secondary bed, or 10·5 degrees out of a possible fall of 15·5 degrees during the whole process.

In considering this question of temperatures the following facts must be borne in mind—(1) that the beds were small in area; (2) that their position was exposed, that they stood in metal tanks supported entirely above the ground-level, and that each tank was widely separated from the others; and (3) that since the tanks were constructed of thin galvanised iron, their exteriors readily lost heat by radiation as well as by contact with the cold air.

The somewhat lower temperatures found in series B are explained by the fact that the B tanks are somewhat more exposed than the A tanks, which stand between the B tanks and a wooden wind-screen.

Another series of readings was made during January and February, 1900. This included readings of the temperature of the interior of the beds of the A series. This series included 26 readings of each set, the averages of which are given in the following table:—

Temperatures in degrees Fahrenheit.

Air.	Crude sewage.	Air.	Primary beds.			Air.	Secondary beds.		
			Interior of bed A.	Effluent from bed A.	Effluent from bed B.		Interior of bed A1.	Effluent from bed A1.	Effluent from bed B1.
43·5	50·5	42·0	50·5	46,0	46·0	41·0	48·0	45·0	45·0

In series A the temperature of the beds themselves was taken about four hours after they had been emptied, and the average temperature of the primary bed was then found to be equal to that of the sewage which had flowed into the bed, viz., 50·5° Fahr., the temperature of the outside air being 42°. The average temperature of the interior of the secondary bed was 48°, or 2° higher than that of the effluent from the primary bed with which it had been filled, and 3° above that of the effluent drawn off four hours before the temperature of the bed was taken, the temperature of the outside air being at 41° Fahr.

These details may be summarised as follows—The temperature of the liquid, while it was standing in the primary bed, fell 4·5° Fahr., but after the liquid had been drawn off, the bed recovered from this loss of temperature in four hours; this recovery could evidently only be effected by some internal action which was attended with the production of heat, and was probably due to the action of the bacteria upon the organic matters contained in the bed. The liquid, in passing through the secondary bed, lost a further degree in temperature, but the bed, after standing empty for four hours, rose in temperature again to the extent of 3° Fahr.

Between October, 1899, and February, 1900, estimations were made of the composition of the air contained in the body of the primary bed B when empty.

From the 19th of October to the end of 1899 the air present in the interstices of the coke-bed, after it had remained empty for the average time of 21 hours on several different occasions, contained the following average percentages of oxygen and carbon dioxide—

Oxygen	10·3
Carbon dioxide	5·7

Between January 1st and February 23rd, 1900, when the bed had remained empty on many occasions for an average period of five hours, the following average percentages were found in the interstitial air—

Oxygen	8·0
Carbon dioxide	5·7

Fresh air contains on an average the following percentages—

Oxygen	20·96
Carbon dioxide	0·04

The average proportion of oxygen present in the air at the bottom of the bed, as compared with that present in fresh air, therefore was, up to the end of 1899, with the bed standing empty for 21 hours, about 50 per cent.

From the commencement of the year 1900 until February 23rd, with the bed standing empty for the average period of five hours, the aëration, as measured by the above proportion of oxygen, was about 38 per cent. This was by no means so satisfactory a condition as could be desired, and was probably due to the fact that the bed had become clogged by the heavy suspended matters of the crude sewage, and that the bacteria acting on these matters caused a rapid absorption of oxygen from the air with liberation of carbon dioxide and other gases.

The effluent from the primary beds was capable of sustaining the life of gold fish apparently indefinitely. Less hardy fish, such as roach, dace, and perch, became sickly after living in the effluent for a week or two: it should be remarked, however, that these fish were in a somewhat sickly condition before they were placed in the effluent.

VI. THE TREATMENT OF SETTLED SEWAGE IN COKE-BEDS AT THE NORTHERN OUTFALL WORKS (BARKING). SERIES III.

The results obtained from the experiments of Series I. and of Series II. indicated that a preliminary sedimentation of the crude sewage was necessary before allowing it to flow upon the coke-beds, in order to avoid the choking of the beds. This last series of experiments was therefore instituted more especially with the view of finding out the best means of settling the sewage before treatment in coke-beds. This series of experiments extended from the 7th of November, 1900, until the 10th of August, 1901. The iron tanks used in the previous experiments were adapted to the requirements of this series.

The two upper tanks, which were on a higher level than the others, and which had been used as primary beds in the previous experiments, were emptied of their coke, and were used as settling tanks (A and B). Each of these tanks was supplied with crude sewage from the mains by a 1½-inch iron pipe which dipped into the tank to a depth of 7 feet from the top.

In order to distribute the sewage, and to prevent the sediment of sludge on the bottom of the tank from being disturbed, the crude sewage flowed upon a board 8 inches square fixed about 6 or 7 inches below the open end of the feed pipe.

A 1-inch iron pipe was used in each tank as a syphon for conveying the settled sewage from the settling tanks to the coke-beds in the lower tanks. One end of each of these pipes was continued to a depth of 5 feet below the top of the settling tank, the other end of each syphon pipe discharged the sewage upon the first of a series of three consecutive wooden platforms; the last platform of each series was perforated and was placed about 2 feet above the surface of the coke in the lower tanks. The object of these platforms was to secure aëration of the settled sewage.

The total capacity of each of the subsidence tanks was 1,000 gallons, but the tanks were only filled to a depth of 9·5 feet and this gave a working capacity of 950 gallons.

The two lower tanks were used for the coke-beds. The bed which was worked in connection with settling tank A was known as the "coarse coke-bed A." It was composed of the coke which had been used in connection with the previous series of experiments, and the size of the fragments was such that they would pass through a 2-inch mesh and be rejected by a $\frac{1}{2}$-inch mesh.

The other tank was known as the "fine coke-bed B." The coke of which it was composed had also been used before, and was of such a size as would pass a $\frac{1}{2}$-inch mesh and be rejected by a $\frac{1}{16}$-inch mesh. Both of the tanks were filled with coke to a depth of 6 feet. The beds were underdrained with perforated 2-inch iron pipes arranged as a "fourway," with three open ends, while the fourth end was connected with the outlet tap. Large pieces of coke were arranged around the pipes in order to prevent choking.

When the two settling tanks were first started, they were filled with roughly screened crude sewage to within 6 inches of the top, and this was allowed to settle for 24 hours; sufficient of the sedimented sewage to fill the coke-beds was then syphoned off to the beds. The sewage from tank A was always supplied to coke-bed A, while that from tank B always passed on to bed B. After the beds had been filled from the tanks, the latter were immediately filled up with fresh sewage, which was allowed to settle until it was time for the coke-beds to receive a fresh charge. This method of procedure was maintained throughout the experiments of Series III., except as regards the number of consecutive hours during which the sewage remained undisturbed in the settling tanks. After the coke-beds had been filled they remained undisturbed for two hours; they were then emptied, and remained with air filling the interspaces until the time arrived for re-charging them with sewage. This rest period necessarily varied with the number of charges which the beds received during the 24 hours. The number of fillings per day ranged between one and three. The beds were filled at 4 a.m., 2 p.m. and 10 p.m. when they were receiving three fillings per day.

Both the coke-beds always rested on Sundays; and on several days during January, February and March, 1901, it was impossible to fill the coke-beds on account of the tanks having become frost-bound. The freezing was due to the elevated and exposed position of the tanks, which caused them to be in contact on all sides with the cold air.

Both beds rested from April 24th to May 6th, 1901. This was thought to be advisable because their purifying powers had apparently deteriorated.

It must be borne in mind that these beds were dealing with sewage which had undergone very imperfect sedimentation, on account of the small size of the settling tanks and the unsatisfactory manner of feeding and discharging them; and it was further shown, latter on, that the sewage had undergone very slight anaërobic or "septic" action in these tanks. The sewage supplied to the beds was therefore not in a suitable condition for undergoing rapid purification in the coke-beds, hence the three fillings per day which the beds had received just previous to April 24th, 1901, were too many for them to deal with satisfactorily. Other rests which the beds received were necessitated by public holidays, by repairs to the pumps or by the cleaning of the engine.

Throughout the experiments, the coarse coke-bed A was filled with settled sewage 287 times, and the fine coke-bed B was filled 313 times.

The settling tanks were primarily arranged for the purpose of intercepting the grosser suspended matter from the sewage which passed through them. Such matter consists principally of sand and road detritus and of substances chemically known as "cellulose." Since sand and mineral road detritus are not acted upon by bacteria at all, and cellulose is only very slowly broken up by aërobic bacterial action, it follows that these substances should be intercepted, since, if they are allowed to enter the coke-beds, the capacity of the beds becomes very rapidly reduced.

It was anticipated that bacterial change would occur in the sediment, and the tanks were carefully watched in order to detect any signs of so-called "septic" or anaërobic bacterial action which might take place in them. On December 13th, 1900, an examination of the deposit in the settling tanks was made and indicated that some of the sediment or sludge had disappeared from the bottom of the tanks.

During a period of rest which lasted from July 12th to 16th, 1901, "septic" action occurred in the settling tanks, and large masses of sludge were lifted to the surface by the gas evolved during the anaërobic action. The sludge which had been deposited in the tanks was very much disturbed by this movement, as well as by the alteration of the level of the liquid in the tanks while the settled sewage was being syphoned off for the purpose of filling the coke-beds. Further, on account of the small size of the tanks, some of the sludge, which had been lifted by the gas bubbles, was drawn through the syphon pipes and thus gained access to the coke-beds.

On January 28th, 1901, the settling tank A was thoroughly cleaned out and a fresh start was made.

Throughout the period of experiment, the amount of suspended matter or sludge in the crude sewage which entered the tank had been carefully determined, and it was known how much should be present as a sediment on the bottom of the tank. But when the quantity of this sludge was estimated, during the clearing out of the settling tank, it was found that the amount was considerably less than that which had entered the tank. No less than 20·2 per cent. of this total solid matter was found to have been liquefied by "septic" action between January 28th and August 6th, 1901, in settling tank A; this is equal to 37·4 per cent. of the solid organic matter in the sewage supplied to the tank. The reduction of the quantity of solid matter in tank B was only 6 per cent. of the total solids, or 12·8 per cent. of the solid organic matter in the sewage supplied to the tank between February 9th and August 6th, 1901.

The great difference between the amounts of "septic" action which had occurred in the two tanks is doubtless due to the fact that tank A, in which the "septic" action appears to have been the more pronounced, had not been disturbed during three weeks from June 5th to 28th, on account of the period of rest accorded to the coke-bed which was worked in connection with the tank A; whereas tank B was practically in continuous use. As has been already stated the disturbance of the sludge during working was considerable, and undoubtedly interfered with the "septic" action. There seems also little doubt that the low temperature of these tanks, due to their free exposure on all sides to the air, was inimical to bacterial change. Similar experiments carried out at the Southern Outfall, with settling tanks constructed in masonry and sunk in the ground, gave much more uniform and satisfactory results, and this appears to be due to their maintaining a higher and more uniform temperature, as well as to their feed being so arranged as to avoid disturbance of the sedimented sludge.

The amount of sludge produced weekly in each of the two subsidence tanks averaged about 9 gallons, and it contained 89·5 per cent. of moisture. The average quantity of sewage which passed through each tank was 1,620 gallons weekly in the case of tank A, and 1,412 gallons in the case of tank B.

The results of these experiments, as far as the action of the coke-beds is concerned, may be considered as very satisfactory. Bearing in mind the small size of the settling tanks and the small amount of "septic" action which took place in them, the chemical condition of the final effluent and the small loss of capacity of the coke-beds compare very favourably with the results of the earlier experiments, and prove the great advantage of preliminary sedimentation.

The average percentage amount of purification effected by the combined action of the settling tank A and of the coarse coke-bed A, as measured by the relative quantities of oxygen absorbed from permanganate by the dissolved putrescible matter in the crude sewage and in the final coke-bed effluent, was 51·8; the highest average purification effected by the double ragstone-beds of Series I. with two fillings per day amounted to 51·6, but the double coke-beds of Series I. yielded the best results with one filling per day, when an average of 64·9 per cent. of purification was effected. It will thus be seen that the purification effected by the settling tank A and by the coarse coke-bed A of Series III. was equal to that effected by the double ragestone-beds of Series I.

A more useful comparison between the results of the various experiments may be obtained by comparing the actual amount of purification effected by the individual beds on the liquid supplied to them. The following is a list of the figures representing such results.

	Average percentage purification effected throughout the experiments, by the beds on the liquid supplied to them.
Series I.—	
Coarse ragstone-bed	20·6
Fine ragstone-bed	35·9
Coarse coke-bed	22·5
Fine coke-bed	52·6
Series II.—	
Primary coarse bed A	46·3
Secondary coarse bed A1 ...	31·9
Primary coarse bed B	47·0
Secondary fine bed B1 ...	52·1
Series III.—	
Coarse coke-bed A	38·8
Fine coke-bed B	51·2

From these results it will be seen that the fine coke-bed in the last series of experiments dealing with settled sewage, effected a purification practically equal in amount to the best results obtained from any single bed in previous experiments. But it will be remembered that in the instances where the amount of purification effected by a single bed in previous experiments was equal to that of the fine coke-bed B of the last experiment, the coke-beds were dealing with sewage which had received previous treatment in a primary coke-bed, whereas in the last experiment the coke-bed was dealing with sewage which had been only imperfectly settled and which had been subjected to but very slight "septic" action.

In the case of the coarse coke-bed the amount of purification effected was greater in the last series of experiments than that effected by the secondary coarse bed A1 in the previous series of experiments. The result obtained by the coarse coke-bed A is hardly comparable with the results obtained by the primary coarse beds of Series I. and II., as the sewage supplied to them had not been treated in any way, whereas in Series III. the sewage had been previously subjected to sedimentation.

It will therefore be seen that the coke-beds used in the experiments of Series III. effected practically as much purification on a sewage which had been previously settled as the secondary coke-beds of Series I. and II. effected on a sewage which had been previously treated in primary coke-beds. But the advantage of the method of previous settlement and treatment in a single coke-bed, over that of primary and secondary treatment in coke-beds without previous settlement, is that in the latter process the primary coke-beds are rapidly thrown out of action by loss of capacity by choking, while in the former process the choking is avoided. The results of the experiments at the Council's Outfall Works and at other centres indicate that when the settlement of the sewage is conducted on a large scale, and is accompanied by energetic "septic" action, the coke-beds do not continuously lose capacity by the accumulation in them of sewage sludge, but only decrease in capacity to a limited and definite extent by the growth of purifying bacteria upon the coke surfaces. This growth is necessary and desirable if it is kept, as it can be kept, within reasonable limits.

From November 7th, 1900, to January 27th, 1901, the samples of sewage supplied to the two settling tanks were mixed together before being analysed, as were also the samples of the settled sewage flowing from the two settling tanks to the coke-beds; on and after January 28th these samples were all separately analysed.

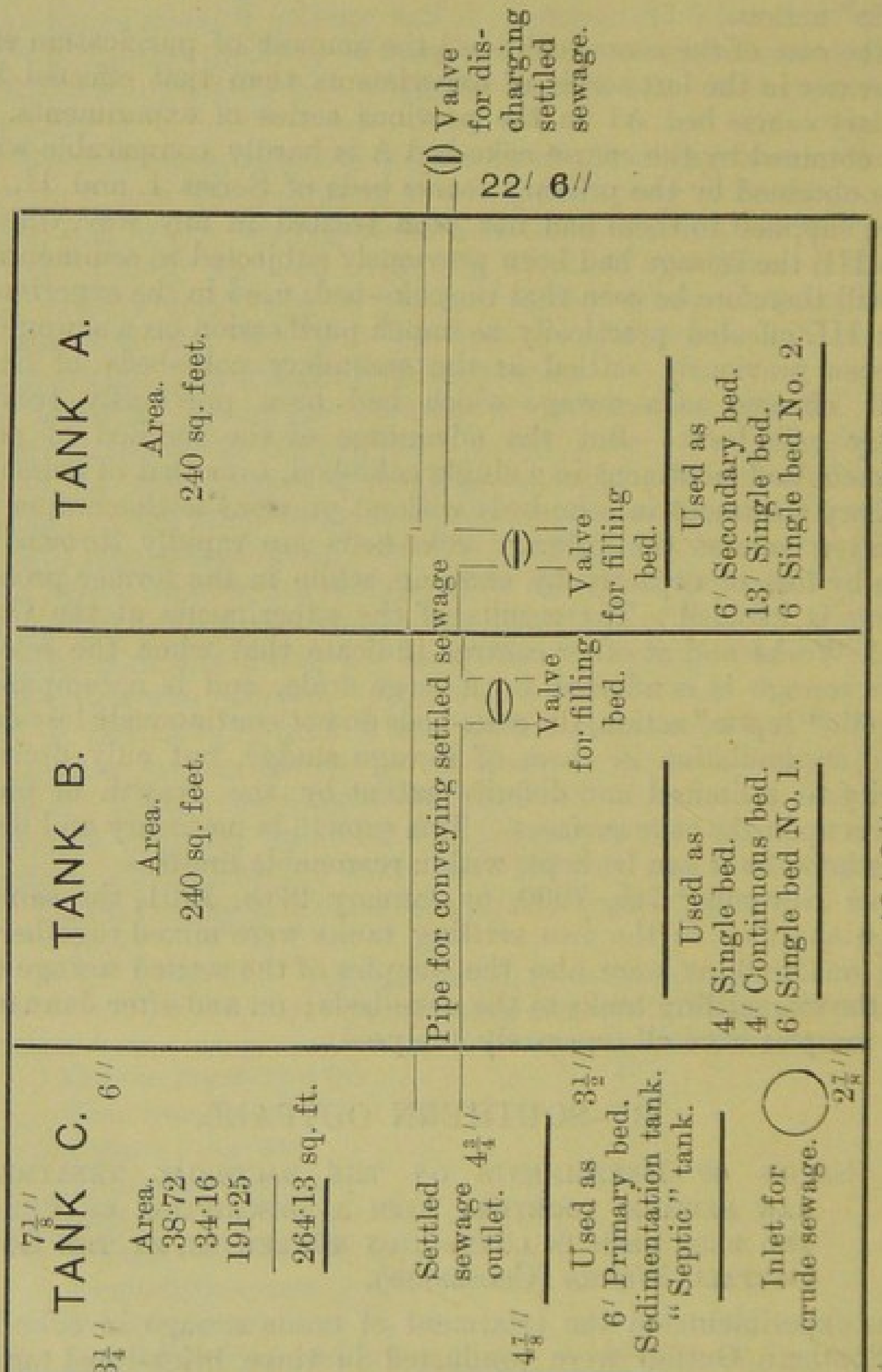
B.—SOUTHERN OUTFALL.

VII. SERIES OF EXPERIMENTS ON THE BACTERIAL TREATMENT OF RAW SEWAGE, TOGETHER WITH A DESCRIPTION OF THE TANKS AND BEDS USED IN CONNECTION THEREWITH, AT THE SOUTHERN OUTFALL WORKS (CROSSNESS).

The experiments on the treatment of crude sewage in coke-beds at the Southern Outfall were conducted in three brick-lined tanks with brickwork bottoms, which had been constructed for other purposes, but which were specially provided with suitable outlets and with means of charging them with raw sewage by means of a pump and distributing troughs. A series of parallel loose-jointed stoneware drainpipes were laid on the bottom of the tanks, and were connected with suitable outlets; this arrangement served to draw off the effluent.

The following is a plan of the tanks used in connection with the bacterial or natural treatment of sewage.

Two of these tanks (A, B) are precisely similar in dimensions, being 22 feet 6 inches long, 10 feet 8 inches wide, and 13 feet deep, and the superficial area of each is $\frac{2}{363}$rd of an acre. The third tank (C) is of less regular shape, but is practically of the same area as tanks A and B, and is 6 feet in depth.



The figures against the inside of the lines representing the sides of the tank C indicate the depth of sludge referred to on p. 29 (Series II.).

The figures against the outside of the lines of the plan, indicate the dimensions of the tanks.

The pipe with the valves was used in connection with the experiments of Series III.

List of experiments on the bacterial treatment of sewage effluent and of raw sewage carried out at the Southern Outfall Works (Crossness).

Date.	Tank used.	Name of bed.	Description of experiment.
22 Apl., 1898, to 22 Feb., 1899	Tank B ... ... Tank C ... ... Tank A	The single coke-bed The 6-foot primary coke-bed The 6-foot secondary coke-bed	(Series I.) These experiments were carried out with a view to obtaining information as to the best method of treating the sewage in coke-beds on the south side of the Thames.
27 Feb., 1899, to 28 July, 1900	Tank A	The 13-foot single coke-bed	(Series II.) This bed was used for experiments with an increased depth of bed and latterly with sedimented sewage.
7 Nov., 1899, to 26 May, 1900	Tank B	The 4-foot single coke-bed	Used for continuous treatment of sewage.
24 Dec., 1899, to 13 Jan., 1900	6 Precipitation channels Tank of 280 gallons capacity	... ...	This was a short experiment on the rapid sedimentation of raw sewage and its subsequent treatment in a small coke-bed.
1 Nov., 1900, to 5 Oct., 1901	Tank A ... ... Tank B ... ... Tank C	The 6-foot single coke-bed No. 2 The 6-foot single coke-bed No. 1 Settling and "septic" tank	(Series III.) This series of experiments was carried out for the purpose of obtaining information on the settlement of raw sewage and its subsequent treatment in coke beds.

VIII. The Treatment of Crude Sewage in Single and in Double Coke-beds at the Southern Outfall Works (Crossness). Series I.

This series of experiments lasted from the 22nd of April, 1898, until the 22nd of February, 1899.

One of the tanks (B) was filled to a depth of 4 feet with coke of uniform size, each fragment being about as large as a walnut. The coke was drawn from the retorts of the gasworks at the Crossness Outfall, and was found by long soaking in water to absorb 15 per cent. of its weight of water. The coke-bed had a sewage capacity of 3,000 gallons, which was equal to 50 per cent. of the volume occupied by the coke and air space; the volume of the coke and air space amounted to 960 cubic feet.

This coke-bed is best described as "the single coke-bed," since it was used for the purpose of subjecting the sewage to a single treatment only.

The other two tanks (A, C,) were filled to a depth of 6 feet with precisely similar coke, which was obtained from the South Metropolitan Gasworks. The sewage capacity of each of these tanks was 4,500 gallons. As compared with the single coke-bed, the capacity of the beds was therefore increased in proportion to the increased volume of coke which they contained.

Tank C was at a higher level than Tank A, and the two coke-beds were, therefore, easily rendered available for a process of double treatment. The raw sewage was pumped into Tank C, and the effluent from this tank was allowed to flow by gravitation into Tank A and there to undergo a second treatment.

In order to avoid confusion the two tanks, A and C, were called "the double coke-bed," and for purposes of distinction Tank C was called the "primary," and Tank A the "secondary coke-bed."

It should be stated that effluent from the primary coke-bed was passed through a small laboratory coke-vessel pending the preparation of the secondary coke-bed. This laboratory coke-vessel consisted of a glass bottle of 2·75 gallons capacity, which was filled with small coke, and which had a sewage capacity of 1·25 gallons, or about 45 per cent. of that of the coke which it contained.

These beds were charged with crude sewage, which was pumped by a special engine and pump direct from the suction culvert of the main pumping engines at the Outfall, and the sewage was distributed by means of a wooden trough over the surface of the bed.

The single coke-bed was first filled with sewage on April 22nd, 1898, and from that date until June 23rd, 1898, it was charged with crude sewage twice daily, with the exception of Sundays, when it rested entirely, and of Saturdays, when it received one filling only.

In consequence of this bed having received two fillings daily before it was properly matured, it became foul, and was therefore unable to deal with the sewage in a satisfactory manner. It is now known that when a new bacteria-bed is first started, the work imposed upon it must be very slight until the bacteria in the bed have multiplied sufficiently to cover the surfaces of the material of which the bed is composed. From June 23rd, 1898, this coke-bed rested for a fortnight and was afterwards filled only once a day until the 7th of November, 1898; it was then filled twice daily until the end of this series of experiments on the 22nd of February, 1899. This bed was filled 345 times during these experiments, and it dealt with about 862,500 gallons of raw sewage.

The process of filling the single 4-foot bed occupied about 7 minutes; the bed was allowed to remain full for 3 hours; it was then discharged by allowing the effluent to flow away from the bottom of the bed. The process of emptying occupied about an hour. When the bed was filled only once a day, it was allowed to stand empty for the remainder of the 24 hours. When the bed was filled twice daily, the series of processes was repeated every 12 hours.

The construction of the primary coke-bed for the first stage in the double treatment of sewage was commenced on July the 12th, 1898, but owing to the difficulty of procuring coke at that time, it was not completed until the 1st of September. During the construction of the bed, however, it was frequently charged with crude sewage in order to get forward with the "maturing" of the bed.

The secondary coke-bed used for the second contact in the double treatment of sewage was also "matured" by frequent charges of sewage during its construction. The bed was complete on the 21st of June, 1898, and from that date until the 31st of August, 1898, it was used as a single bed.

During that period it received 60 fillings of raw sewage, and 244,200 gallons of sewage in all were passed through it.

When the primary coke-bed was completed on the 1st of September, 1898, this bed was worked in conjunction with it as a secondary bed, and it received the effluent from the primary bed and subjected it to a second process of treatment.

These beds were filled 219 times between the 1st of September, 1898, and the 22nd of February, 1899.

The surface of each working coke-bed was broken up to a depth of several inches twice a week by being raked over; this kept the surface open, and there was no appearance of its becoming clogged.

At longer intervals a hole extending from the surface of the coke-bed to the bottom of the tank was dug in the coke. The whole of the coke on every occasion was found to be perfectly sweet when it was thus exposed, and it possessed only a slight earthy odour. The surface of the upper portion, to a depth of 3 or 4 inches, was not quite bright, but it emitted no foul smell.

The results of the chemical estimations of the raw sewage and of the effluents in connection with this series of experiments will be found on pp. 43, 44, 54, 55.

The sewage which was subjected to coke-bed treatment varied much in character as judged by the amount of suspended matter and of dissolved oxidisable matter which it contained. The effluent derived from this sewage appeared as a rule to vary in quality with the sewage from which it was produced.

It will be understood that the results deal only with the dissolved oxidisable matter in the sewage and in the effluent. The solid suspended matters of the sewage wholly disappeared in the coke-bed, and were therefore not taken into account.

It appears, however, very probable that the purification of the raw sewage is most complete when the sewage is in a fairly dilute and fresh condition. The least satisfactory results in this series of experiments were obtained during the hot dry weather of the summer, when the sewage arrived at Crossness in a less dilute condition, owing to the absence of rain, and in an offensive and putrescent condition owing to the high temperature of the air. Even when the sewage was poured upon the coke-beds in this offensive condition, the effluent from the beds was not offensive in character, and it did not become offensive when it was kept. It differed from better effluents only by containing a larger amount of dissolved oxidisable matter.

The relative amounts of dissolved putrescible matter in the sewage, in the chemical effluent, in the coke-bed effluent, and in the water of the river Thames, as measured from May 9th, 1898, to February 22nd, 1899, by the amount of oxygen which the daily samples absorbed from permanganate, are shown in the following table.

The percentage purification effected by the coke-beds has been calculated from sets of figures which correspond as to date, and not from the averages given below, which have been derived from estimations made on all the samples of the sewage and of the coke-bed effluents during the course of the experiments.

TABLE VI.

Nature of liquid.	Average amount of oxygen absorbed from permanganate in 4 hours at 80° Fahr.			Percentage purification calculated on raw sewage.
Raw sewage	5·199	5·273	—	—
Chemical effluent	4·288	—	—	17·6
Coke-bed effluent (single treatment)	—	2·498	—	52·2
Coke-bed effluent (double treatment)	—	1·626	—	68·4
River water, high water	—	—	0·496	—
River water, low water	—	—	0·629	—

A comparison of these numbers with one another shows that by substituting a single coke treatment for chemical treatment, the effluent sewage discharged into the river would be completely free from suspended impurity, and would possess a purity, as regards dissolved putrescible matter, of 52·2 as compared with 17·6 in the present effluent, representing an improvement of 66·3 per cent. If discharged after double treatment in the coke-beds the percentage of improvement on the chemical effluent would be 74·3. The bacterial action continuing in the river would rapidly bring the purity of such a liquid into a condition equalling that of the river water itself.

IX. THE TREATMENT OF CRUDE SETTLED SEWAGE IN A COKE-BED THIRTEEN FEET DEEP; THE RAPID SEDIMENTATION AND SUBSEQUENT BACTERIAL TREATMENT OF CRUDE SEWAGE; AND THE TREATMENT OF SETTLED SEWAGE IN A FOUR-FOOT COKE-BED BY THE CONTINUOUS METHOD OF FEEDING, AT THE SOUTHERN OUTFALL WORKS (CROSSNESS). SERIES II.

This second series of experiments at the Southern Outfall Works extended from the 27th of February, 1899, until the 28th of July, 1900. The experiments consisted of the treatment of crude sewage and afterwards of settled sewage in a coke-bed 13 feet deep; and of the treatment of crude sewage continuously supplied to a coke-bed 4 feet deep.

Tank A was used for the 13-foot coke-bed; this had been used in the previous series of experiments as the 6-foot secondary bed.

On February 28th, 1899, the first addition was made to the 6-foot bed, and its depth was increased to 7 feet 5 inches, but the full depth of 13 feet was not attained until April 11th, 1899. The bed was, however, worked while it was being deepened, so as to "mature" the new coke as rapidly as possible.

The history of the bed may be divided into three periods—

i. The bed received crude unsettled sewage between February 27th, 1899, and October 9th, 1899. It was filled once a day from February 27th to March 25th, 1899, and generally twice a day from March 27th to October 9th, 1899, except on Saturdays, when it received only one filling, and on Sundays, when it rested entirely.

Its capacity diminished rapidly, as is shown by the following figures—

March 9th, 1899, capacity 7,900 gallons, or 41 per cent. of the empty tank capacity;
June 8th, 1899, capacity 6,670 gallons, or 34 per cent. of the empty tank capacity;
October 10th, 1899, capacity 5,530 gallons, or 28 per cent. of the empty tank capacity.

ii. The bed received very roughly sedimented sewage between October 13th, 1899, and April 5th, 1900, and was filled twice a day until December 22nd, 1899, and then three times a day until April 5th, 1900.

In consequence of the loss of capacity suffered by the bed when it was fed with crude sewage (Period I.), it was decided to allow the crude sewage to settle before it reached the bed. This was effected by pumping it into a large wooden tank placed on the top of the bed; the overflow from this tank passed on to the bed.

The capacity of the bed on January 12th, 1900, was 6,000 gallons, or 31 per cent. of the empty tank capacity. The bed had been resting from December 22nd, 1899.

iii. The bed received sedimented sewage between May 3rd and July 28th, 1900, and it was filled generally four times a day.

The process of sedimentation consisted in allowing the crude sewage to flow through a tank on its way to the coke-bed. It entered this tank through a broad pipe, which descended nearly to the bottom, and was drawn off by a pipe, the end of which was immersed below the surface of the liquid. The passage through the tank occupied about five hours.

The capacity of the coke-bed on June 16th, 1900, was 6,000 gallons, after resting from April 5th to May 2nd, 1900, and on October 8th, 1900, it was 6,290 gallons, after resting from July 28th, 1900.

In consequence of the bed having been altered before this last measurement was taken, its capacity was calculated on a measurement of only the lower 6 feet of the bed.

The process of filling this bed occupied from 20 to 25 minutes; it was allowed to remain full for two hours, and the process of emptying extended over from one hour to one hour and a half. The number of hours during which the bed rested between the successive emptyings and fillings varied according to the number of times it was filled during the 24 hours. When the number of fillings per day did not exceed two, the fillings were made during the daytime, but when the number of fillings exceeded two, they were distributed evenly over the whole 24 hours.

The bed was charged once only on Saturdays and remained empty on Sundays and on holidays. The other rests were due either to accidents occurring to the driving belt or to the pump, or to the necessity arising for making alterations in the arrangements or for making capacity determinations of the bed.

Taking the average sewage capacity of the bed as being equal to 6,000 gallons, the quantity of sewage dealt with per acre per day would be, for one filling, 1,089,000 gallons; for two fillings, 2,178,000 gallons; and for three fillings, 3,267,000 gallons.

In the table on pp. 54 and 55 are set forth the averages of the chemical examination of the crude sewage as supplied to the bed and of the effluent from the bed for each of the periods mentioned above.

Throughout the period during which the coke-bed was filled four times a day, the effluent from it was clear and free from odour.

In order to ascertain whether the surface of the fragments of coke became fully aërated throughout the bed between the successive chargings with raw sewage, two vertical pipes were inserted into the bed reaching to the depths of 6 feet and 13 feet respectively. After the sewage had flowed away from the bed, samples of air were drawn off from the interspaces between the coke fragments at stated intervals, and the percentage proportions of oxygen and carbonic acid were estimated in this air. The results, which in the case of the 13-foot depth were only of a preliminary character, indicated that even after the air had been in contact with the lower strata of the coke for 70 hours, the air still contained an average of about 75 per cent. of its original oxygen, and the average amount of carbonic acid did not exceed 3 per cent., as is indicated by the tabulated results below.

This evidently represents an entirely satisfactory condition of aëration of the coke surfaces.

A more detailed statement of the results of analysis of the interstitial air is given in the following table :—

TABLE VII.

Six-foot depth.			Thirteen-foot depth.		
Number of hours since sewage drained off.	Percentage of oxygen in the air from the bed.	Percentage of carbonic acid in the air from the bed.	Number of hours since sewage drained off.	Percentage of oxygen in the air from the bed.	Percentage of carbonic acid in the air from the bed.
4	19·8	0·4	22	18·4	1·4
24	9·8	5·8	26·75	14·0	3·8
24·5	10·0	6·0	50·75	14·8	3·0
37	17·8	2·0	51·25	15·3	3·3
40·5	16·8	2·4	70	14·7	0·8

The results prove that, even in the case of the deep 13-foot bed, the air at the lower part of the bed was not seriously deficient in oxygen.

On June 20th, 1900, the depth of the sludge in the brick tank from which the 13-foot coke-bed was filled varied between 2⅞ inches at the inlet to the tank, and 7⅛ inches at the further end of the tank. The depth of the sludge was 4¾ inches at the outlet from the tank to the coke-bed; this outlet was at about two-thirds of the distance from the inlet to the further end. The depth of the sludge in this tank at various points is indicated in the plan on page 22.

The average percentage of organic matter in the dried sludge from the tank was 35·8.

During three weeks, between December 24th, 1899, and January 13th, 1900, the coke-bed experiments in progress at the Southern Outfall Works at Crossness were stopped in order to carry out a large scale experiment on the rapid sedimentation of the whole of the crude sewage received from South London and the subsequent treatment of a small portion of the sedimented sewage in a coke-bed. The sewage received at this Outfall underwent sedimentation in six settling channels, but was not treated with chemicals during the three weeks. It was allowed to flow more rapidly than usual through six channels, the rate of flow averaging 7·4 feet per minute, whilst the usual rate of flow of the chemically-treated sewage is 1·5 feet per minute.

Four of the channels had each a capacity of 6,000,000 gallons and two a capacity of 3,000,000 gallons each. Each channel was 581 feet in length.

A portion of this rapidly sedimented sewage was afterwards treated in a small coke-bed contained in a tank of 280 gallons capacity. The bed was filled three times a day. Its capacity remained constant during the experiments, and the bed suffered in no way from choking.

In the table on pp. 54-5 the average results of the chemical examination of the raw sewage, of the settled sewage, and of the coke-bed effluent, are given, together with the percentage of purification effected.

This experiment showed that rapidly settled sewage could be dealt with in coke-beds without reducing their capacity, and that this treatment yielded a satisfactory effluent. The period over which this experiment extended was too short to admit of "septic" action being set up in the settling channels; but it seems reasonable to anticipate that if the rapid sedimentation were accompanied by "septic" action, a still greater amount of purification would be effected.

From November 7th, 1899, to May 26th, 1900, experiments were carried out on the continuous feeding of a coke-bed with settled sewage supplied through a distributor. For this purpose the 4-foot single bed in Tank B was used, and various methods of continuously feeding the bed with settled sewage were adopted.

A decided decrease in the amount of purification of the settled raw sewage was apparent when a quantity of sewage equal to that dealt with on the intermittent principle was passed continuously through the bed. This decrease was probably due to—

(*a*) The overcharging of the bed with sewage.

(*b*) The reduction of the bacterial action owing to the chilling of the sewage by contact with the cold air during the winter time.

It appears desirable that the temperature of sewage should not fall below 53° Fahr. if the bacteria are to rapidly carry on their purifying action. This temperature is always exceeded when the sewage is supplied to the bed on the intermittent system.

The continuous feeding of the bed further appeared at times to have the effect of washing the useful deposit from the surfaces of the coke fragments.

The various methods of continuous feeding adopted during these experiments did not effect a satisfactory purification, and they did not deal with the sewage as rapidly as it was dealt with by the intermittent treatment.

X. THE TREATMENT OF CRUDE SEWAGE BY CONTINUOUS PASSAGE THROUGH A SETTLING TANK AND BY SUBSEQUENT INTERMITTENT PASSAGE THROUGH COKE-BEDS AT THE SOUTHERN OUTFALL WORKS (CROSSNESS). SERIES III.

The last series of experiments on the bacterial or natural treatment of crude sewage at the Southern Outfall Works (Crossness) were commenced on the 1st of November, 1900.

They were undertaken with the view of supplementing the results obtained from the rough experiments (Series II.) on the "septic" treatment of sewage, which had lasted from May 3rd to July 28th, 1900.

The experiments were carried out in the three brick tanks used in connection with the experiments of Series I. and II.

Tank C, which had been previously used as a 6-foot primary coke-bed (Series I.), had been emptied of the coke and had been used as a settling and "septic" tank for the crude sewage before it underwent treatment in the coke-bed during the later experiments of Series II. After the sludge has been removed it was again used as a settling or "septic" tank during Series III. of the experiments. Tank B, which had been used as a 4-foot single coke-bed, was increased in depth to 6 feet with coke fragments which passed through a 2-inch mesh and which were rejected by a 1-inch mesh. This bed was called the "6-foot single bed No. 1." Tank A was filled to a depth of 6 feet with coke fragments similar in size to those forming bed No. 1. This bed was called "the 6-foot single bed No. 2." It had previously contained 13 feet of coke, and the 6-foot bed was formed by removing sufficient coke to leave a bed of 6 feet in depth.

Both beds were underdrained with loosely jointed earthenware agricultural drain-pipes.

The capacity of the septic tank was 9,000 gallons, but the actual quantity of liquid in the tank varied somewhat during the working.

For the purpose of measuring the quantity of sewage which was supplied to the settling and "septic" tank, a meter was fixed to the delivery pipe which conveyed the crude sewage to the "septic" tank.

From the settling tank an outlet-pipe conveyed the settled sewage to either No. 1 or No. 2 coke-bed, or when the coke-beds were not being filled, to the main effluent discharge culvert.

At first the settled sewage was supplied to the beds by allowing it to overflow from wooden troughs, but this method was afterwards replaced by one in which the liquid fell from the distributing pipes into perforated wooden trays placed upon the surface of the beds.

The filling of each bed occupied about half an hour; the bed remained full for two hours and occupied one hour in emptying. The resting period varied with the number of fillings per 24 hours.

The crude sewage samples for analysis were taken at the inlet to the tank, and the settled sewage samples were taken at the outlet.

The arrangement of the tanks is shown in the diagram on page 22. It should, however, be borne in mind that the bottom of Tank C was on the same level as the top of Tanks A and B.

At first both the beds were filled with settled sewage four times a day, but about the middle of January, 1901, No. 1 bed was worked on the continuous supply principle for one week, and then both the beds were thrown out of work until April the 15th, 1901. This rest was necessitated at first on account of lime water from the chemical treatment of the sewage at this Outfall having gained access to the beds, and afterwards by the choking of the suction pipe of the pump supplying the settling tank with the crude sewage. Owing to a change in the pumping arrangements which was made in March, 1901, it was impossible to give the settling tank a continuous supply of sewage, and it was also impossible to always fill the beds four times each day.

The other days during the specified period, on which the coke-beds were not filled, were either Sundays, when they never were in use; Saturdays, when the height of the sewage in the main was not sufficient during the morning to work the pump; public holidays and the first week in August, which latter was fixed as the time for the annual holiday of the coke-bed samplers.

The original capacity of the wet coke-beds was not estimated, since in the case of both beds the coke had been previously in use, but after the experiments of Series II. had been discontinued for about 10 weeks and the coke had been reduced in depth from 13 to 6 feet, the capacity of the bed was measured and found to be 2,900 gallons, or 32·2 per cent. of the total capacity of that portion of the tank (measured when empty) which contained the coke-bed.

The following table indicates the results of the measurements of the capacity of the beds made at various times.

TABLE VIII.

Date.	Capacity of bed No. 1.		Capacity of bed No. 2.	
	Gallons.	Percentage of empty tank.	Gallons.	Percentage of empty tank.
1900				
Oct. 8			2,900	32·2
Nov. 5			2,750	30·6
Dec. 6			2,550	28·4
1901				
Jan. 9	2,130	23·7	2,150	23·9
" 21			2,100	23·3
Mar. 7			2,600	28·9
May 1			2,475	27·5
June 12			2,300	25·5
Aug. 21			2,200	24·4
Oct. 5			2,175	24·2

The first five sets of figures in the fourth column of the above table represent the measurements made while the beds were receiving four fillings per day. During the period covered by the last five sets of figures, the beds were being filled as many times during the day as circumstances permitted, but never more than four times. The average number of times the beds were filled per day during this latter period was about 2·5. On the 7th of March, 1901, when the capacity of bed No. 2 had increased by 500 gallons, it had been resting for seven weeks. It will, however, be observed that the decrease in capacity after that date was not as sudden as during the first three months. This difference is accounted for by the decreased number of fillings per day which the bed had received.

The ease with which the capacity of the coke-bed No. 2 was increased by a short rest suggests that its loss of capacity was mainly due to accumulated organic or putrescible matter in the bed; this would, no doubt, be largely avoided by more perfect previous sedimentation of the sewage and by more energetic "septic" action, both of which conditions would be fulfilled when larger settling channels were used.

During the passage of the crude sewage through the "septic" tank, a small proportion of the solid organic matter was liquefied by bacterial action, but the action was not as great as was expected. On the 18th of January, 1901, the tank was roughly covered over, and by the 28th of January a thick scum about an inch in thickness had formed on the top of the liquid; this scum continued to increase in thickness and toughness. The bacterial action appeared also to have increased, since gas was evolved in larger quantity; but the solution of organic matter was not more marked than before the cover was placed over the tank.

Comparing the results produced by bacterial action in the settling tank during periods when its surface was protected by scum, with periods when the scum was absent, it was found that the liquefying effect produced by the bacteria on the sludge proceeded as satisfactorily in the absence as in the presence of the scum.

The solution of organic matter continued, but on February 27th, 1901, the pump feeding the septic tank became choked with sludge, owing to the stoppage of the main pumps at the east end of the engine house for alterations, and the experimental work had to be stopped. The pipe in connection with the pump which took the sewage from the main sewers at the Outfall Works was, therefore, shortened by about 5 feet, in order to prevent choking in the future, and as a consequence of this shortening of the pipe, the end of it was often above the level of the sewage in the mains. It was, therefore, only when the level of the sewage rose to a certain height that the feed pipe of the pump was in the liquid, and that the pump could be used for filling the "septic" tank. The alterations in the pumping arrangements consequently prevented the "septic" tank from receiving in future a continuous feed of crude sewage.

On February 27th, 1901, the scum on the top of the liquid in the "septic" tank had entirely disappeared.

On March 28th, 1901, an examination of the "septic" tank was made, when it was found that 25·6 per cent. of the sediment or sludge had been liquefied by bacterial action. During the whole period that the tank had been in action, 41·2 per cent. of the sludge disappeared. The great difference in the percentage reduction of sludge in the tank during the period from November 1st, 1900, to March 28th, 1901, and the period from November 1st, 1900, to October 5th, 1901, is probably due to—

(*a*) The efficiency of the "septic" tank increasing with the length of time during which it had been in use, since the sludge was not cleared out of the tank at the end of the first period.

(*b*) The fact that during the first period the sewage was supplied to the tank almost uninterruptedly, whereas during the period March 29th, 1901, to October 5th, 1901, the sewage supply to the "septic" tank was by no means continuous, owing to alterations in the pumping arrangements.

The weekly average quantities of crude sewage which passed through the "septic" tank were—

From November 1st, 1900, to March 28th, 1901	131,817 gal.,	or	21,969 gal.	per day.
From March 29th, 1901, to October 5th, 1901	89,898 ,,	,,	14,983 ,,	,, ,,

The solid matter deposited in the "septic" tank consisted of—

(*a*) *Mineral Matter*, principally sand, grit and mineral road detritus, which are not affected by the "septic" action, and which could be separated from the other deposited solids to a great extent by previous sedimentation.

(*b*) *Organic matter*, comprising, in addition to fæcal matter, husks of cereals, chips of wood, paper, etc., which latter are only acted upon by the bacteria in the "septic" tank with extreme slowness.

A much more accurate idea of the action which occurred in the "septic" tank is obtainable, therefore, when the reduction of the solid matter is calculated as a percentage of the total solid organic matter deposited in the tank.

The figure thus obtained is 71·4 per cent. for the whole period from the 1st of November, 1900, to the 5th of October, 1901.

The usual method of working the "septic" tank was to allow a unit volume of sewage about six hours to pass through the tank. This was equal to the average time which a unit volume of sewage takes to pass through the large settling channels in the chemical and sedimentation process.

During these experiments daily analyses were made of the crude sewage as it flowed into the settling tank, of the settled sewage as it flowed from the settling tank upon the coke-beds, and of the effluents from the coke-beds. In the table on pp. 56 and 57 the average results of these estimations are set forth.

No estimations were made of the suspended matters in the effluents from the coke-beds, as more often than not the quantity was too small for the purpose.

XI. CONCLUSIONS ARRIVED AT BY THE EXPERIMENTAL TREATMENT.

The points which have been established by the experimental work are the following:—

1. That by suitable continuous undisturbed sedimentation the

raw sewage is deprived of matter which would choke the coke-beds, and the sludge which settles out is reduced in amount by bacterial action to a very considerable extent. This reduction might undoubtedly be increased by the preliminary removal of road detritus.

2. That the coke-beds, after they have developed their full purifying power by use, have an average sewage capacity of about 30 per cent. of the whole space which has been filled with coke.

3. That the sewage capacity of the coke-bed, when the bed is fed with settled sewage, fluctuates slightly, but undergoes no permanent reduction. The bed does not choke, and its purifying power undergoes steady improvement for some time.

4. That coke of suitable quality does not disintegrate during use.

5. That the "bacterial effluent" of settled sewage from the coke-beds does not undergo offensive putrefaction at all even in summer heat, and can never become offensive. That this effluent satisfactorily supports the respiration of fish.

6. That the use of chemicals is quite unnecessary under any circumstances when the above method of treatment is adopted.

XII. TABULATION OF THE RESULTS OF THE CHEMICAL EXAMINATION OF THE CRUDE SEWAGE, OF THE SETTLED SEWAGE, AND OF THE EFFLUENTS AT THE OUTFALL WORKS.

For the purpose of comparing the results of the experiments on the treatment of crude sewage, detailed in the foregoing sections, the following tables will be found useful. The results of the estimation of the raw sewage and of the final effluent in respect of each experiment are set forth in tables IX. to XVII. Each table of this group consists of one week's results of the estimations made during the various experiments. These figures are typical, and the week chosen was generally one as near the end of the experiment as possible, after the beds had been uninterruptedly in use for a series of three or four weeks, in some cases longer. In addition to one week's results, each table also includes the maximum and the minimum results of each of the various estimations recorded. In order that these figures may be more readily seen, the maximum results have been printed in type thicker than usual, and the minimum in italic type. In some instances the maximum or the minimum estimation was recorded more than once, but in such cases only one day's estimations are given unless the figures were the same on only two days, when both are given. It is more particularly in respect of the minimum of the nitrous or nitric nitrogen that repetition occurs, and owing to the minimum generally being "nil" and to its frequent occurrence, it appears in the tables several times, that is on days when the maximum or minimum of other estimations are recorded.

In the table "The rapid settlement of raw sewage," &c., on p. 47, a slight deviation from the general form of the first group of tables has been made. This was considered necessary since the experiment was conducted more particularly with a view to gaining information respecting the rapid settlement of raw sewage in the channels used at Crossness in connection with the chemical treatment and precipitation.

In the last table but one, on pp. 48-9, it has been necessary to indicate in columns 2 and 3 the maximum and minimum results for the sewage which refer to bed No. 1, and another maximum and minimum in those columns which refer to bed No. 2.

In the table XVIII., pp. 50 to 57, the averages of the various estimations in each experiment are given, together with the percentage purification effected by each individual tank or bed on the liquid with which it dealt, and the percentage of purification effected by the whole process on the raw sewage. The percentage purification is calculated from the amount of oxygen absorbed by the total putrescible matter and by the dissolved putrescible matter in the various liquids. Similar figures relating to the chemical treatment of the sewage at each Outfall Works are added for the purpose of comparison.

In the following tables all quantities, except where otherwise stated, are expressed in parts per 100,000. To convert parts per 100,000 into grains per gallon, multiply by 0·7; to convert grains per gallon into parts per 100,000, multiply by $\frac{10}{7}$.

TABLE IX.—*Typical, maximum and minimum results of the estima-*
4 hours at 80° Fahrenheit by the total putrescible matter and by
present in the sewage and in the effluents from the various

NORTHERN OUTFALL.

The treatment of raw sewage in two successive coke-beds (coarse and
One filling of

Date.	Raw Sewage.					Final Ragstone-		
		Oxygen absorbed by					Oxygen absorbed by	
	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3
1898								
Nov. 21	Not estimated	10·000	**5·714**	trace	0·1303	Not estimated	3·000	2·857
,, 22		12·857	**5·714**	0·0900	0·0081		2·714	2·571
,, 23		11·429	6 857	0·0400	0·0930		2·714	2·857
,, 24		15·714	6·714	*nil*	0·1651		3·286	3·286
,, 25		17·143	6·857	*nil*	0·0509		3·286	3·000
,, 26		14·286	6 286	0·2000	*nil*		2·143	2·143
Oct. 5		Not estimated	3·286	*nil*	*nil*		Not estimated	2·714
,, 7			2·571	0·0260	*nil*			2·000
,, 10			2·143	0·1000	*nil*			2·571
,, 14			2·571	0·0500	*nil*			*1·714*
,, 17			*2·000*	0·1700	0·0470			1·857
,, 18			3·143	0·0400	0·0243			2·286
Nov. 7		*8·487*	4·809	trace	0·0821		2·687	2·546
,, 30		15·714	**8·571**	0·0200	0·1873		3·571	3·571
Dec. 1		**27·143**	6·143	*nil*	0·0231		4·000	**4·000**
,, 7		18·571	7·000	*nil*	0·0563		3·571	3·429
,, 8		10·000	4 286	**0·4000**	**1·0624**		2·143	2·143
,, 14		15·714	7·429	0·0100	0·0873		3·429	3·286
,, 16		14·286	7·286	0·0200	0·1059		**4·286**	3·714
,, 29		14·286	6·286	0·0800	0·1727		3·000	2·571
,, 30		21·429	6·714	0·1000	0·1446		3·000	2·857
1899								
Jan. 2		10·000	5·143	0·1000	0·2420		*1·857*	1·857

Two fillings of

Date.	1	2	3	4	5	1	2	3
1899								
Mar. 20	Not estimated	Not estimated	6·163	*nil*	0·2017	Not estimated	Not estimated	2·661
,, 21			6·604	*nil*	0·5250			2·830
,, 22			6·604	*nil*	0·4009			3·234
,, 23			5·796	*nil*	0·1759			2·291
,, 24			6·334	*nil*	0·2036			2·696
,, 25			5·796	*nil*	0·2017			3·100
Jan. 11		**27·143**	6·000	*nil*	0·1571		3·857	2·857
,, 12		18·571	4·429	trace	0·0139		**4·571**	2·429
,, 14		11·429	*3·571*	*nil*	0·0670		2·714	2·143
,, 16		*10·000*	4·143	**0·1500**	*nil*		*2·286*	*1·429*
,, 17		11·429	4·286	0·0300	*nil*		2·429	2·000
,, 25		Not estimated	5·940	trace	0·0544		Not estimated	2·829
Feb. 9			4·429	*nil*	**1·1170**			2·143
Mar. 1			6·143	*nil*	0·0660			2·571
,, 29			**7·413**	*nil*	0·0964			2·426
April 5			7·277	*nil*	0·2134			**3·909**
,, 6			5·796	*nil*	0·1071			3·639

tions of suspended solids, of oxygen absorbed from permanganate in the dissolved putrescible matter, and of the nitrous and nitric nitrogen bacteria-beds at the Outfall Works of the London County Council.

SERIES I.

fine) and in two successive Kentish ragstone-beds (coarse and fine).
the beds per day.

bed Effluent.		Final Coke-bed Effluent.				
			Oxygen absorbed by			
Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5
0·0600	2·2560	Not estimated	2·714	2·000	0·0229	0·9450
0·0200	2·8924		2·143	2·000	0·0100	2·1864
0·0460	2·7370		2·429	2·286	0·0540	2·2049
0·0140	2·4690		2·429	2·429	0·0100	2·0436
0·0100	2·5703		2·429	2·143	0·0300	1·8824
Slight trace	2·1830		*1·714*	1·571	trace	1·0456
nil	0·2500		Not estimated	**0·714**	0·0260	*nil*
0·0260	*nil*			1·000	0·0260	*nil*
0·2843	0·0907			1·286	0·2000	*nil*
0·0460	0·1599			1·000	0·0640	0·1583
0·1700	0·8193			1·143	0·2301	0·2413
0·1000	0·6589			1·286	**0·2500**	0·2277
0·0400	2·6136		1·980	1·980	0·0460	1·9861
nil	1·6723		2·857	2·714	0·0200	1·4809
nil	1·8929		3·143	3·000	trace	1·3231
0·0400	2·5724		**3·286**	**3·143**	0·0500	1·4134
0·0400	3·0877		1·857	1·571	0·0300	2·0209
0·0400	4·0751		2·714	2·286	0·0500	**2·9866**
0·0500	0·5651		**3·283**	2·714	0·0500	1·0956
0·0400	**5·8394**		2·286	1·857	trace	2·7580
0·0100	3·1749		2·286	1·857	*nil*	2·4393
0·0200	2·7649		2·571	2·429	0·0400	...

the beds per day.

0·0300	2·2664	Not estimated	Not estimated	2·241	0·0500	0·7750
0·3300	1·6923			2·426	0·1500	0·8967
0·4000	1·3597			2·830	0·0700	0·7531
0·7000	1·4429			2·021	0·1800	0·7137
1·0000	1·2339			2·291	**0·5000**	0·1160
1·2500	*nil*			2·291	0·2000	*nil*
0·2200	3·6800		**4·000**	**3·000**	0·2000	0·8739
0·1000	1·9027		2·429	1·714	0·0700	1·4077
0·2000	1·2741		1·714	1·429	0·0300	1·7780
0·1500	2·8624		*1·571*	1·429	0·0400	2·4867
0·0500	2·4357		1·857	*1·286*	0·0340	2·1089
0·2000	3·7937		Not estimated	2·121	0·0460	**2·7254**
0·0200	2·1523			1·714	trace	1·9536
trace	1·1017			1·857	0·0200	2·4183
0·0700	3·9103			2·696	*nil*	0·4553
0·3500	**10·2331**			2·560	0·0300	0·2586
4·6000	*nil*			2·156	0·2500	0·1259

NORTHERN OUTFALL.

TABLE X.—*The treatment of raw sewage in two successive coarse*

Filling of the beds

Date.	Raw Sewage.					Final Effluent	
		Oxygen absorbed by					Oxygen
	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter.) 2
1899							
Sept. 11 ...	Not estimated	Not estimated	5·864	nil	0·1401	Not estimated	Not estimated
" 13 ...			**7·519**	*nil*	0·1290		
" 15 ...			6·079	nil	0·1893		
July 19 ...			6·394	*nil*	0·0393		
" 21 ...			5·306	nil	*trace*		
" 24 ...			5·583	*nil*	0·1724		
" 26 ...			5·413	nil	0·2186		
" 28 ...			6·014	*nil*	0·1687		
" 31 ...			6·774	nil	0·1716		
Aug. 28 ...			*3·840*	*nil*	0·0883		
" 30 ...			5·683	nil	**0·6883**		
Sept. 4 ...			6·917	*nil*	0·1651		

One filling of

Date.	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter.) 2
1899							
Nov. 27 ...	77	12·306	7·071	*nil*	0·0864	14	4·101
" 28 ...	90	12·000	**10·143**	*nil*	0·1669	4	3·857
" 29 ...	66	**13·714**	7·857	0·0200	0·0674	11	4·714
" 30 ...	64	11·429	6·429	0·0200	0·0666	7	3·143
Dec. 1 ...	74	11·857	7·000	*nil*	0·1719	10	2·571
" 2 ...	113	11·857	5·857	*nil*	0·1717	11	3·857
July 5 ...	...	Not estimated	6·593	*nil*	0·0883	...	Not estimated
" 8 ...	...		5·631	slight trace	0·2053	...	
" 12 ...	...		6·181	*nil*	0·2750	...	
Oct. 3 ...	64		6·616	*nil*	0·5004	3	
" 14 ...	70		7·004	*nil*	0·3310	4	
" 16 ...	*27*		4·533	*nil*	0·4254	9	
" 17 ...	84	12·500	6·593	*nil*	0·5084	**17**	4·004
" 19 ...	79	11·739	6·647	*nil*	0·2923	11	3·536
" 24 ...	**114**	13·304	6·161	*nil*	0·3459	13	4·481
" 30 ...	53	8·123	4·061	*nil*	0·0771	9	1·820
Nov. 4 ...	50	7·143	*2·520*	*nil*	0·0890	*nil*	1·680
" 6 ...	41	*6·441*	3·080	**0·4000**	**0·6671**	7	*1·540*
" 18 ...	90	11·429	5·857	*nil*	trace	3	**5·429**
Dec. 5 ...	81	12·000	7·286	*nil*	*nil*	7	4·143
" 9 ...	59	11·000	6·143	*nil*	trace	14	3·429

SERIES II.

coke-beds, and in two successive coke-beds, one fine and one coarse.

on alternate days.

from two coarse beds.			Final Effluent from coarse and fine beds.				
absorbed by				Oxygen absorbed by			
the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5
2·406	0·2000	1·0714	Not estimated	Not estimated	1·353	0·0300	0·8360
2·106	0·0400	2·7750			1·353	0·0200	3·3666
2·127	0·0700	1·8361			1·064	0·0500	**3·7986**
4·081	0·1700	*nil*			**2·727**	0·0357	2·7696
1·224	*nil*	trace			1·224	0·0300	2·3450
2·584	**0·6400**	0·2829			1·087	0·0561	1·7453
2·406	0·4500	0·2386			*0·626*	0·0480	1·7549
1·804	0·3000	0·5839			*0·626*	0·0600	1·7071
2·504	0·3000	0·6830			1·179	**0·0760**	*0·0954*
1·981	0·0831	1·6897			1·383	0·0300	3·5214
1·981	0·1500	2·2786			1·229	*nil*	2·5886
1·053	0·0600	**3·4857**			1·353	*nil*	2·3086

the beds per day.

3·394	0·0600	1·1650	1	2·546	2·263	0·0600	1·3354
2·286	0·0700	1·9433	*nil*	2·286	1·857	0·0800	*0·1030*
2·714	0·0540	1·9549	9	**3·714**	**2·286**	0·0540	0·3076
2·429	0·0400	1·9386	10	2·286	1·714	0·0460	2·1861
2·571	0·1200	0·9550	10	2·000	2·000	0·0500	2·8310
2·429	0·3000	0·8847	10	2·143	1·857	0·1000	2·4257
2·610	*nil*	*0·0794*	...	Not estimated	1·236	0·2500	1·7000
2·336	*nil*	0·1536	...		0·960	**0·4000**	0·3696
2·473	*nil*	0·3036	...		*0·714*	0·2300	1·7021
2·127	0.0600	**3·8516**	*nil*		1·353	0·0200	3·6463
3·846	**1·0000**	2·5544	3		1·236	0·0300	1·5001
1·923	0·0400	2·6330	*nil*		1·373	*nil*	2·2261
2·609	0·0400	1·3304	3	2·060	1·373	0·0200	1·3706
1·414	0·0400	1·4724	6	1·839	1·414	0·0200	**4·3550**
2·100	0·0400	1·1506	4	1·821	1·540	0·0400	3·0489
1·274	0·0200	1·7346	1	*0·840*	0·840	0·0200	2,2610
1·260	0·0400	1·7344	*nil*	*0·840*	0·840	0·0200	3·1854
1·120	0·0300	2·7904	1	1·120	0·980	*nil*	3·2414
2·571	0·2000	1·0481	*nil*	1·714	1·286	0·0800	2·3600
2·714	0·1200	1·5754	9	2·286	2·143	0·0600	3·4947
2·429	0·2000	1·0214	16	2·000	1·714	0·0300	2·2664

NORTHERN OUTFALL.

Two fillings of

Date.	Raw Sewage.					Final Effluent	
		Oxygen absorbed by					Oxygen
	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter). 2
1900							
May 14 ...	58	12·000	7·200	*nil*	*trace*	6	4·000
,, 15 ...	66	13·200	6·600	*nil*	*trace*	6	3·800
,, 16 ...	68	13·400	5·800	*nil*	*trace*	8	3·600
,, 17 ...	68	12·800	6·000	*nil*	*trace*	6	3·600
,, 18 ...	72	13·000	7·400	*nil*	*trace*	6	3·200
,, 19 ...	72	12·200	4·600	*nil*	*trace*	8	3·000
1899							
Dec. 12 ...	59	11·571	7·286	*nil*	**0·5269**	10	4·000
,, 21 ...	30	*8·857*	5·000	0·0600	0·0247	11	4·429
,, 28 ...	69	11·143	6·429	*nil*	0·0816	14	4·000
,, 29 ...	139	12·857	7·000	*nil*	0·1613	**19**	4·714
,, 30 ...	77	9·857	4·571	*nil*	0·0873	7	3·286
1900							
Jan. 6 ...	57	9·714	4·286	*nil*	0·0357	3	3·714
,, 24 ...	58	13·940	6·274	0·0300	0·0880	*nil*	3·920
Feb. 5 ...	100	14·454	6·632	**0·4000**	0·1858	2	3·762
,, 6 ...	**140**	13·266	4·542	0·2000	0·0276	8	2·574
,, 21 ...	58	14·652	8·316	0·3000	0·1684	16	3·960
,, 27 ...	76	9·600	*3·200*	0·0400	0·0785	10	*1·800*
Mar. 19 ...	*19*	13·400	5·800	0·0600	0·1674	6	3·200
Apl. 3 ...	76	**15·800**	**9·000**	*nil*	0·1178	10	4·600
,, 6 ...	98	13·600	6·400	*nil*	*trace*	10	**5·800**
,, 18 ...	78	14·800	8·200	*nil*	*trace*	14	5·200
,, 19 ...	62	14·000	6·600	*nil*	*trace*	14	5·200

SERIES II.—continued.

the beds per day.

from two coarse beds.			Final Effluent from coarse and fine beds.				
absorbed by				Oxygen absorbed by			
the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5
2·400	0·0700	1·1444	*nil*	2·600	1·400	0·0200	2·1706
2·400	0·3000	0·9082	2	2·000	1·800	*nil*	2·3958
2·200	0·2000	0·7596	4	2·000	1·200	0·0200	1·6842
2·200	0·3000	0·6626	4	2·000	1·200	0·0300	2·5550
2·400	0·0600	1·3614	*nil*	2·000	1·600	0·0500	2·3686
1·800	0·0500	0·9232	2	1·800	1·200	0·0600	1·1566
2·857	0·2000	1·0287	*nil*	2·143	1·857	0·0300	2·6336
2·714	0·2000	2·3243	7	5·000	3·857	0·0600	*0·3647*
2·571	*0·0300*	0·6390	4	2·286	1·714	0·0200	1·7719
2·857	0·0600	0·7671	9	2·429	2·143	0·0400	1·8333
2·286	0·1500	0·1861	16	2·000	1·429	0·0600	1·7607
2·000	0·3000	*0·1311*	3	2·143	1·857	0·0600	0·4499
2·352	0·2000	0·6320	6	1·960	1·764	0·0400	1·7302
1·980	0·0400	2·0472	2	2·178	1·782	0·0400	3·0542
1·584	0·0400	1·4388	lost	1·584	1·386	*nil*	2·5502
1·782	0·0600	8·7576	4	1·980	1·386	0·0400	6·4790
1·200	0·0600	1·3566	*nil*	*1·200*	*1·000*	0·0400	2·3236
2·800	0·0400	2·2340	*nil*	2·200	1·600	0·0200	3·1888
2·400	0·1000	1·3004	*nil*	2·800	2·000	0·0700	2·2882
3·800	0·0400	1·1664	4	2·600	2·400	0·0600	1·8904
2·800	0·1000	3·1248	2	3·200	2·600	0·1200	3·5650
3·000	0·4000	0·8180	4	2·800	2·200	0·1000	3·5464

NORTHERN OUTFALL. SERIES III.

TABLE XI.—*The treatment of raw sewage by settlement in a tank and by subsequent treatment in a coarse coke-bed.*

The number of fillings of the bed per day varied between 1 and 3, and averaged 1·2.

Date.	Raw Sewage.					Final Effluent from coarse bed A.				
		Oxygen absorbed by					Oxygen absorbed by			
	Suspended solids.	the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).	Nitrous Nitrogen.	Nitric Nitrogen.	Suspended solids.	the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).	Nitrous Nitrogen.	Nitric Nitrogen.
	1	2	3	4	5	1	2	3	4	5
1901										
Mar. 18	52	12·352	7·058	*nil*	trace	18	5·098	2·744	0·0600	0·5005
„ 19	48	13·600	8·400	0·0300	0·1993	8	5·200	3·400	0·0400	0·8773
„ 20	72	13·400	8·800	0·0400	trace	10	4·200	3·800	*nil*	0·5589
„ 21	60	13·400	6·000	*nil*	*nil*	14	6·000	3·600	0·0600	0·4097
„ 22	48	12·600	7·000	*nil*	trace	8	4·400	3·000	0·0360	0·1907
„ 23	62	13·200	5·800	*nil*	trace	6	5·400	2·200	0·0500	0·2977
1900										
Nov. 30	26	**17·820**	**15·246**	*nil*	trace	10	5·742	4·752	0.0300	0·5345
Dec. 13	**206**	15·400	6·800	*nil*	trace	8	5·800	4·200	0·0300	0·8958
„ 28	68	10·800	6·000	*nil*	trace	4	*2·400*	1·800	0·0400	0·8668
„ 31	50	*8·600*	3·000	0·0800	trace	16	4·800	2·400	0·0300	0·6729
1901										
Jan. 29	74	15·200	10·800	**0·1000**	0·3554	18	7·000	5·000	0·0400	1·3222
Feb. 6	118	13·800	6·600	0·0300	**0·6754**	16	6·400	3·600	0·0300	0·3225
Apl. 2	48	13·400	8·600	**0·1000**	0·3509	8	4·800	2·800	*nil*	0·6541
May 6	*20*	8·910	5·346	*nil*	*nil*	2	3·168	2·970	*nil*	3·8198
„ 7	24	10·096	5·148	*nil*	*nil*	*0*	2·970	2·376	0·0600	2·1787
„ 8	102	13·200	5·800	*nil*	*nil*	*0*	3·400	2·200	*nil*	1·3478
„ 14	54	13·000	8·600	*nil*	*nil*	8	4·600	2·800	**0·2400**	*nil*
June 28	56	11·400	5·400	*nil*	trace	**44**	**12·800**	**7·600**	0·0600	**5·4079**
July 27	42	8·626	*2·941*	*nil*	*nil*	10	3·724	*1·372*	*nil*	1·1245

The treatment of raw sewage by settlement in a tank and by subsequent treatment in a fine coke-bed.

The number of fillings of the bed per day varied between 1 and 3, and averaged 1·3.

	Raw Sewage.					Final Effluent from fine bed B.				
1901										
July 1	120	13·400	4·600	*nil*	*nil*	6	3·800	2·600	*nil*	1·6980
„ 2	44	10·800	5·800	*nil*	trace	6	3·800	2·400	0·0300	1·0949
„ 3	70	12·400	5·600	0·0300	*nil*	8	3·000	1·800	0·0300	1·0907
„ 4	38	11·000	6·000	*nil*	*nil*	4	3·000	2·400	*nil*	1·1232
„ 5	48	10·800	4·800	*nil*	*nil*	2	3·200	2·400	0·0300	1·0814
„ 6	38	10·000	4·400	*nil*	*nil*	2	3·000	2·600	0·0500	1·3216
1900										
Nov. 8	68	14·652	8·316	*nil*	trace	6	3·168	2·178	0·0340	**8·5542**
„ 9	66	14·652	10·494	*nil*	trace	6	5·148	**4·158**	0·0600	2·3398
„ 30	*26*	**17·820**	**15·246**	*nil*	trace	*nil*	3·910	3·567	*nil*	1·7044
Dec. 13	**206**	15·400	6·800	*nil*	trace	2	3·800	3·400	0·0360	1·6931
1901										
Jan. 14	46	12·800	7·000	*nil*	trace	8	**5·200**	3·200	*nil*	1·3912
„ 22	70	13·332	6·078	*nil*	trace	**14**	4·116	2·940	0·0260	1·1256
„ 29	60	13·400	9·000	0·0500	**0·5209**	*nil*	4·000	3·000	*nil*	1·5781
Feb. 2	50	11·800	5·200	*nil*	*nil*	2	4·600	3·800	**0·7000**	*nil*
„ 6	50	11·000	6·000	**0·2200**	0·0736	*nil*	4·200	3·800	0·0300	1·4961
Apl. 18	54	10·692	5·550	*nil*	*nil*	**14**	3·960	2·178	0·4340	0·4940
May 6	*26*	8·910	5·346	*nil*	*nil*	*nil*	2·376	2·376	*nil*	5·4041
July 27	40	*8·234*	*2·548*	*nil*	*nil*	4	*1·961*	*0·980*	0·0400	1·5395.

SOUTHERN OUTFALL. SERIES I.

TABLE XII.—*The treatment of raw sewage in a single coke-bed 4 feet deep.*

One filling of the bed per day.

Date.	Raw Sewage.					Coke-bed Effluent.				
	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.
		the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).				the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).		
	1	2	3	4	5	1	2	3	4	5
1898										
Oct. 31	Not estimated	Not estimated	5·564	trace	**trace**	Not estimated	Not estimated	*1·053*	0·2000	0·1871
Nov. 1			4·211	trace	**trace**			1·203	0·1500	**0·2914**
„ 2			6·164	trace	*nil*			1·654	0·1500	0·2657
„ 3			**6·917**	*nil*	*nil*			**1·956**	0·1000	0·2057
„ 4			6·466	*nil*	*nil*			**2·556**	0·1600	0·1529
„ 5			7·354	*nil*	*nil*			2·557	0·1000	**0·3143**
July 18			*2·431*	Not estimated				1·214	Not estimated	
Aug. 31			**9.727**	„	„			1·976	„	„
Sep. 16			9·677	„	„			**5·069**	„	„
„ 26			3·226	**0·1714**	*nil*			1·690	0·2286	*nil*
Oct. 15			5·280	*nil*	*nil*			2·470	**0·3057**	trace
„ 20			5·031	trace	*nil*			2·671	*nil*	trace

Two fillings of the bed per day.

Date.	Raw Sewage 1	2	3	4	5	Coke-bed Effluent 1	2	3	4	5
1899										
Feb. 13	Not estimated	Not estimated	4·983	*nil*	*nil*	Not estimated	Not estimated	2·657	trace	0·1229
„ 14			5·783	*nil*	*nil*			3·323	0·0100	0·0471
„ 15			**4·817**	*nil*	trace			**2·353**	0·0100	0·0729
„ 16			3·866	*nil*	*nil*			2·160	*nil*	trace
„ 17			3·564	*nil*	*nil*			1·661	*nil*	0·0571
„ 18			4·484	*nil*	*nil*			2·353	0·0200	trace
1898										
May 11	53·4		9·006	Not estimated	Not estimated	**4·3**		**5·446**	Not estimated	Not estimated
„ 19	42·1		**9·916**			2·7		5·041		
June 3	*25·4*		4·416			*0·7*		2·057		
„ 11	30·6		*2·991*			1·7		*1·207*		
„ 16	**56·4**		5·773			1·3		1·756		
Nov. 28	Not estimated		6·627	trace	*nil*	Not estimated		3·159	0·0800	**0·4571**
„ 30			5·209	*nil*	*nil*			1·489	**0·2400**	0·1957
Dec. 19			5·357	**0·0600**	trace			2·976	0·0400	trace
1899										
Jan. 14			5·429	trace	**0·0571**			2·857	0·0500	0·3286
„ 21			5·714	*nil*	*nil*			2·707	0·0600	*nil*

SOUTHERN OUTFALL. SERIES I.—continued.

TABLE XIII.—*The treatment of raw sewage in two successive coke-beds.* The number of fillings of the beds per day varied between 1 and 2, and averaged 1·3.

Date.	Raw Sewage.					Final Effluent from two coke-beds.				
	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.
		the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).				the crude liquid (total putrescable matter).	the clear liquid dissolved putrescible matter).		
	1	2	3	4	5	1	2	3	4	5
1899	Not estimated	Not estimated				Not estimated	Not estimated			
Feb. 13			4·983	*nil*	*nil*			1·661	0·0600	0·3129
„ 14			5·783	*nil*	*nil*			1·849	0·1000	0·1900
„ 15			4·817	*nil*	trace			1·671	0·0800	0·1243
„ 16			3·866	*nil*	*nil*			1·354	0·0300	0·1771
„ 17			3·564	*nil*	*nil*			1·201	0·0300	0·2400
„ 18			4·484	*nil*	*nil*			1·513	0·0400	0·1629
1898										
July 18			*2·431*	Not estimated	Not estimated			0·760	Not estimated	Not estimated
Aug. 13			2·769					*0·700*		
„ 31			**9·727**					1·216		
Sep. 16			9·677					**4·454**		
„ 26			3·226	**0·1714**	*nil*			1·843	0·4143	*nil*
„ 28			3·951	trace	*nil*			1·671	**0·5714**	*nil*
Oct. 8			5·701	*nil*	*nil*			2·280	*trace*	*nil*
Nov. 28			6·627	trace	*nil*			2·431	0·2000	**0·9814**
1899										
Jan. 14			5·429	trace	**0·0571**			2·000	0·0300	0·7429

SERIES II.

TABLE XIV.—*Treatment of raw sewage in a coke-bed 13 feet in depth.* One filling of the bed per day.

Date.	Raw Sewage.					Coke-bed Effluent.				
	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.
		the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).				the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).		
	1	2	3	4	5	1	2	3	4	5
1899	Not estimated	Not estimated				Not estimated	Not estimated			
Mar. 20			3·720	*nil*	*nil*			1·489	0·1000	trace
„ 21			6·101	*nil*	*nil*			2·231	0·0200	**0·2043**
„ 22			**9·227**	trace	*nil*			**4·464**	0·0300	0·1186
„ 23			4·661	0·0100	*nil*			1·956	0·0200	0·1014
„ 24			5·803	*nil*	*nil*			2·529	0·0100	0·1829
„ 25			4·167	*nil*	*nil*			1·489	0·0300	0·1629
Mar. 4			4·203	*nil*	*nil*			2·317	*nil*	*nil*
„ 7			3·951	**0·0300**	*nil*			2·736	0·1000	trace
„ 8			4·103	trace	*nil*			1·369	**0·1200**	0·0743
„ 14			*3·607*	*nil*	**trace**			1·427	trace	0·0529
„ 15			3·760	*nil*	*nil*			*1·353*	*nil*	trace

Two fillings of the bed per day.

Date.	Raw Sewage.					Coke-bed Effluent.				
		Oxygen absorbed by					Oxygen absorbed by			
	Suspended solids.	the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).	Nitrous Nitrogen.	Nitric Nitrogen.	Suspended solids.	the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).	Nitrous Nitrogen.	Nitric Nitrogen.
	1	2	3	4	5	1	2	3	4	5
1899										
Oct. 2	Not estimated	Not estimated	3·924	0·0240	*nil*	Not estimated	Not estimated	2·354	0·0500	*nil*
,, 3			6·436	*nil*	*nil*			1·884	0·0400	trace
,, 4			7·143	*nil*	*nil*			3·039	0·0300	0·4991
,, 5			5·966	*nil*	**0·2503**			2·356	*nil*	trace
,, 6			6·031	*nil*	*nil*			2·221	*nil*	*nil*
,, 7			4·684	*nil*	*nil*			0·941	*nil*	*nil*
Apl. 7	**88·4**		4·000	0·0400	0·0157			2·000	0·0100	0·1143
,, 20	26·1		**7·496**	*nil*	*nil*			4·306	*nil*	trace
,, 22	38·3		6·637	0·0300	*nil*			**4·329**	0·0100	0·3614
May 3	*19·9*		4·711	*nil*	*nil*			2·799	0·0300	0·2971
,, 18			5·429	**0·0500**	*nil*			2·857	0·1400	0·0657
July 4	Not estimated		2·479	*nil*	*nil*			*0·731*	trace	0·1143
Aug. 26			5·041	*nil*	*nil*			2·017	trace	**1·5750**
Sep. 12			5·771	*nil*	*nil*			2·309	**0·5514**	*nil*
,, 15			*1·457*	*nil*	*nil*			1·311	*nil*	*nil*

The treatment of roughly settled sewage in a coke-bed 13 feet in depth.

Two fillings of the bed per day.

Date.	Raw Sewage: 1	2	3	4	5	Coke-bed Effluent: 1	2	3	4	5
1899										
Dec. 4	Not estimated	13·106	9·043	*nil*	*nil*	Not estimated	3·014	2·097	*nil*	*nil*
,, 5		11·367	6·759	*nil*	*nil*		3·007	2·457	*nil*	*nil*
,, 6		11·607	8·334	*nil*	*nil*		4·167	2·827	*nil*	*nil*
,, 7		10·827	7·819	*nil*	*nil*		5·113	3·759	*nil*	*nil*
,, 8		10·976	6·763	*nil*	*nil*		3·894	2·857	*nil*	*nil*
,, 9		*5·530*	4·147	*nil*	*nil*		3·533	2·137	*nil*	*nil*
Oct. 16		Not est'm't'd	*3·073*	*nil*	*nil*		Not est'm't'd	*1·689*	0·0540	0·3373
,, 23			6·493	*nil*	*nil*			2·164	**0·6614**	trace
Nov. 7		8·571	4·209	**0·1360**	trace		3·316	2·104	0·5400	**1·7310**
,, 23		12·963	8·060	*nil*	**0·1137**		3·041	2·910	*nil*	0·2051
,, 25		6·481	3·836	*nil*	*nil*		*1·983*	1·719	*nil*	*nil*
Dec. 19		13·703	9·911	0·0100	trace		**7·289**	3·353	0·1300	0·3404
,, 22		**21·356**	**11·976**	*nil*	*nil*		6·493	**4·906**	*nil*	trace

Three fillings of the bed per day.

Date.	Raw Sewage: 1	2	3	4	5	Coke-bed Effluent: 1	2	3	4	5
1900										
Mar. 26	Not estimated	5·888	4·000	0·0500	trace	Not estimated	2·666	1·888	0·0300	trace
,, 27		9·355	7·391	*nil*	*nil*		4·623	3·870	*nil*	0·1740
,, 28		8·539	6·179	*nil*	*nil*		4·045	3·370	*nil*	0·4100
,, 29		9·438	7·303	*nil*	*nil*		4·269	3·146	*nil*	*nil*
,, 30		7·629	6·082	trace	*nil*		4·020	2·783	*nil*	*nil*
,, 31		7·979	6·363	*nil*	*nil*		4·242	3·434	*nil*	trace
Jan. 15		4·156	*3·010*	0·2000	0·4640		*1·719*	*1·290*	0·0400	**3·8780**
,, 18		8·602	6·129	0·1400	0·6840		6·236	**5·376**	0·3200	2·0290
,, 26		6·154	4·615	*nil*	*nil*		2·418	*0·879*	0·0500	0·3842
Feb. 1		9·246	**8·817**	0·1500	*nil*		5·053	4·516	0·3200	0·5176
,, 5		6·559	3·440	0·0300	**0·9110**		1·935	1·398	0·0500	1·1800
,, 9		6·180	5·730	0·0600	0·0830		2·432	2·432	**0·3900**	0·4050
,, 20		6·250	4·886	**0·3300**	0·1460		2·955	2·386	0·2900	0·5070
,, 23		8·804	6·630	0·1300	0·1440		**6·630**	4·130	0·2000	0·1680
Mar. 24		*4·444*	3·555	*nil*	*nil*		2·033	1·666	*nil*	trace
Apl. 3		**9·696**	8·181	*nil*	*nil*		5·252	3·939	*nil*	*nil*

SOUTHERN OUTFALL. SERIES II.—continued.

The treatment of settled sewage in a coke-bed 13 feet in depth.

Four fillings of the bed per day.

Date.	Raw Sewage.					Coke-bed Effluent.				
	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.	Suspended solids.	Oxygen absorbed by		Nitrous Nitrogen.	Nitric Nitrogen.
		the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).				the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).		
	1	2	3	4	5	1	2	3	4	5
1900										
July 23	Not estimated	5·435	4·130	nil	*nil*	Not estimated	2·282	1·848	0·0500	0·0663
„ 24		6·087	4·239	*nil*	*nil*		2·065	1·630	trace	trace
„ 25		7·391	3·696	nil	*nil*		2·282	1·848	*nil*	trace
„ 26		6·774	4·623	*nil*	*nil*		2·580	1·613	*nil*	*nil*
„ 27		6·421	4·947	nil	*nil*		2·421	2·105	*nil*	trace
„ 28		6·774	4·215	*nil*	*nil*		2·258	1·290	trace	trace
May 4		5·019	4·134	nil	*nil*		3·077	1·828	0·1000	**0·2490**
„ 8		5·543	4·021	*nil*	*nil*		2·391	1·728	**0·2800**	trace
„ 9		5·326	4·565	nil	*nil*		3·913	**2·826**	trace	trace
„ 11		6·777	2·666	*nil*	*nil*		**5·333**	1·888	*nil*	*nil*
„ 19		4·681	2·979	nil	trace		1·915	1·383	0·1100	0·2420
„ 24		6·421	**5·789**	*nil*	*nil*		2·947	2·000	*nil*	*nil*
„ 31		6·304	4·891	nil	trace		2·608	1·848	*nil*	*nil*
June 7		**7·708**	4·781	*nil*	*nil*		3·553	2·510	*nil*	*nil*
„ 26		3·636	*2·525*	nil	*nil*		1·818	1·414	*nil*	trace
July 3		*3·367*	3·163	*nil*	*nil*		1·632	1·449	*nil*	*nil*
„ 20		6·044	3·626	nil	*nil*		*1·538*	*1·209*	trace	trace

Table XV.—*The treatment of settled sewage in a coke-bed 4 feet in depth.*

Continuous feeding of the bed.

	Raw Sewage.					Coke-bed Effluent.				
	1	2	3	4	5	1	2	3	4	5
1900										
May 21	Not estimated	5·158	3·789	*nil*	*nil*	Not estimated	3·052	2·105	0·0900	0·2600
„ 22		4·271	3·239	*nil*	*nil*		2·708	1·875	trace	*nil*
„ 23		5·684	4·526	*nil*	*nil*		2·368	2·824	*nil*	*nil*
„ 24		4·631	3·157	*nil*	*nil*		2·526	1·894	*nil*	*nil*
„ 25		5·473	3·578	*nil*	*nil*		3·578	2·105	*nil*	*nil*
„ 26		5·789	3·368	*nil*	*nil*		2·526	1·368	*nil*	*nil*
1899										
Dec. 12		**10·897**	8·837	*nil*	trace		4·419	2·946	*nil*	0·1646
„ 21		10·641	**9·183**	*nil*	*nil*		**8·600**	**7·580**	*nil*	*nil*
1900										
Jan. 15		4·623	3·440	0·1000	**0·6890**		3·010	1·182	0·0200	**3·4140**
„ 23		3·516	3·186	*nil*	trace		1·868	*0·769*	0·3100	0·6229
„ 24		*2·580*	*2·366*	*nil*	0·1149		2·105	1·496	0·2900	0·9898
Feb. 6		6·413	3·587	**0·3300**	0·3150		2·065	1·402	0·0500	0·2110
Mar. 31		4·242	3·232	*nil*	lost		*1·818*	1·111	0·0300	trace
Apr. 10		4·251	4·019	0·0300	0·1950		3·823	3·137	**0·7100**	trace

TABLE XVI.—*The rapid settlement of raw sewage and the subsequent treatment of the effluent from it, in a small coke-bed.*

Three fillings of the bed per day.

Date.	Raw Sewage.			Settled Sewage.			Settled Sewage as supplied to the coke-bed.	Coke-bed Effluent.
	Suspended solids.	Oxygen absorbed by		Suspended solids.	Oxygen absorbed by		Oxygen absorbed by	Oxygen absorbed by
		the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).		the crude liquid (total putrescible matter).	the clear liquid (dissolved putrescible matter).	the clear liquid (dissolved putrescible matter).	the clear liquid (dissolved putrescible matter).
	1	2	3	1	2	3	3	3
1899								
Dec. 24 ...	**84**	9·621	5·831	14	7·434	5·539	...	...
" 25 ...	33	9·131	6·039	10	7·216	5·743	6·166	**4·043**
" 26 ...	36	9·880	6·141	16	8·677	6·274	5·314	2·973
" 27 ...	40	10·350	7·289	19	9·329	7·434	5·507	2·973
" 28 ...	47	11·516	**8·163**	16	9·621	**8·017**	6·286	2·857
" 29 ...	47	**12·841**	7·936	19	**10·244**	7·791	5·143	2·429
" 30 ...	46	11·340	*4·419*	14	8·780	5·357	5·000	2·371
" 31 ...	*30*	10·267	6·100	16	8·394	*4·564*	...	...
1900								
Jan. 1 ...	36	10·119	5·801	20	7·737	5·951	4·233	1·991
" 2 ..	66	9·374	5·209	23	8·333	5·357	5·297	2·357
" 3 ...	50	11·064	6·721	13	9·103	6·721	**7·294**	3·103
" 4 ...	41	*8·599*	5·547	14	*5·963*	5·270	6·400	2·941
" 5 ...	37	9·937	7·609	17	9·316	7·143	6·766	2·886
" 6 ...	40	9·047	5·554	17	7·619	5·714	5·466	2·733
" 7 ...	40	9·047	4·920	16	7·777	5·396	...	...
" 8 ...	34	9·419	6·593	19	8·931	6·593	5·286	2·143
" 9 ...	60	10·334	6·413	**26**	9·270	5·774	*4·000*	1·857
" 10 ...	49	10·249	7·299	19	8·696	7·453	4·761	2·309
" 11 ...	34	9·627	6·831	13	8·696	7·143	5·339	*1·731*
" 12 ...	34	11·094	7·143	14	9·271	7·599	6·024	2·846
" 13 ...	36	9·984	6·451	*6*	8·140	6·603	6·574	2·919

SOUTHERN OUT

TABLE XVII.—*The treatment of settled*

The number of fillings of the beds per day

Date.	Raw sewage.					Effluent from	
		Oxygen absorbed by					Oxygen
	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (total putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter). 2
1901							
July 15 ...	30	5·102	3·571	**nil**	**nil**	Not estimated	1·632
,, 16 ...	36	5·760	4·242	*nil*	*nil*		2·020
,, 17 ...	41	7·373	5·555	**nil**	**nil**		2·626
,, 18 ...	34	7·653	4·898	*nil*	*nil*		2·347
,, 19 ...	18	6·900	4·100	**nil**	**nil**		2·100
Apl. 15 ...	11	7·179	5·579	*nil*	*nil*		**4·947**
,, 16 ...	19	7·127	5·106	**nil**	**nil**		3·085
,, 20 ...	*10*	5·252	3·838	*nil*	*nil*		1·717
June 6 ...	**74**	10·000	**6·236**	**nil**	**nil**		4·301
,, 21 ...	70	**12·526**	6·000	*nil*	*nil*		3·474
Aug. 19 ...	25	3·637	*1·920*	**nil**	**nil**		2·223
,, 24 ...	15	*3·441*	2·043	*nil*	*nil*		1·828
Oct. 4 ...	20	4·528	3·113	**nil**	**nil**		*1·320*

Four fillings of

1900							
Dec. 17 ...	33	5·494	3·956	*nil*	*nil*	Not estimated	2·747
,, 18 ...	24	4·565	3·478	*nil*	*nil*		1·847
,, 19 ...	29	4·674	4·021	*nil*	*nil*		1·847
,, 20 ...	30	3·830	3·404	*nil*	*nil*		2·127
,, 21 ...	24	3·829	3·404	*nil*	*nil*		1·916
,, 22 ...	18	3·871	3·333	*nil*	*nil*		1·720
Nov. 13 ...	29	7·246	**6·224**	*nil*	*nil*		3·571
,, 15 ...	33	5·369	3·894	*nil*	*nil*		2·947
,, 28 ...	**38**	7·065	4·782	*nil*	*nil*		**3·913**
Dec. 13 ...	36	**7·634**	5·269	*nil*	*nil*		2·795
,, 27 ...	*12*	3·333	3·118	*nil*	*nil*		1·720
,, 28 ...	14	3·793	3·579	*nil*	*nil*		1·684
,, 29 ...	24	3·063	*2·553*	*nil*	*nil*		1·489
,, 31 ...	15	*2·842*	2·631	*nil*	*nil*		1·474
1901							
Jan. 1 ...	20	4·042	3·511	*nil*	*nil*		*1·383*
,, 2 ...	22	4·946	4·623	**0·0240**	**trace**		2·473
,, 15 ...	29	**7·824**	5·979	trace	**trace**	{	Continu
,, 16 ...	15	**7·824**	**6·391**	*nil*	*nil*	}	

Continuous feeding of the bed.

1901							
Jan. 14 ...	31	6·250	5·833	*nil*	*nil*	Not estimated	4·791
,, 15 ...	29	7·824	5·979	**trace**	**trace**		5·979
,, 16 ...	*15*	7·824	6·391	*nil*	*nil*		**6·598**
,, 17 ...	29	**8·200**	**6·700**	*nil*	*nil*		6·400
,, 18 ...	**49**	6·176	5·784	*nil*	*nil*		5·098
,, 19 ...	24	5·148	4·852	*nil*	*nil*		3·366
,, 21 ...	25	*4·059*	*3·168*	*nil*	*nil*		*2·871*

FALL. SERIES III.

sewage in single coke-beds.

varied between 1 and 4, and averaged 2·5.

No. 1 Bed.			Effluent from No. 2 Bed.				
absorbed by				Oxygen absorbed by			
the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrogen. 4	Nitric Nitrogen. 5	Suspended solids. 1	the crude liquid (total putrescible matter). 2	the clear liquid (dissolved putrescible matter). 3	Nitrous Nitrog n. 4	Nitric Nitrogen. 5
1·326	0·0920	*nil*	Not estimated	1·632	1·561	trace	*nil*
1·555	0·0700	*nil*		1·999	1·444	0·0760	0·0700
1·616	0·0360	*nil*		2·222	1·515	0·0780	*nil*
1·735	*nil*	*nil*		2·041	1·633	trace	*nil*
1·600	0·0280	*nil*		2·000	1·500	*nil*	trace
3·789	**0·9400**	**0·1060**		4·842	**3·684**	0·2200	**0·7520**
2·339	0·3400	0·3010		3·723	3·298	**0·5000**	0·2390
1·313	0·0420	0·0970		1·616	1·111	0·0300	trace
3·118	0·0640	*nil*		**4·946**	3·656	0·0560	0·0970
2·315	trace	*nil*		3·778	2·315	0·0280	*nil*
1·314	0·0260	trace		1·920	1·516	0·0140	0·0490
1·613	0·0300	trace		1·720	1·290	*nil*	trace
1·037	0·1160	0·1850		*1·320*	*1·037*	0·2340	0·0560

the beds per day.

1·979	*nil*	*nil*	Not estimated	2·572	1·867	*nil*	*nil*
1·632	*nil*	*nil*		1·630	1·521	*nil*	0·0810
1·632	0·0360	0·1370		2·065	1·630	trace	trace
1·915	trace	*nil*		2·127	1·702	*nil*	*nil*
1·595	0·0900	0·1150		1·798	1·595	trace	0·1580
1·397	trace	*nil*		1·505	1·290	0·0360	0·0500
2·551	*nil*	trace		3·469	2·347	*nil*	*nil*
2·430	trace	0·2850		2·526	2·000	0·0160	**0·6830**
3·043	trace	*nil*		4·348	2·826	0·0240	trace
1·935	*nil*	*nil*		2·903	1·935	*nil*	0·1550
1·505	0·1600	0·1094		1·827	1·505	**0·2100**	0·1162
1·473	0·0960	**0·3541**		1·684	*1·158*	0·1100	0·0163
1·276	0·0900	0·2121		*1·489*	1·383	0·0600	0·1730
1·158	**0·2500**	0·1374		1·579	1·263	0·0960	0·2094
1·276	0·1280	0·1399		*1·489*	1·276	0·0740	0·1164
1·258	0·0840	0·1821		2·258	2·013	0·1280	0·0792
ous process of filling				5·464	**5·051**	0·1240	0·1180
				5·876	**5·051**	0·0440	C·0770

4·166	**0·0940**	0·1520					
5·361	0·0900	0·0880					
5·671	trace	trace					
5·600	trace	trace					
4·608	*nil*	*nil*					
2·574	trace	*nil*					
2·178	0·0520	**C·1599**					

TABLE XVIII.—*Averages of the results of the analysis of crude sewage and with the bacterial or natural treatment of crude sewage at the bed or tank on the liquid supplied to it and the percentage purification relating to the "chemical" treatment of crude sewage and to the treat*

Period over which the averages extend. From (1)	To (2)	Description of the liquid examined. (3)	Description of liquid before treatment. (4)	Number of contacts in successive beds. (5)	Number of fillings of the beds daily. (6)
NOR	THERN	OUTFALL.			
1 Jan., 1900	31 Dec., 1901	Crude sewage	...	...	...
		Effluent from chemical treatment and sedimentation	Crude sewage	...	...
		Effluent from one-acre coke-bed	"Chemical" effluent	1	2
1 Jan., 1900	31 Dec., 1901	Crude sewage	...	...	...
		Effluent from chemical treatment and sedimentation	Crude sewage	...	...
		SERIES I.			
22 Sept., 1898	9 Jan., 1899	Crude sewage	...	...	...
		Effluent from the primary ragstone-bed	Crude sewage	...	1
		Effluent from the secondary ragstone-bed	Primary-bed effluent	2	1
11 Jan., 1899	15 April, 1899	Crude sewage	...	...	...
		Effluent from the primary ragstone-bed	Crude sewage	...	2
		Effluent from the secondary ragstone-bed	Primary-bed effluent	2	2
22 Sept., 1898	9 Jan., 1899	Crude sewage	...	...	...
		Effluent from the primary coke-bed	Crude sewage	...	1
		Effluent from the secondary coke-bed	Primary-bed effluent	2	1
11 Jan., 1899	15 April, 1899	Crude sewage	...	...	...
		Effluent from the primary coke-bed	Crude sewage	...	2
		Effluent from the secondary coke-bed	Primary-bed effluent	2	2

of the effluents from each of the coke-beds and tanks used in connection Council's Outfalls, together with the percentage purification effected by each effected on the crude sewage by each method of treatment. Similar figures ment of sewage effluent in the one-acre coke-bed are also added for comparison.

Suspended solids.	Oxygen absorbed from permanganate in 4 hours at 80° Fahr.						Nitrous nitrogen.	Nitric nitrogen.
	By the crude liquid (total putrescible matter).	Percentage purification effected by the individual tank or bed.	Percentage purification effected by the whole treatment	By the clear liquid (dissolved putrescible matter).	Percentage purification effected by the individual tank or bed	Percentage purification effected by the whole treatment		
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
54·2	11·670	...	...	5·684	...	...	Not estimated.	
13·2	7·117	39·0	...	5·497	3·3	...	0·0215	0·0425
Not estimated	1·024	85·6	91·2	0·880	84·0	84·5	0·0662	0·9971
54·2	11·670	...	...	5·684	...	...	Not estimated	
13·2	8·067	30·9	30·9	5·880	No purification effected			
Not estimated	14·482	...	...	5·377	...	...	0·0323	0·1119
	7·903	45·4	...	4·290	20·2	...	0·0420	0·2167
	3·096	60·8	78·6	2·860	33·3	46·8	0·0367	1·9056
Not estimated	14·444	...	...	5·477	...	...	0·0079	0·1483
	8·730	39·6	...	4·319	21·2	...	0·0106	0·1297
	3·222	63·1	77·7	2·643	38·8	51·7	0·2842	2·4370
Not estimated	14·482	...	...	5·377	...	...	0·0323	0·1119
	7·076	51·1	...	4·176	22·3	...	0·0300	0·1254
	2·573	63·6	82·2	1·890	54·7	64·9	0·0476	1·3407
Not estimated	14·444	...	...	5·477	...	...	0·0079	0·1483
	6·984	51·6	...	4·241	22·6	...	0·0178	0·0915
	2·286	67·3	84·2	2·111	50·2	61·5	0·0988	1·1639

Period over which the averages extend.		Description of the liquid examined. (3)	Description of liquid before treatment. (4)	Number of contacts in successive beds. (5)	Number of fillings of the beds daily. (6)
From (1)	To (2)				
NORTHERN		OUTFALL.—SERIES II.			
17 July, 1899	18 Sept., 1899	Crude sewage	...	...	...
		Effluent from primary coarse coke-bed A	Crude sewage	...	Filled on alternate days
		Effluent from secondary coarse coke-bed A	Primary-bed effluent	2	
4 July, 1899 and 21 Sept., 1899	15 July, 1899 and 9 Dec., 1899	Crude sewage	...	...	...
		Effluent from primary coarse coke-bed A	Crude sewage	...	1
		Effluent from secondary coarse coke-bed A	Primary-bed effluent	2	1
11 Dec., 1899	19 May, 1900	Crude sewage	...	...	...
		Effluent from primary coarse coke-bed A	Crude sewage	...	2
		Effluent from secondary coarse coke-bed A	Primary-bed effluent	2	2
17 July, 1899	18 Sept., 1899	Crude sewage	...	...	...
		Effluent from primary coarse coke-bed B	Crude sewage	...	Filled on alternate days
		Effluent from secondary fine coke-bed B	Primary-bed effluent	2	
4 July, 1899 and 21 Sept., 1899	15 July, 1899 and 9 Dec., 1899	Crude sewage	...	...	...
		Effluent from primary coarse coke-bed B	Crude sewage	...	1
		Effluent from secondary fine coke-bed B	Primary-bed effluent	2	1
11 Dec., 1899	19 May, 1900	Crude sewage	...	...	...
		Effluent from primary coarse coke-bed B	Crude sewage	...	2
		Effluent from secondary fine coke-bed B	Primary-bed effluent	2	2
		SERIES III.			
7 Nov., 1900	10 Aug., 1901	Crude sewage	...	...	...
		Effluent from settling tank A	Crude sewage	...	...
		Effluent from coarse coke-bed A	Settled sewage	1	Varied. Average 1·2
7 Nov., 1900	10 Aug., 1901	Crude sewage	...	...	...
		Effluent from settling tank B	Crude sewage	...	...
		Effluent from fine coke-bed B	Settled sewage	1	Varied. Average 1·3

Suspended solids.	Oxygen absorbed from permanganate in 4 hours at 80° Fahr.						Nitrous nitrogen.	Nitric nitrogen.
	By the crude liquid (total putrescible matter).	Percentage purification effected by the individual tank or bed.	Percentage purification effected by the whole treatment	By the clear liquid (dissolved putrescible matter).	Percentage purification effected by the individual tank or bed	Percentage purification effected by the whole treatment		
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Not estimated				6·028	...	...	nil	0·2290
				3·382	43·9	...	0·1911	0·5962
				2·271	32·9	62·3	0·1648	1·4117
71·6	11·218	...	...	6·135	...	...	0·0070	0·2373
13·3	5·236	53·3	...	3·463	43·6	...	0·1240	0·7072
6·7	3·493	33·3	68·9	2·274	34·3	62·9	0·0875	1·4314
65·6	12·488	...	...	6·357	...	...	0·0264	0·0938
17·5	5·927	52·5	...	3·266	48·6	...	0·0743	0·3878
7·4	3·739	36·9	70·1	2·285	30·0	64·1	0·1182	0·9811
Not estimated				6·028	...	...	nil	0·2290
				3·407	43·6	...	0·0647	0·5005
				1·259	63·0	79·1	0·0376	2·3568
71·6	11·218	...	...	6·135	...	...	0·0070	0·2373
13·7	5·334	52·5	...	3·442	43·9	...	0·1112	0·5523
3·2	1·773	66·8	84·2	1·410	59·0	77·0	0·0679	2·3611
65·6	12·488	...	...	6·357	...	...	0·0264	0·0938
14·0	5·600	55·2	...	3·185	49·9	...	0·0573	0·3281
3·1	2·328	58·4	81·4	1·780	44·1	72·0	0·0535	2·1593
66·5	12·933	...	...	6·882	...	...	0·0115	0·0412
17·7	8·419	34·9	...	5·427	21·1	...	0·0022	0·1689
10·0	5·100	39·4	60·6	3·320	38·8	51·8	0·0360	0·7524
67·0	12·829	...	...	6·648	...	...	0·0106	0·0326
13·9	8·235	35·8	...	5·341	19·7	...	0·0022	0·1319
3·2	3·358	59·2	73·8	2·604	51·2	60·8	0·0567	1·2931

Period over which the averages extend. From (1)	To (2)	Description of the liquid examined. (3)	Description of liquid before treatment. (4)	Number of contacts in successive beds. (5)	Number of fillings of the beds daily. (6)
SOUTHERN		OUTFALL.—SERIES I.			
12 July, 1898	7 Nov., 1898	Crude sewage	...	...	...
		Effluent from 4-foot single coke-bed	Crude sewage	1	1
22 April, 1898	23 June, 1898	Crude sewage	...	...	...
and					
8 Nov., 1898	22 Feb., 1899	Effluent from 4-foot single coke-bed	Crude sewage	1	2
12 July, 1898	22 Feb., 1899	Crude sewage	...	...	...
		Effluent from primary coke-bed	Crude sewage	...	...
		Effluent from secondary coke-bed	Primary-bed effluent	2	Varied. Average, 1·3
		SERIES II.			
27 Feb., 1899	25 Mar., 1899	Crude sewage	...	...	...
		Effluent from 13-foot single-coke-bed	Crude sewage	1	1
27 Mar., 1899	9 Oct., 1899	Crude sewage	...	...	...
		Effluent from 13-foot single coke-bed	Crude sewage	1	2
13 Oct., 1899	22 Dec., 1899	Crude sewage	...	...	...
		Effluent from 13-foot single coke-bed	Roughly settled sewage	1	2
16 Jan., 1900	5 April, 1900	Crude sewage	...	...	...
		Effluent from 13-foot single coke-bed	Roughly settled sewage	1	3
3 May, 1900	28 July, 1900	Crude sewage	...	...	...
		Effluent from 13-foot single coke-bed	Settled sewage	1	4
7 Nov., 1899	26 May, 1900	Crude sewage	...	...	...
		Effluent from 4-foot single coke-bed	Settled sewage	1	Continuous feed
24 Dec., 1899	13 Jan., 1900	Crude sewage	...	...	...
		Settled sewage	Crude sewage	...	...
		Settled sewage as supplied to the coke-bed	Crude sewage	...	...
		Effluent from the small tank coke-bed	Settled sewage	1	3

Suspended solids.	Oxygen absorbed from permanganate in 4 hours at 80° Fahr.						Nitrous nitrogen.	Nitric nitrogen.
	By the crude liquid (total putrescible matter).	Percentage purification effected by the individual tank or bed.	Percentage purification effected by the whole treatment	By the clear liquid (dissolved putrescible matter).	Percentage purification effected by the individual tank or bed	Percentage purification effected by the whole treatment		
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Not estimated				5·257 2·346	... 55·4	... 55·4	nil 0·0429	0·0068 0·1183
36·4 1·8	Not estimated			5·286 2·613	... 50·6	... 50·6	0·0029 0·0398	0·0033 0·1434
Not estimated				5·170 2·802 1·725	... 45·8 38·4	... ... 66·6	0·0019 0·0255 0·0892	0·0045 0·1136 0·3916
Not estimated				4·856 2·268	... 53·3	... 53·3	0·0026 0·0270	nil 0·0693
29·7 Not estimated	...	...	...	4·826 2·546	... 47·2	... 47·2	0·0034 0·0355	0·0023 0·1673
Not estimated	10·110 3·748	... 62·9	... 62·9	6·522 2·753	... 57·8	... 57·8	0·0044 0·0540	0·0048 0·1778
Not estimated	7·274 3·446	... 52·6	... 52·6	5·442 2·601	... 52·2	... 52·2	0·0623 0·0881	0·0884 0·4288
Not estimated	5·449 2·365	... 56·6	... 56·6	3·904 1·731	... 55·7	... 55·7	nil 0·0168	nil 0·0256
Not estimated	5·708 3·379	... 40·8	... 40·8	4·376 2·234	... 48·9	... 48·9	0·0124 0·0781	0·0343 0·2262
43·9 16·4 Not estimated	10·136 8·503	... 16·1	... ...	6·381 6·354 5·603 2·637	... 00·4 12·2 52·9	... ... 58·7	Not estimated	

Period over which the averages extend.		Description of the liquid examined. (3)	Description of liquid before treatment. (4)	Number of contacts in successive beds. (5)	Number of fillings of the beds daily. (6)
From (1)	To (2)				
SOUTHERN OUTFALL.—SERIES III.					
1 Nov., 1900	10 Jan., 1901	Crude sewage	...	...	...
		Settled sewage	Crude sewage	...	...
		Settled sewage as supplied No. 1 coke-bed	Crude sewage	...	...
		Effluent from No. 1 coke-bed	Settled sewage	1	4
14 Jan., 1901	21 Jan., 1901	Crude sewage	...	...	...
		Settled sewage	Crude sewage	...	...
		Settled sewage as supplied to No. 1 coke-bed	Crude sewage	...	...
		Effluent from No. 1 coke-bed	Settled sewage	1	Continuous feed
15 April, 1901	4 Oct., 1901	Crude sewage	...	...	...
		Settled sewage	Crude sewage	...	...
		Settled sewage as supplied to No. 1 coke-bed	Crude sewage	...	...
		Effluent from No. 1 coke-bed	Settled sewage	1	Varied. Average 2·5
1 Nov., 1900	21 Jan., 1901	Crude sewage	...	...	...
		Settled sewage	Crude sewage	...	...
		Settled sewage as supplied to No. 2 coke-bed	Crude sewage	...	...
		Effluent from No. 2 coke-bed	Settled sewage	1	4
15 April, 1901	4 Oct., 1901	Crude sewage	...	...	...
		Settled sewage	Crude sewage	...	...
		Settled sewage as supplied to No. 2 coke-bed	Crude sewage	...	...
		Effluent from No. 2 coke-bed	Settled sewage	1	Varied. Average 2·5
1 Jan., 1900	31 Dec., 1901	Crude sewage	...	...	...
		Effluent from chemical treatment and sedimentation	Crude sewage	...	...

Suspended solids.	Oxygen absorbed from permanganate in 4 hours at 80° Fahr.						Nitrous nitrogen.	Nitric nitrogen.
	By the crude liquid (total putrescible matter).	Percentage purification effected by the individual tank or bed.	Percentage purification effected by the whole treatment	By the clear liquid (dissolved putrescible matter).	Percentage purification effected by the individual tank or bed	Percentage purification effected by the whole treatment		
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
24·1	4·830	...	...	3·956	...	...	0·0005	nil
11·6	4·353	9·9	...	3·803	3·9	...	nil	nil
Not estimated	4·487	7·1	...	3·563	9·9	...	0·0012	nil
	2·257	49·7	53·3	1·805	49·3	54·4	0·0305	0·0586
28·9	6·497	...	...	5·530	...	...	nil	nil
18·4	5·681	12·6	...	5·125	7·3	...	0·0091	nil
Not estimated	6·121	5·8	...	5·187	6·2	...	0·0046	nil
	5·015	18·1	22·8	4·308	16·9	22·1	0·0337	0·0571
25·3	6·327	...	...	4·066	...	...	nil	nil
14·2	5·596	11·5	...	4·141	No purification effected	...	nil	nil
Not estimated	5·529	12·6	...	3·776	7·1	...	0·0003	nil
	2·379	57·0	62·4	1·732	54·1	57·4	0·0956	0·0451
24·7	4·983	...	...	4·113	...	...	0·0004	nil
12·4	4·452	10·7	...	3·914	4·8	...	0·0012	nil
	4·671	6·3	...	3·737	9·1	...	0·0011	0·0024
Not estimated	2·465	47·2	50·5	1·989	46·8	51·6	0·0314	0·0876
25·3	6·327	...	...	4·066	...	...	nil	nil
14·2	5·596	11·5	...	4·141	No purification effected	...	nil	nil
Not estimated	5·481	13·4	...	3·820	6·0	...	0·0010	nil
	2·452	55·3	61·2	1·802	52·8	55·7	0·0942	0·0626
41·4	8·231	...	...	5·319	...	...	Not estimated	
8·1	5·948	27·8	27·8	4·683	11·9	11·9		

From Table XVIII. it will be seen that the suspended solids (column 7) were removed practically to the same extent by the settling tank of Series III. at the Northern Outfall as by the primary beds of Series II. There was, therefore, a distinct gain in using settling tanks instead of primary beds, since the suspended matter which was left in the tanks was largely composed of mineral substances and of substances not readily decomposed by bacterial action, and which in previous experiments had been found to choke the primary beds. In a permanent installation of bacteria-beds it is proposed that in addition to the ordinary settling tanks, preliminary settling tanks or "detrituschambers" should be used for the removal of road detritus.

With reference to the purification effected by the coke-beds, as estimated by the relative amounts of oxygen absorbed from permanganate by the crude sewage and by the final effluent from any particular experiment (columns 8 and 11), that effected in the experiments of Series III. was generally lower than in any of the other experiments carried out at the Northern Outfall. It should, however, be borne in mind that in the experiments of Series III. the sewage was subjected to only one contact in coke-beds, whereas in all the experiments of Series I. and II. it was subjected to two contacts in successive beds (column 5).

It should be noted that the variation in the amount of purification effected by the beds when they received two fillings per day, as compared with that effected when they received only one filling per day, was not always consistent, since sometimes the amount of purification effected increased with the number of fillings of the bed per day.

When the figures relating to the experiments are considered, the amount of purification effected is seen to have been influenced in a more regular manner by variations in the number of fillings per day of the coke-beds at the Southern Outfall than it was at the Northern Outfall. The only apparent exception to this regular variation occurred during the experiments of Series II. This apparent exception is, however, most important as showing the value of a previous settlement of the sewage. It will be observed that while the 4-foot bed was being increased in depth to form the 13-foot single coke-bed of Series II. it was filled only once per day. At the end of a month the bed, which was still under 13 feet in depth, was filled twice per day, and although the efficiency of the bed was probably increasing daily yet the amount of purification effected fell during the time it received two fillings per day (column 12). The next modification of the experiments with this bed was the rough settlement of the sewage before it passed on to the coke-bed. Reference to column 12 will show that this rough settlement increased the amount of purification effected. After the bed had been dealing with two fillings per day of roughly settled sewage for about two months, the fillings were increased to three per day and the purification effected consequently decreased in amount (columns 9 and 12). The next and last change in the experiments of Series II. was to subject the sewage to more perfect sedimentation and to fill the bed four times per day. Notwithstanding the extra work apparently imposed upon the bed by this increase in the number of fillings, the percentage amount of purification effected increased, and there is every reason to believe that this was largely, if not entirely, due to the more perfect sedimentation of the sewage previous to its treatment in the coke-bed.

The experiments of Series III. were conducted on lines similar to those which were adopted in the last stage of the experiments of Series II. The amount of purification effected was slightly less while the beds received four fillings per day than it was during the last period of the previous series, when the same number of fillings was made. When the number of fillings was reduced the purification increased in amount.

The amount of nitric nitrogen estimated in the various effluents during the experiments at the Southern Outfall was not always as concordant as it was at the Northern Outfall. The variations, however, were not so great as to call for any special observations thereon and were probably due to the influence of salt water.

XIII. METHODS EMPLOYED IN MAKING THE CHEMICAL EXAMINATIONS OF THE SEWAGE AND OF THE VARIOUS EFFLUENTS.

Throughout the experiments on the bacterial treatment of the London sewage at the Outfall Works of the London County Council the following estimations were made in the crude sewage and in the various effluents.

1. The total amount of suspended matter.
2. The amount of oxygen absorbed from permanganate
   - (*a*) By the various liquids in their natural condition.
   - (*b*) By the various liquids after they had been filtered by means of ordinary filter paper.
3. The amount of nitrogen present in the form of nitrite (nitrous nitrogen).
4. The amount of nitrogen present in the form of nitrate (nitric nitrogen).

All quantities, except where otherwise stated, are expressed in parts per 100,000. To convert parts per 100,000 into grains per gallon, multiply by 0·7; to convert grains per gallon into parts per 100,000, multiply by $\frac{10}{7}$.

1. The total amount of suspended matter in the raw sewage and in the various effluents was estimated by evaporating 100 cubic centimetres of the liquid to dryness and then weighing the residue. Another portion of the liquid was passed through ordinary filter paper and 100 cubic centimetres of this filtered liquid were evaporated to dryness and the residue was weighed. The difference between the weights of the residues from the two separate 100 cubic centimetre portions was the weight of the suspended solids in 100 cubic centimetres of the liquid and from this weight the parts per 100,000 were calculated.

The removal of suspended solids from a putrescible liquid is the first step towards the purification of that liquid.

The important constituent of the suspended solids is, however, the organic matter, or that portion which if left undisturbed eventually decomposes and generally gives rise to unpleasant and noxious products. It is this decomposition which should be carried out more or less completely in the settling or "septic" tank and finally in the bacteria-bed.

The removal of the suspended solids in the bacterial treatment of sewage, so far as it relates to the organic matter, is really the resolution of such matter into the liquid and gaseous forms.

The other constituent of the suspended solids is mineral matter and this portion should be settled out in a detritus chamber previous to the sewage passing through the settling tank and subsequently through the coke-bed.

The removal of the suspended solids from a liquid which has to undergo bacterial treatment in a coke-bed is therefore the first step towards the purification of that liquid, and should take place as much as possible in the settling or "septic" tank; the action of the coke-bed being more particularly restricted to the purification of the liquid from dissolved putrescible matter.

2. The amount of oxygen absorbed from permanganate by the various liquids was estimated by treating a measured quantity of the liquid in a stoppered bottle with a measured quantity of a standand solution of potassium permanganate and sulphuric acid. The bottle containing the liquid was then placed for four hours in a constant temperature chamber which was kept at 80° F. At the end of this time the bottle was removed from the constant temperature chamber and the potassium permanganate which had not been affected or deprived of its oxygen was estimated by adding a solution of iodide of potassium to the solution in the bottle and then titrating it with a standardised solution of sodium hyposulphite. Towards the completion of the titration a solution of starch was added as an indicator.

Two estimations of the amount of oxygen absorbed were made in each liquid. In one case the liquid used was in the condition as collected, and in the other case the liquid, before treatment with the reagents mentioned above, was filtered through ordinary filter paper. The results of these two estimations are respectively set forth in the tables in this book under the headings "Oxygen absorbed from permanganate in 4 hours at 80° F. by the crude liquid (total putrescible matter)" and "Oxygen absorbed from permanganate in 4 hours at 80° F. by the clear liquid (dissolved putrescible matter)."

These estimations are to some extent a measure of the putrescibility of the liquid.

The oxygen is absorbed by oxidisable matter either floating in the liquid as minute solid particles or as oxidisable matter dissolved in the liquid. The estimations under the heading "Oxygen absorbed . . by the crude liquid" include both dissolved and suspended oxidisable matter, whereas those under the heading "Oxygen absorbed . . . by the clear liquid" include the dissolved oxidisable matter only.

In the second volume of the Interim Report of the Commissioners appointed in 1898 to inquire and report what methods of treating and disposing of sewage may properly be adopted, Professor E. A. Letts, D.Sc., Ph.D., gives evidence on page 479 respecting the absorption by sewage of oxygen from permanganate and from the oxygen dissolved in sea water. As the result of determinations he says that "the amount of oxygen actually absorbed" from that dissolved in sea water "was about three times as great as the amount shown by the permanganate test."

Notwithstanding this evidence, which may, however, furnish a factor for ascertaining the actual amount of oxygen which an impure liquid would absorb from that dissolved in a more pure liquid when the two liquids are mixed together, the estimation of the amount of oxygen absorbed from permanganate has its value as a means of comparison between different liquids and as a means of measuring the amount of purification effected by any method of sewage treatment.

3. The nitrous nitrogen in the various liquids was estimated by Griess's method. The quantity of liquid and the degree of dilution most convenient for examination were determined by a rough preliminary titration. The liquid was diluted with water free from nitrite, and 100 cc. of it were placed in a Nessler glass with 1 cc. of meta-phenylene-diamine and 1 cc. of dilute sulphuric acid (one of acid to two of water). The colour produced was then matched by treating in a similar manner a standard solution of potassium nitrite, made up to 100 cc. with water free from nitrite. The liquids in the Nessler glasses were allowed to stand for about 20 minutes before the final comparison was made.

4. The nitric nitrogen was estimated before September, 1898, by means of the action of the copper-zinc couple. A portion of the liquid under examination was allowed to stand over-night in an accurately stoppered bottle with a piece of zinc covered with a black deposit of spongy copper which had been obtained by immersing it in a solution of copper sulphate. The action of the "couple" converted the nitrite and nitrate into ammonia. The ammonia thus formed, together with that previously present in the liquid, was then estimated directly by the Nessler process without previous distillation. From the amount of nitrogen thus found the quantities of nitrogen in the free ammonia and in the nitrite in the original liquid were deducted, and the amount of nitrogen as nitrate was obtained.

Since September, 1898, the nitrogen as nitrite and nitrate has been estimated by Crum's process as it is described on pp. 430–432 of Sutton's Handbook of Volumetric Analysis. The nitrite and nitrate were acted upon by sulphuric acid used in the presence of metallic mercury, and the resulting nitric oxide was measured. The quantity of nitrogen in the nitric oxide thus estimated, minus the quantity of nitrogen as nitrite estimated by Griess's method, represented the quantity of nitrogen in the liquid as nitrate.

The process for the estimation of nitrogen as nitrate which necessitated the previous estimation of the free ammonia in the various liquids was only in use during the earlier experiments and was used for only a short time at the commencement of the experiments on the treatment of crude sewage. When the Crum's process was adopted for the estimation of nitrate, the estimation of the ammonia in the various liquids was abandoned. The estimations of ammonia have therefore not been inserted in this book.

Nitrite and nitrate in an effluent are present as products of the oxidising action of nitrifying bacteria in the coke-bed. Their amount measures the extent to which oxidation and purification have taken place. A nitrate is a fully oxidised product while a nitrite is a partially oxidised product. Both are produced by the oxidation of nitrogenous compounds present in the sewage. Their presence and permanence indicate that purification of the sewage has taken place, since they cannot exist in raw sewage. It has been shown that the presence of nitrate in an effluent may prevent the putrefaction of a certain amount of organic substances from occurring in another effluent with which the nitrate effluent has been mixed.

XIV. ALTERATION OF METHOD OF TREATMENT SUGGESTED BY THE EXPERIMENTS.

The present method of dealing with the London sewage is by treatment with solutions of lime and of protosulphate of iron, followed by sedimentation in settling channels. The effluent from this process is allowed to flow into the river Thames and the sediment or sludge is carried out and discharged on a falling tide in the estuary of the river. The introduction of this method of treatment was the means of considerably improving the condition of the water of the river Thames below London, but at that time it was stated that the sewage effluent would still carry into the river a large amount of putrescible matter in solution, and it was recommended that, as opportunity occurred, the effluent should be further treated on land or by other means, before it entered the river.

As no suitable land was available at the Council's Outfall Works, land treatment was not seriously considered, but on the publication of the Massachusetts experiments on the bacterial purification of sewage in coke-beds, a series of experiments was started by the London County Council with a view to obtaining information as to the suitability of the process to the treatment of London sewage.

At first the experiments at the Council's Outfall Works were concerned only with the treatment of the effluent from the "chemical sedimentation" process. The results obtained were so satisfactory as to warrant an extension of the experiments in the direction of the treatment of crude sewage.

The result of the later experiments with crude sewage has been such as to show that the sewage of London can be satisfactorily treated on the following lines.

1. The crude sewage as it arrives at the Outfall Works, and after it has been deprived by "screening" of the coarser matters only, would be allowed to flow through a catch pit or detritus chamber in which a large proportion of solid suspended mineral matter would be deposited. The rate of flow through the detritus chamber would be regulated in such a manner as to allow of the deposition of a maximum quantity of the heavier mineral matter, such as road detritus, with a minimum quantity of the putrescible matter. With a suitable rate of flow the deposited matter in the detritus chamber should consist almost entirely of road detritus, which could be deposited on waste land without becoming offensive or injurious.

2. After passing through the detritus chamber, the sewage would pass through the present settling channels, at such a rate that it would

remain in the channel about 6 hours. The sediment or "sludge" would not be removed, but would be allowed to remain, and to be removed by so-called "septic" bacterial action. This bacterial action would at first be feeble, but after the channel had been working for some weeks, the action would become much more energetic owing to the gradual increase in the number of suitable bacteria. When the action in the channel had become fully established, a very large proportion of the sediment or "sludge" would disappear partly as gas and partly by being liquefied. It might be necessary at long intervals to remove some "sludge" from the settling channels, but much less sludge would be produced than is at present produced by the "chemical sedimentation" treatment. During the experiments (Series III.) at the Southern Outfall Works on the sedimentation of sewage previous to its treatment in bacteria-beds, it was found that 41·2 per cent. of the total solid matter suspended in the sewage, including road detritus, was resolved into the liquid and gaseous forms by the action in the settling tank: this amounts to 71·4 per cent. of the organic matter suspended in the sewage, excluding the road detritus.

Considerable economy would therefore result from the reduction in the amount of sludge requiring transport to the estuary, and a further economy would be effected by discontinuing the addition of chemicals to the sewage, as not only would the cost of the chemicals be saved, but also the cost of carrying them away in the sludge.

3. The next step in the process of treatment suggested by the experiments at the Council's outfalls is the purification of the effluent from the settling channels in the bacteria-beds. The effluent would be drawn from below the level of the sewage in the channel in order to avoid the disturbance of any scum which may have formed on the surface of the sewage. By this means the effluent drawn from the channel would contain a minimum quantity of suspended matter; it would certainly not contain any suspended matter which would choke the bacteria-bed either permanently or for a lengthened period.

The effluent as it leaves the "septic" channel must undergo some mechanical process of aëration in order to remove sulphuretted hydrogen. This may be effected by allowing the liquid to fall through a perforated tray, so as to break it up into separate streams.

The channel effluent would be supplied to the bacteria-bed until the liquid was level with the top of the coke forming the bed, and would be allowed to remain for two hours in the bed. At the expiration of this time the liquid would be drawn off, and the bed would be allowed to rest empty until it is time to fill it again. It has been found possible to carry out four fillings of the bed per 24 hours; with this number of fillings the resting period of the bed would extend to about 2½ hours after each filling and emptying. The effluent drawn from the bed is then sufficiently pure for admission into the lower Thames. It would never lead to offensive smell or deaëration of the river water, and would readily support fish life.

It was found that sewage could be dealt with at the rate of 4,356,000 gallons per acre in 24 hours in a coke-bed 6 feet in depth.

The above are the main points in the bacterial treatment of London sewage as suggested by the experiments conducted at the Council's

Outfall Works. But it should be borne in mind that while these experiments guarantee a successful and satisfactory result being obtained on the large scale, they were conducted with plant very much smaller than even a unit of the total plant that would be necessary for treating the whole of the sewage of London. Under these circumstances it would be well to commence the treatment on the large scale by constructing and working with several unit beds before proceeding to construct the whole installation.

DIVISION II.

BACTERIOLOGICAL.

BY

A. C. HOUSTON, M.B., D.Sc.

CONTENTS.

DIVISION II.—BACTERIOLOGICAL.

INTRODUCTION TO DIVISION II.

In February, 1898, I was directed by the Main Drainage Committee of the London County Council to investigate from the bacteriological point of view, the experiments in progress at the Northern Outfall Works (Barking) and at the Southern Outfall Works (Crossness), on the bacteria-bed treatment of sewage. This investigation occupied two years, and four reports and a supplementary report have been published on the subject. The reports being now out of print, the Council have asked me to assist Dr. Clowes in preparing a statement embodying in a condensed form the chief results of our chemical and bacteriological investigations.

At the time when this enquiry was commenced, hardly anything was known of the biological composition of effluents from bacteria-beds. Valuable reports, however, had been published on the bacteriology of crude sewage.* Nevertheless, none of these reports, notwithstanding their high order of merit, seemed to contain precisely the kind of information necessary in order to allow of a useful comparison being made between the effluents from bacteria-beds and the corresponding samples of raw sewage. It was, for example, of vital importance from the health point of view to determine how far, if at all, sewage became *modified in its biological characters* as the result of its treatment in bacteria-beds. But to obtain information on this as well as on other points of great importance, it seemed to be necessary to introduce some new features into the methods previously in use for the bacteriological examination of sewage. Strictly speaking and as a counsel of perfection, the proper procedure would have been to determine, antecedent to a similar survey of the bacteria flora of the effluents from the bacteria-beds, not only the presence, but the *relative abundance*, of *all* the different kinds of bacteria in multiple samples of crude sewage. But this would have been, if not an impossible task, at all events the work of many years. It thus became necessary to limit the observations

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* For example:—Mr. Jordan: Reports of the State Board of Health of Massachusetts (1888-90. Part II.). Sir Henry Roscoe and Mr. Lund: Transactions of the Royal Society (1892). Mr. J. Parry Laws and Dr. Andrewes: Micro-organisms of Sewage (1894)—London County Council.

to the determination of the relative abundance of one or more species of microbes in the crude sewage and effluents. In the past, the practice has largely been to determine the total number of bacteria of all sorts present in a substance and perhaps to add a few brief notes as to the presence or absence of particular microbes, but without special reference to the *relative abundance* of such microbes. Such a method of examination could hardly be regarded as a satisfactory means of comparing untreated crude sewage with the effluents from bacteria-beds, that is, of measuring the biological *status* of an effluent in its possible relation to disease. It needs to be remembered that, at the commencement of this enquiry, there were no trustworthy data enabling sanitarians to judge how far the effluents from bacteria-beds should be regarded as dangerous to health. Since then, as a result of the investigations described in this report, in opening two separate discussions at the British Medical Association meetings held at Ipswich (1900)* and at Cheltenham (1901)† it was considered advisable to sound a note of warning as regards the danger of too readily accepting as true any statements seeking to prove the non-pathogenic qualities of the effluents from bacteria-beds. But it must be specially noted that this is a separate question altogether from the future possibilities of the bacteria-bed treatment of sewage when considered from the economic and practical point of view, and in those cases when the effluent is destined to be discharged into a *non-drinking water* stream. In this direction, my opinions have always been of a hopeful and favourable character. It must be definitely understood, however, that in this report I limit my observations to the results obtained at Crossness and at Barking.

Stated very briefly, the chief tests‡ on which reliance was placed in carrying out this enquiry were as follows—

Total number of bacteria (gelatine at 20° C. and agar at 37° C.).
Number of bacteria causing liquefaction of gelatine.
Number of spores of aërobic bacteria.
Number of B. coli and closely allied forms.
Number of spores of B. enteritidis sporogenes (*Klein*).
Presence and relative abundance of streptococci.
Pathogenic qualities of sewage and effluents (animal experiments).

Although the work occupied two years, and in certain directions

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* *British Medical Journal*, August 18th, 1900.

† *British Medical Journal*, August 17th, 1901.

‡ For later and more detailed information on this subject reference may be made to my report to the Royal Commission on Sewage Disposal. (Page 135, Second Report, Royal Commission on Sewage Disposal, 1902.)

yielded information of a kind previously lacking,[*] it is in no sense contended that the investigation was of so exhaustive a character as to render unnecessary further study of the subject in all its aspects. On the contrary, it is my firm conviction that for a long series of years the energies of many competent workers will be required to be devoted to this research before our knowledge of the subject of sewage disposal by bacteria-bed methods can be regarded as in any way complete.

In two respects the enquiry may be said to have yielded information of special importance.

One result of this investigation is to—

(1) Afford presumptive evidence of a strong kind that the effluents from bacteria beds cannot reasonably be considered as much, if at all, more safe in their possible relation to disease than crude sewage.

Beyond question this portion of the enquiry was of primary and pressing importance, and the results obtained can only be interpreted as meaning that, until reliable evidence to the contrary is forthcoming, the effluents from bacteria-beds ought to be regarded as nearly, if not quite, as unfit to be discharged into *drinking-water* streams as would be the sewage before treatment.

(2) Draw attention to the wide distinction between the biological composition, on the one hand, of sewage and of sewage effluents, and, on the other, of waters of potable sort.

It may be said that this distinction has been already fully established; but this is not an accurate statement of the case. A study of past bacteriological records reveals the fact that the *mere presence*, not the *relative abundance*, of microbes of one or another sort has formed, generally speaking, the basis of our conceptions of the wholesomeness or otherwise of waters to be used for domestic purposes. And, although it has for long been admitted that sewage is the most common and most dangerous source of the pollution of our water supplies, the *relative abundance* of microbes of intestinal sort in multiple samples of sewage has, at all events in this country, failed to attract the serious attention of bacteriologists. Yet again, the distinction between bacterial tests indicating recent, and therefore presumably specially dangerous, contamination, and bacterial tests not of necessity implying pollution with bacteria of recent animal outcome has been to a great extent overlooked in the past. Lastly, it would seem to be almost obvious to consider that

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[*] For example :—The determination of the relative abundance of *B. coli*, of spores of *B. enteritidis sporogenes*, and of *streptococci* in multiple samples of crude sewage and of effluents, as well as the estimation of the number of bacteria causing liquefaction of gelatine and the number of spores of aërobic bacteria.

before condemning a water because it contains microbes of a sort seemingly to be associated with sewage contamination, some information should be forthcoming of the relative abundance of such bacteria in sewage itself. But information of this kind was, if not wholly unobtainable, acquired with considerable difficulty. It will not, I think, be denied that the records obtained during the progress of the enquiry (notably as regards *B. coli*, *B. enteritidis sporogenes* and *Streptococci*) have a direct and important bearing on this subject. Nevertheless, it is freely admitted that extended investigation over a considerable time is, in this direction, most desirable.

Although my final conclusions are given in a special section of this report, it is desirable definitely to state here that I concur with Dr. Clowes in the advisability of treating London crude sewage by bacterial methods in place of the existing unsatisfactory chemical mode of treatment.

A. C. H.

THE BACTERIAL TREATMENT OF SEWAGE.

DIVISION II.—BACTERIOLOGICAL.

I. Description of the bacteria-beds at the Northern Outfall Works (Barking), and at the Southern Outfall Works (Crossness).

The above heading is retained for the sake of completeness; since, however, the matter is fully dealt with in Division I., it will be unnecessary to do more than merely mention here the descriptive terms applied to the different beds.

At Crossness.

4-foot coke-bed	Series I.
6-foot coke-bed (primary)	,, I.
6-foot coke-bed (secondary)	,, I.
13-foot coke-bed	,, II.

At Barking.

i. The coke and ragstone beds were four in number, namely, two of coke (coarse and fine respectively), and two of ragstone (coarse and fine respectively). Series I.

ii. Double coke-beds.

Primary coarse coke-bed (A)	Series II.
Secondary coarse coke-bed (A1) ...	,, II.
Primary coarse coke-bed (B)	,, II.
Secondary fine coke-bed (B1)	,, II.

II. Description of the chief methods used in the bacteriological examination of the sewage and of the effluent.

For later and more detailed information on this subject reference may be made to my report to the Royal Commission on Sewage Disposal. (Page 135, Second Report, Royal Commission on Sewage Disposal, 1902.)

It is not proposed to describe here all the methods used in the bacteriological examination of sewage, but only the chief methods employed throughout the course of the investigation.

Collection of samples.

The samples were collected in sterile glass-stoppered bottles. The bottles were filled completely with the sample, and the contents were examined as soon after collection as possible.

Dilution of sewage.

The microbes in sewage are so numerous that it is necessary to dilute the sewage with a large quantity of sterile water, in order to render numerical estimation and further study possible. In the earlier experiments, the dilutions used were 1 in 10, 1 in 100, and 1 in 10,000. But it is better to make a series of dilutions, namely, 1 to 10, 1 to 100, 1 to 1000, 1 to 10,000, and 1 to 100,000.

Total number of bacteria.

In estimating the total number of bacteria, gelatine plates were used. From 0·1 to 1·0 c.c. of diluted crude sewage or effluent (1 of sewage or effluent to 10,000 of sterile water) was added to 10 c.c. of sterile gelatine contained in a test tube. After the gelatine had been melted, the mixture was poured into a Petri's capsule, and after solidification had taken place the plate was inverted, incubated at 20° C., and the colonies subsequently counted at as late a date as the liquefaction of the gelatine and the crowding of the colonies permitted.*

In some of the later experiments agar plate cultures (incubated at 37° C.) were also used.

Spores of aërobic bacteria.

In estimating the number of spores of bacteria, the following plan was usually adopted:—To 10 c.c. of sterile gelatine in a test tube was added 1 c.c. of diluted sewage or effluent (1:10), and the mixture heated to 80° C. for ten minutes and then poured into a Petri's capsule. After the gelatine had become quite solid, the plate was inverted and incubated at 20° C.†

Number of bacteria causing liquefaction of gelatine.

In estimating the number of liquefying organisms the following plan was usually adopted:—The contents of a test tube containing 10 c.c. of sterile nutrient gelatine were melted and poured into a sterile Petri's capsule. After the gelatine had become quite solid, the surface of the medium was inoculated with 0·1 c.c. of diluted sewage or effluent (1: 10,000). The diluted sewage or effluent (representing 0·00001 c.c.) was then spread over the entire surface of the gelatine with a sterile platinum instrument. The plate was next inverted and incubated in this position at 20° C. until the colonies were sufficiently advanced in their growth for observation. Although this method is the best available, it must be remembered that some bacteria liquefy the gelatine so very slowly that they might readily escape being counted as liquefying germs under the above conditions of experiment.

Spores of B. enteritidis sporogenes (Klein).‡

The method for detecting the presence of the spores of this bacillus is as follows:—Dilute one part of crude sewage or of effluent, as the case may be, with 99 parts of sterile water; of this dilution add 1·0, 0·1, and 0·01 c.c. severally to three sterile milk tubes, or 10%, 1%, 0·1%, and 0·01% dilutions may be used and milk tubes severally inoculated with 1 c.c. from each of these dilutions. Heat the tubes to 80° C. for ten minutes, and cultivate anaërobically by Buchner's method at a temperature of 37° C. When *B. enteritidis sporogenes* is present, the casein

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* Fig. 1. † Fig. 2, and figs. 3, 4, 5, 6. ‡ Fig. 7.

FIG. 1.—Gelatine plate culture of diluted Crossness crude sewage. $\frac{1}{10000}$ c.c. of Crossness crude sewage. 402 colonies = 4,020,000 microbes per c.c. of sewage. About natural size.

FIG. 2.—*Bacillus subtilis.* Preparation from an agar culture, showing spores. The spores of this micro-organism are frequently found in London crude sewage. There may be as many as 10 to 20 spores present per c.c. of sewage. × 1,500.

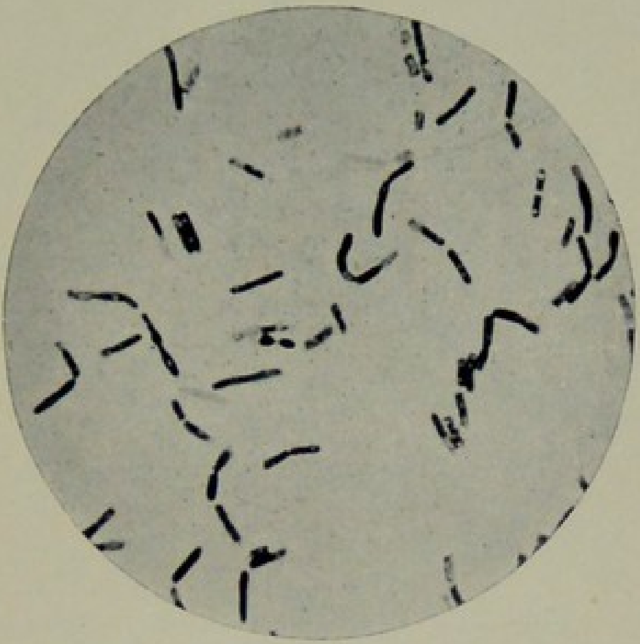

FIG. 3.—*B. megaterium* (or closely allied form). Preparation showing spores. Occasionally found in London crude sewage. × 1,000.

FIG. 4.—*B. mesentericus.* Preparation from an agar culture, showing spores. 10 to 20 spores of *B. mesentericus* per c.c. is a number commonly found in crude sewage. × 1,000.

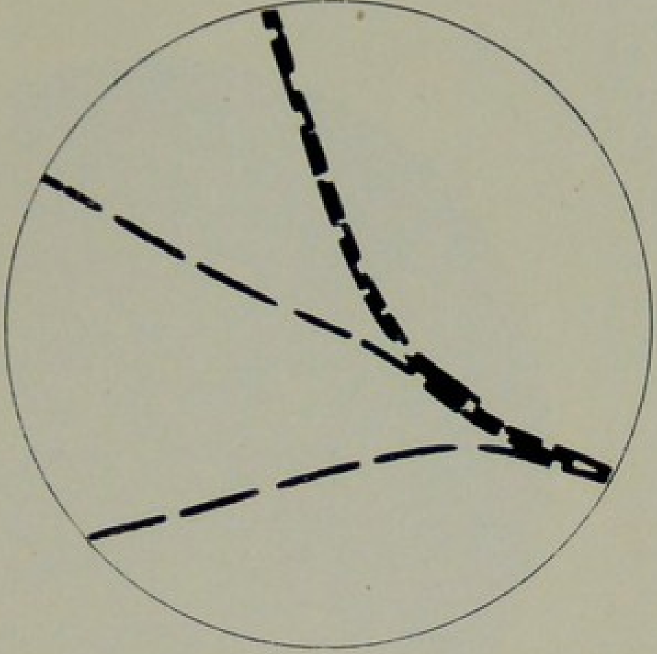

FIG. 5.—*B. mycoides.* Impression preparation from a gelatine plate. × 1,000.
Occasionally found in London crude sewage.

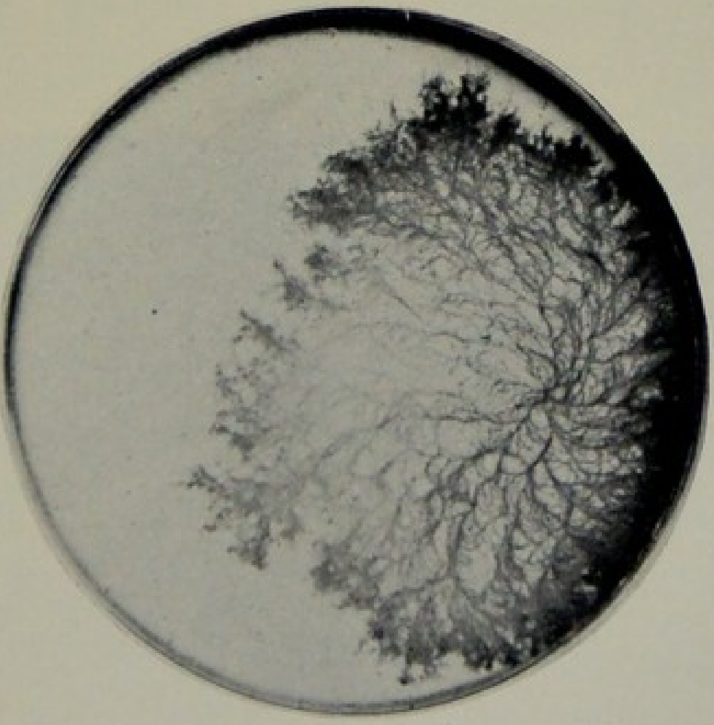

FIG. 6.—*B. mycoides.* Colony growing in an agar plate culture. About natural size.

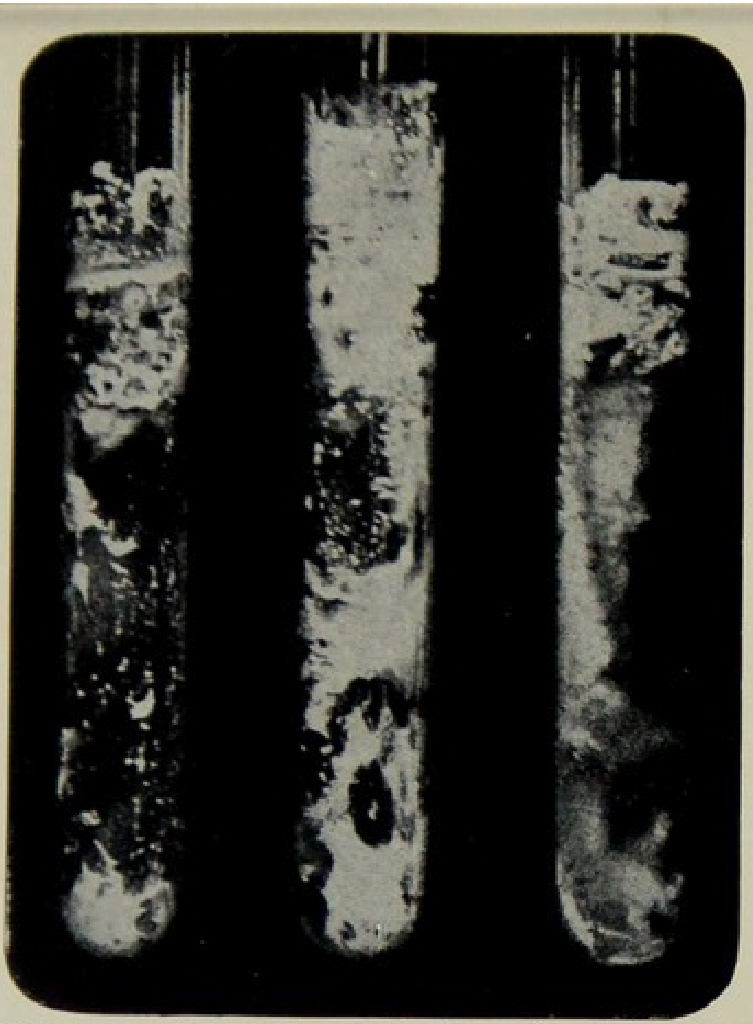

FIG. 7.—Showing the changes produced in milk cultures by the growth of *B. enteritidis sporogenes.* The middle tube was inoculated with $\frac{1}{10}$ c.c. and the lateral ones with $\frac{1}{100}$ c.c. of Crossness crude sewage. The tubes were next heated to 80° C. for ten minutes and then cultivated anaërobically by Buchner's method at 37° C.

About natural size.

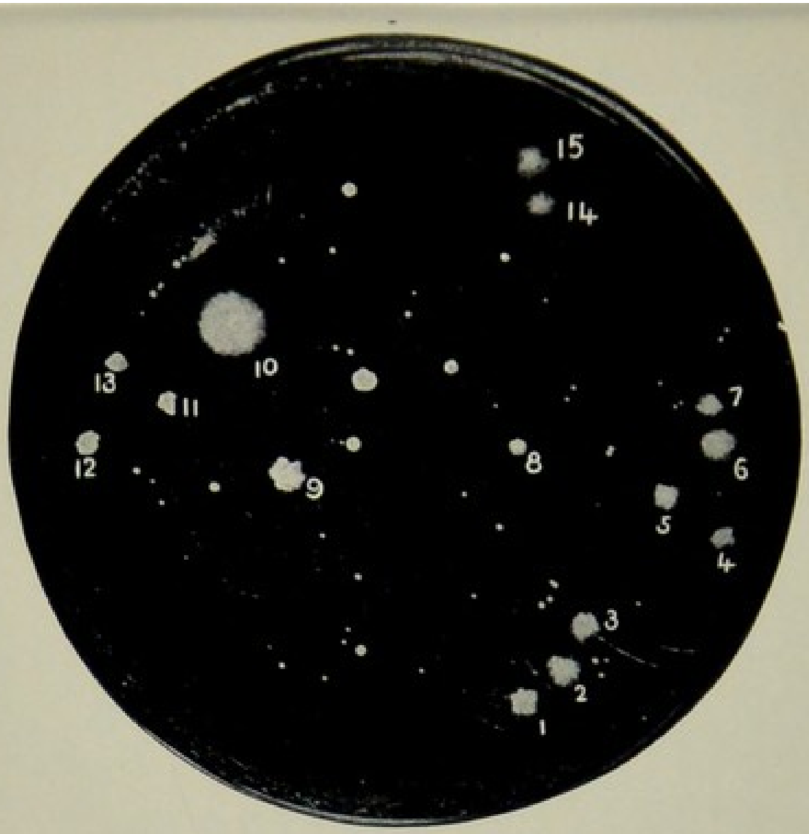

FIG. 8.—Surface phenol gelatine plate culture, containing $\frac{1}{100000}$ c.c. of Crossness crude sewage. The colonies (marked 1 to 15 on figure) seemed, on macroscopic and microscopic examination, to be indistinguishable from *Bacillus coli*. Subcultures of these colonies yielded results as follows :—

Gelatine shake cultures, 1 to 15 inclusive, produced gas in twenty-four hours at 20° C.

Litmus milk cultures (38° C.). By the sixth day 6 and 10 strongly acid (6 commencing clot, 10 solid clot) ; 9 and 11 practically no visible change ; 2, 8, 12, and 13 slightly acid ; 1, 3, 4, 5, 7, 14, and 15 faintly acid.

Broth cultures (38° C.). In twenty-four hours diffuse cloudiness in all the tubes. On the sixth day, all the tubes were tested for indol reaction, and all gave a negative result with the exception of 6, which showed a strong indol reaction.

About natural size.

is precipitated, the whey remains nearly colourless, and there is a marked development of gas. These changes in the milk commonly take place in less than 24 hours, but the limit of observation should always be extended to 48 hours. A guinea-pig inoculated subcutaneously with 1 c.c. of the whey usually dies in less than 24 hours, and presents, on post-mortem examination, appearances which are typical of infection with *B. enteritidis sporogenes* (swollen belly, extensive gangrene, sanguineous exudation full of bacilli, etc.). In certain cases a pathogenic result on inoculation of a rodent is not observed. But in these cases, in my experience, it is usually only necessary to use for inoculation a culture lower in the scale of dilutions, i.e. one containing more of the sewage, in order to obtain a positive result.

B. coli (and closely allied forms).

In searching for *B. coli* in the crude sewage and in sewage effluents, the following plan was adopted:—10 c.c. of sterile gelatine, contained in a test tube, were melted, 0·1 c.c. of five per cent. phenol added, and then the gelatine was poured into a sterile Petri's capsule and allowed to become quite solid. 0·1 c.c. of diluted sewage, or of effluent (1 : 10,000), was next added and spread over the entire surface of the gelatine with a sterile platinum spreader. It is perhaps better to make three gelatine plates and inoculate these severally with $\frac{1}{100000}$, $\frac{1}{10000}$ and $\frac{1}{1000}$ c.c. of sewage or effluent. Colonies which were typical of *B. coli* in their microscopical appearance and in the manner of their growth* were then subcultured in broth (for diffuse cloudiness and indol reaction), in litmus milk (for acidity and clotting), and in gelatine shake culture (for gas formation). It was not, however, found possible in each individual experiment to apply all of these tests, although in the majority of cases, the gas test in gelatine was applied.†

Streptococci.

In searching for *streptococci*, it is best to make three *surface* agar plate cultures, using for this purpose $\frac{1}{1000}$, $\frac{1}{10000}$ and $\frac{1}{100000}$ c.c. of sewage (or effluent), and incubate at 37° C. In 24 to 48 hours, examine the plates under a low power of the microscope and subculture in broth all the minute colonies which resemble those of *streptococci*. After incubation for from 24 to 48 hours at 37° C., the broth cultures must be examined and cover glass preparation from them made for microscopic examination. Those tubes which lead the observer to suspect the presence of *streptococci* should be further studied by preparing stained preparations and subcultures made in gelatine, litmus milk, and other media.§

Inoculation Experiments.

The inoculation of animals cannot be recommended as a routine test; but when a bacterial process yields day by day fairly uniform results, the occasional inoculation of rodents may be important. A negative result would not indicate "purity or safety," but a positive result (1 to 5 c.c. of effluent per 200 grammes body weight) in a rodent would

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* Fig. 8. † Fig. 3. § Figs. 15 to 20.

tend to show that the sewage had not been so modified in its biological characters by its treatment in the bacteria-beds as to be other than a liquid still potentially dangerous in its possible relation to disease in human beings, if discharged into a *drinking-water* stream. The test then, in its positive aspect, and as a means of occasionally comparing the pathogenic qualities of effluents with crude sewage, is a useful one. In point of fact, it was unfortunately found that the effluents from the bacteria-beds were nearly, if not quite, as pathogenic to rodents as the sewage before treatment. Thus in the case of the effluents from the bacteria-beds, as well as when working with the sewage before treatment, it was usually found that the subcutaneous injection of from 1 to 5 c.c. into rodents killed the animals in from 20 to 72 hours.

In brief summary of the chief methods, the following tabular statement may be found useful :—

TEST.	METHOD.	AMOUNT OF SAMPLE. (In cubic centimetres)
Total number of bacteria ...	Make gelatine and agar plate cultures containing—	$\frac{1}{1000}$ $\frac{1}{10000}$ $\frac{1}{100000}$
Number of spores of aërobic bacteria	Make gelatine plate cultures (previously heated to 80° C. for 10 mins.) containing—	1 $\frac{1}{10}$ $\frac{1}{100}$
Number of bacteria causing liquefaction of gelatine	Make *surface* gelatine plate cultures containing—	$\frac{1}{1000}$ $\frac{1}{10000}$ $\frac{1}{100000}$
Spores of B. enteritidis sporogenes (Klein's "enteritidis change" in milk)	Make anaërobic milk cultures (previously heated to 80° C. for 10 mins.) containing—	$\frac{1}{10}$ $\frac{1}{100}$ $\frac{1}{1000}$ $\frac{1}{10000}$
B. coli and closely allied forms	Make *surface* phenol (0·05%) gelatine plate cultures containing—	$\frac{1}{1000}$ $\frac{1}{10000}$ $\frac{1}{100000}$
Streptococci	Make *surface* agar plate cultures containing—	$\frac{1}{100}$ $\frac{1}{1000}$ $\frac{1}{10000}$

Since this report was written, the second report of the Royal Commission on sewage disposal has been published. In this volume a detailed report on methods will be found.

III. THE EXPERIMENTS ON THE BACTERIAL TREATMENT OF CRUDE SEWAGE AT THE SOUTHERN OUTFALL WORKS (CROSSNESS).

A. Results of the bacteriological examination of Crossness crude sewage and of the effluents from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds. (Series I.)

B. Further experiments with the effluents from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds. (Series I.)

C. Experiments with the effluent from the 13-foot coke-bed. (Series II.)

A.—*Results of the bacteriological examination of Crossness crude sewage and of the effluents from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds.* (*Series I.*)

In the following pages, the chief results as regards (1) total number of bacteria, (2) number of spores of bacteria, (3) number of liquefying bacteria, (4) number of *B. coli*, and (5) number of spores of *B. enteritidis sporogenes* are tabulated and summarised.

DIAGRAM I.

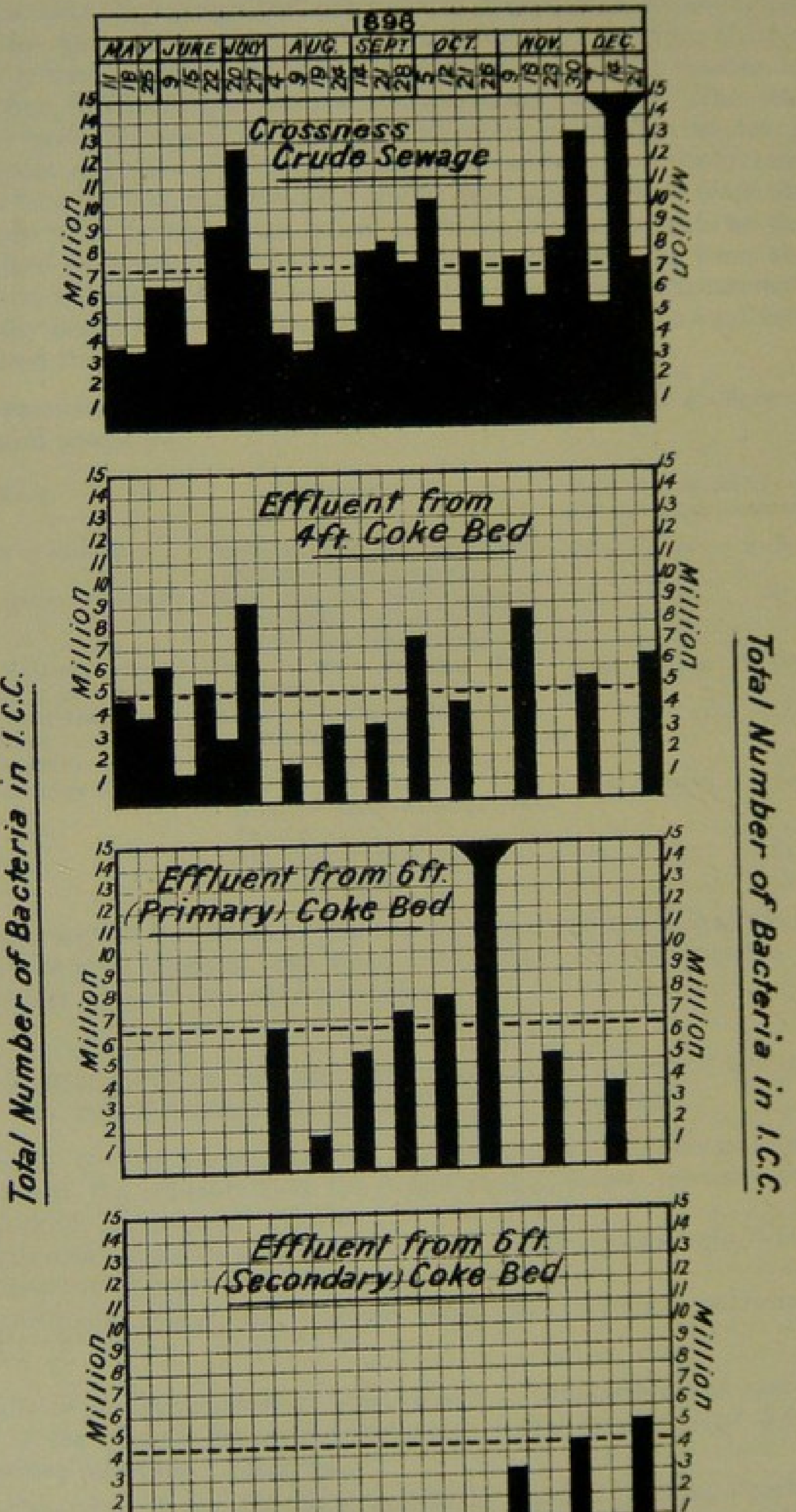

1898
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
11 18 25 9 15 22 20 27 4 9 19 24 14 21 28 5 12 21 26 9 16 23 30 7 14 21
Crossness Crude Sewage
Effluent from 4ft. Coke Bed
Effluent from 6ft. (Primary) Coke Bed
Effluent from 6ft. (Secondary) Coke Bed
Million
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Total Number of Bacteria in 1 C.C.

TABLE I. Total number of bacteria in 1 c.c.

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke-bed.	Effluent from 6-foot secondary coke-bed.
1898				
May 11	3,930,000	4,800,000		
,, 18	3,670,000	4,100,000		
,, 25	6,400,000	6,100,000		
June 9	6,500,000	1,200,000		
,, 15	4,000,000*	5,300,000*		
,, 22	9,100,000	3,000,000		
July 20	12,800,000	9,200,000		
,, 27	7,200,000	...	6,600,000	
August 4	4,200,000	1,800,000		
,, 9	3,600,000	...	1,700,000	
,, 19	5,800,000	3,400,000		
,, 24	4,100,000	...	5,700,000	
September 14	8,000,000	3,400,000		
,, 21	8,600,000	...	7,200,000	
,, 28	7,500,000	7,500,000		
October 5	10,500,000	...	8,000,000	
,, 12	4,000,000	4,200,000		
,, 21	8,000,000	...	15,800,000	
,, 26	5,200,000	...	...	3,100,000
November 9	7,800,000	8,800,000		
,, 16	5,800,000	...	5,300,000	
,, 23	8,600,000	...	...	4,500,000
,, 30	13,500,000	5,400,000		
December 7	5,600,000	...	4,000,000	
,, 14	19,500,000	...	...	5,300,000
,, 21	7,400,000	6,300,000		
Averages	7,357,692 (26 samples)	4,966,666 (15 samples)	6,787,500 (8 samples)	4,300,000 (3 samples)
Percentage reduction (as compared with the raw sewage).		32 per cent.	7 per cent.	41 per cent.
Average number of bacteria in the raw sewage when the samples were comparative with the samples obtained respectively from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds.	6,973,333 (15 samples corresponding to 4-foot samples)	4,966,666 28 per cent. reduction		
	6,675,000 (8 samples corresponding to 6-foot primary samples)	... ...	6,787,500 slight increase	
	11,100,000 (3 samples corresponding to 6-foot secondary samples)	... ...	... ...	4,300,000 61 per cent. reduction

* In connection with the bacteriological examination of these two samples it was sought to ascertain the smallest amount of the liquids capable of giving rise in broth cultures to growth, to offensive smell and to indol production. The results were as follows :—

(*a*) 0·0001, (*b*) 0·000001, and (*c*) 0·0000001 c.c. of Crossness crude sewage was inoculated into each of three bouillon tubes and incubated at 20° C. ; on the seventh day no growth in (*c*), growth and offensive smell in (*a*) and (*b*). (*a*) gave strong indol reaction and (*b*) faint trace.

(*a*) 0·0001, (*b*) 0·000001, and (*c*) 0·0000001 c.c. of the 4-foot single coke-bed effluent was inoculated into each of three bouillon tubes and incubated at 20° C. On the seventh day no growth in (*c*), growth and offensive smell in (*a*) and (*b*). (*a*) and (*b*) both gave distinct indol reaction.

It will be seen that in each case so small an amount as $\frac{1}{1000000}$ c.c. (not $\frac{1}{10000000}$ c.c.) of the liquid gave rise to an offensive smell and indol production in both cultures.

The table shows that the total number of bacteria in the crude sewage (26 samples), the effluent from the 4-foot coke-bed (15 samples), the effluent from the 6-foot primary coke-bed (8 samples), and the effluent from the 6-foot secondary coke-bed (3 samples) averaged 7,357,692, 4,966,666, 6,787,500, and 4,300,000 per c.c. respectively. The percentage reduction of bacteria in the effluents being 32, 7, and 41. The average number of bacteria in the 15 samples of crude sewage corresponding to the 4-foot coke-bed effluents was 6,973,333. In the eight samples corresponding to the 6-foot primary coke-bed effluents the average was 6,675,000. Lastly, the three samples of crude sewage corresponding to the 6-foot secondary coke-bed effluents yielded on an average 11,100,000 bacteria per c.c. Calculated from these figures, the percentage reduction of bacteria was 28 as regards the 4-foot coke-bed effluents; no reduction, but a slight increase as regards the 6-foot primary coke-bed effluents, and 61 per cent. in respect of the 6-foot secondary coke-bed effluents.

As a rule, a rise or fall above or below the mean in the number of bacteria in the crude sewage was associated, in the corresponding effluents, with a similar increase or decrease of microbes. Thus, as regards the crude sewage and the 4-foot coke-bed effluents, there was a correspondence in this respect on 11 occasions out of 15; and as regards the crude sewage and the 6-foot primary coke-bed effluents, this correspondence was observed in all the eight samples. The records of the examination of the 6-foot secondary coke-bed effluents are too few in number to allow of useful conclusions being drawn, but here also the same agreement occurred. The above must not be taken as meaning that the percentage deviation from the mean showed any parallelism as regards the crude sewage and corresponding effluents.

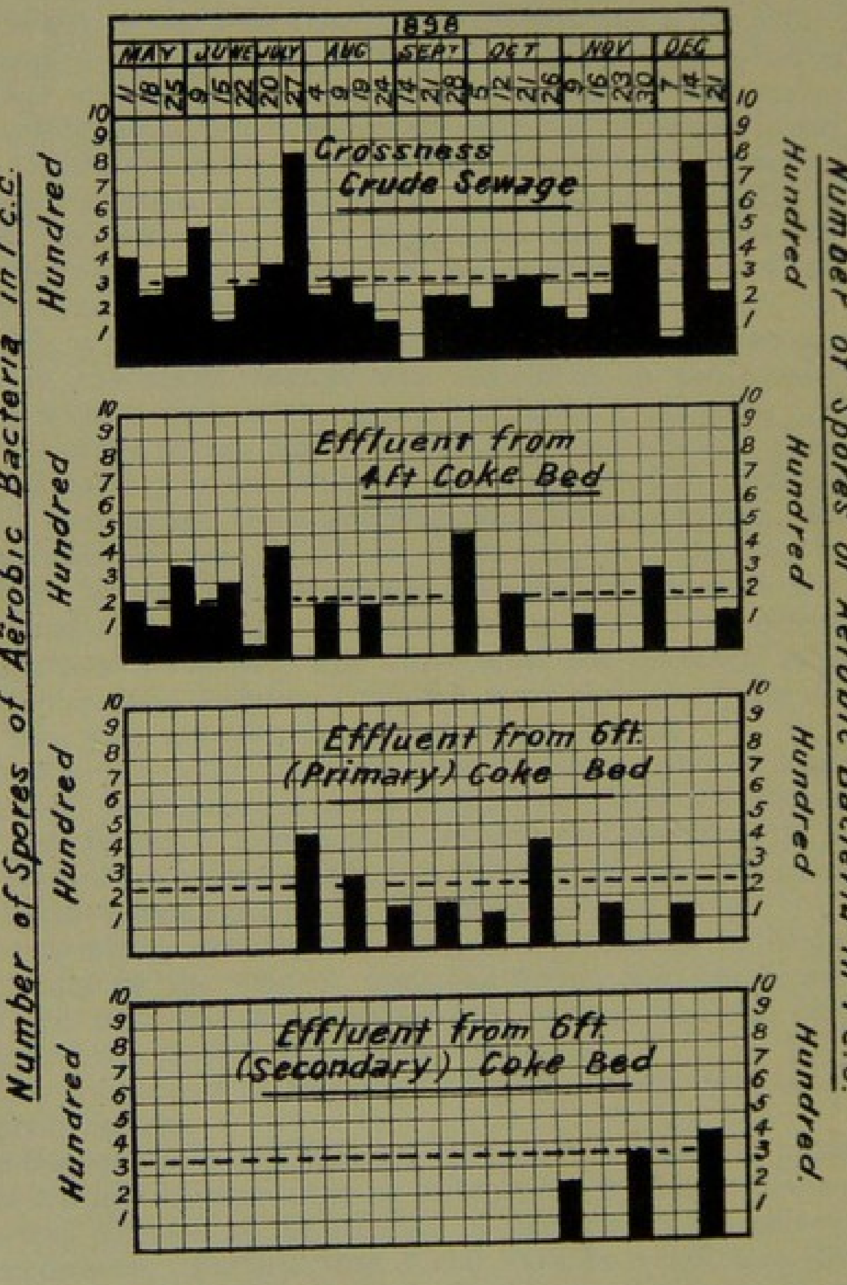
So far as a diminution in the number of bacteria may be taken as an indication of purification, it must be admitted that the above results are not satisfactory. And if they are unfavourable from the point of view of percentage reduction effected, still less are they favourable when judged by the actual state of the effluents.

It is noteworthy that the reduction in the number of bacteria was much greater in the effluent from the 4-foot coke-bed than in the effluent from the 6-foot primary coke-bed, and was nearly as much as in the effluent from the 6-foot secondary coke-bed.

Possibly the records as regards the 6-foot primary coke-bed indicate a retrograde change.

Since the coke-beds are intended to encourage the life processes of bacteria, it might be urged that an increase, or, at all events, the absence of a marked decrease in the number of bacteria in the effluents is of little importance. Further, that it may even be a desirable thing that an effluent only partially purified should carry with it, in order to complete their work, the bacteria which have been engaged in the work of purification. There may be truth in these contentions, but as experience has shown that the bacteria-beds which yield the best chemical results yield also the best results bacteriologically, and as river water already contains all the necessary germs of purification and nitrification, it would seem to be undesirable to discharge with an effluent countless germs of a kind to be associated with the recent evacuations of animals. Moreover, some of these micro-organisms found

DIAGRAM 2


1898
MAY
JUNE
JULY
AUG
SEPT
OCT
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DEC
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20
27
4
9
19
24
14
21
28
5
12
21
26
9
16
23
30
7
14
21
Grossness
Crude Sewage
Effluent from
4ft Coke Bed
Effluent from 6ft.
(Primary) Coke Bed
Effluent from 6ft.
(Secondary) Coke Bed
10
9
8
7
6
5
4
3
2
1
Hundred
Number of Spores of Aërobic Bacteria in 1 c.c.

in sewage are pathogenic, and doubtless many of them, although perhaps slowly working in the direction of purification, are, in a sense, intruders, since the work could probably be more efficiently carried out in their absence by other and less objectionable bacteria.

As regards the value to be assigned to the estimation of the total number of microbes, it may be said that the greater the number of micro-organisms in a liquid containing a mixed bacterial flora the more likely is it that some of them are of a harmful nature. But further than this, the prolonged investigations carried out in this enquiry, as regards the species of microbes and their relative numbers, give to the above figures a special and peculiar value. For while there is no fixed proportion between the total number of bacteria, and, for example, the number of proteus-like germs, of *B. coli* and of spores of *B. enteritidis sporogenes*, it has been abundantly shown that *with a sample of effluent or raw sewage, containing an average number of microbes, say three to nine millions per c.c., the number of "sewage proteus" and of B. coli is likely to be not less than* 100,000, *and of B. enteritidis sporogenes usually more than* 100 *per c.c. respectively. Further, that more than one-tenth of the bacteria are likely to be "liquefiers," and only about one in* 20,000 *present as spores (aërobes).*

As the bacterial composition of London crude sewage does not differ widely from the raw sewage of most other towns, it is believed that these records have a wide range of usefulness. At the risk of repetition it may be pointed out that their bearing on the bacterioscopic examination of potable waters is very important.

TABLE II. Number of spores of aërobic bacteria in 1 c.c.

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke-bed.	Effluent from 6-foot secondary coke-bed.
1898				
May 11	460	260		
" 18	300	140		
" 25	370	380		
June 9	560	230		
" 15	180	300		
" 22	310	60		
July 20	400	430		
" 27	870	...	480	
August 4	280	220		
" 9	340	...	300	
" 19	220	200		
" 24	170	...	180	
September 14	*	*		
" 21	250	...	190	
" 28	260	490		
October 5	200	...	130	
" 12	320	240		
" 21	340	...	420	
" 26	200	...	...	220
November 9	150	140		
" 16	240	...	180	
" 23	510	...	...	320
" 30	440	310		
December 7	70	...	170	
" 14	800	...	...	420
" 21	270	140		
Averages	340 (25 samples)	252 (14 samples)	256 (8 samples)	320 (3 samples)
Percentage reduction (as compared with the raw sewage)		25 per cent.	24 per cent.	5 per cent.

* The rapid liquefaction of the gelatine prevented accurate counting.

TABLE II. Number of spores of aërobic bacteria in 1 c.c.—*continued.*

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke bed.	Effluent from 6-foot secondary coke-bed.
1898				
Average number of spores of bacteria in the raw sewage where the samples were comparative with the samples obtained respectively from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds	322 (14 samples corresponding to 4-foot samples)	252 21 per cent. reduction		
	310 (8 samples corresponding to 6-foot primary samples)	...	256 17 per cent. reduction	
	503 (3 samples corresponding to 6-foot secondary samples)	...	...	320 36 per cent. reduction

The table shows that the number of spores of bacteria in the crude sewage (25 samples), in the effluent from the 4-foot coke bed (14 samples), in the effluent from the 6-foot primary coke-bed (8 samples), and in the effluent from the 6-foot secondary coke-bed (3 samples) averaged 340, 252, 256, and 320 per c.c. respectively. The percentage reduction in the number of spores of aërobic bacteria found in the effluents as compared with the crude sewage being 25, 24, and 5. The average number of spores in the 14 samples of crude sewage corresponding to the 4-foot coke-bed effluents was 322; in the 8 samples corresponding to the 6-foot primary coke-bed effluents 310; and in the 3 samples corresponding to the 6-foot secondary coke-bed effluent the average was 503. Calculated from these figures, the percentage reduction in the number of spores of bacteria was 21 as regards the 4-foot coke-bed effluents, 17 as regards the 6-foot primary coke-bed effluents, and 36 in respect of the 6-foot secondary coke-bed effluents.

Usually a rise or fall above or below the mean in the number of spores of bacteria in the raw sewage was associated with a similar increase or decrease in the number in the corresponding effluents. Thus as regards the crude sewage and the 4-foot coke-bed effluents, there was in this respect a relation between the two, in 11 out of 14 samples; and the raw sewage and the 6-foot primary coke-bed effluents showed a similar correspondence in six out of eight comparative samples. The same relationship was noticed with reference to the 6-foot secondary coke-bed effluents, but here only three samples were examined.

So far as may be judged from a rise or fall above or below the mean, the figures show no distinct parallelism between the total number of bacteria and the number of spores of bacteria in the case either of the crude sewage or of the effluents from the 6-foot primary coke-bed. But as regards the 4-foot coke-bed effluents, there is evidence of a distinct relation.

It will be understood that in the above remarks, when mention is made of a relationship, it does not imply a parallelism as regards *percentage* deviation from the mean.

It is difficult to gauge the exact significance of the number of spores of aërobic bacteria and the number relative to the total number of bacteria. Spores of bacteria are peculiarly resistant to unfavourable physical conditions; fortunately, however, the majority, at all events, of the spores of *aërobic* micro-organisms found in sewage belong to species which are believed to be, relatively speaking, harmless.

Although the actual number of spores in sewage is large, the number relative to the total number of bacteria is very small. Thus in the 26 samples above recorded for every microbe present in the spore-form, there were present over 21,000 in the vegetative form. And this result is not, in all probability, to be attributed solely to the comparative infrequency of bacteria in sewage *capable* of forming spores, but also to the active and continued multiplication of the micro-organisms in the presence of an abundance of suitable pabulum. In the case of effluents from bacteria-beds, it is conceivable that a smaller reduction in the number of spores of bacteria as compared with the reduction in the total number of bacteria, or an actual increase in the number of spores in the effluent as compared with the crude sewage, might be a good rather than a bad sign, since it might be taken as indicating that, the organic pabulum becoming exhausted, the conditions for bacterial life had become so unfavourable as to lead the microbes to form spores in order to escape extinction.

In my reports to the Local Government Board on the bacteriological examinations of soils, I have shown that in surface soils not only is the number of spores very large, but also that they are very numerous in relation to the total number of bacteria. Thus in soils, it is common to find the ratio between the number of spores and number of bacteria—1 : 2; 1 : 3; 1 : 4; 1 : 5; 1 : 6; 1 : 7; 1 : 8; 1 : 9 and 1 : 10. Sometimes the ratio may be 1 : 20; 1 : 30; 1 : 40, or lower, but here the cause is usually to be found in the presence of an excess of moisture and also of organic pabulum. Although the number of bacteria capable of forming spores in soils is peculiarly great, it is probable that the majority of these form spores only when there is a deficiency in the amount of liquid organic pabulum and when the physical conditions are unfavourable.

It is, perhaps, permissible to hazard the conjecture that an increase (actual or relative) in the number of spores of bacteria in effluents from bacteria-beds is possibly a favourable sign. Yet surmises such as the above are best received with reserve, especially as they are to some extent founded on a comparison between a liquid (sewage) in the one case and a solid (soil) in the other.

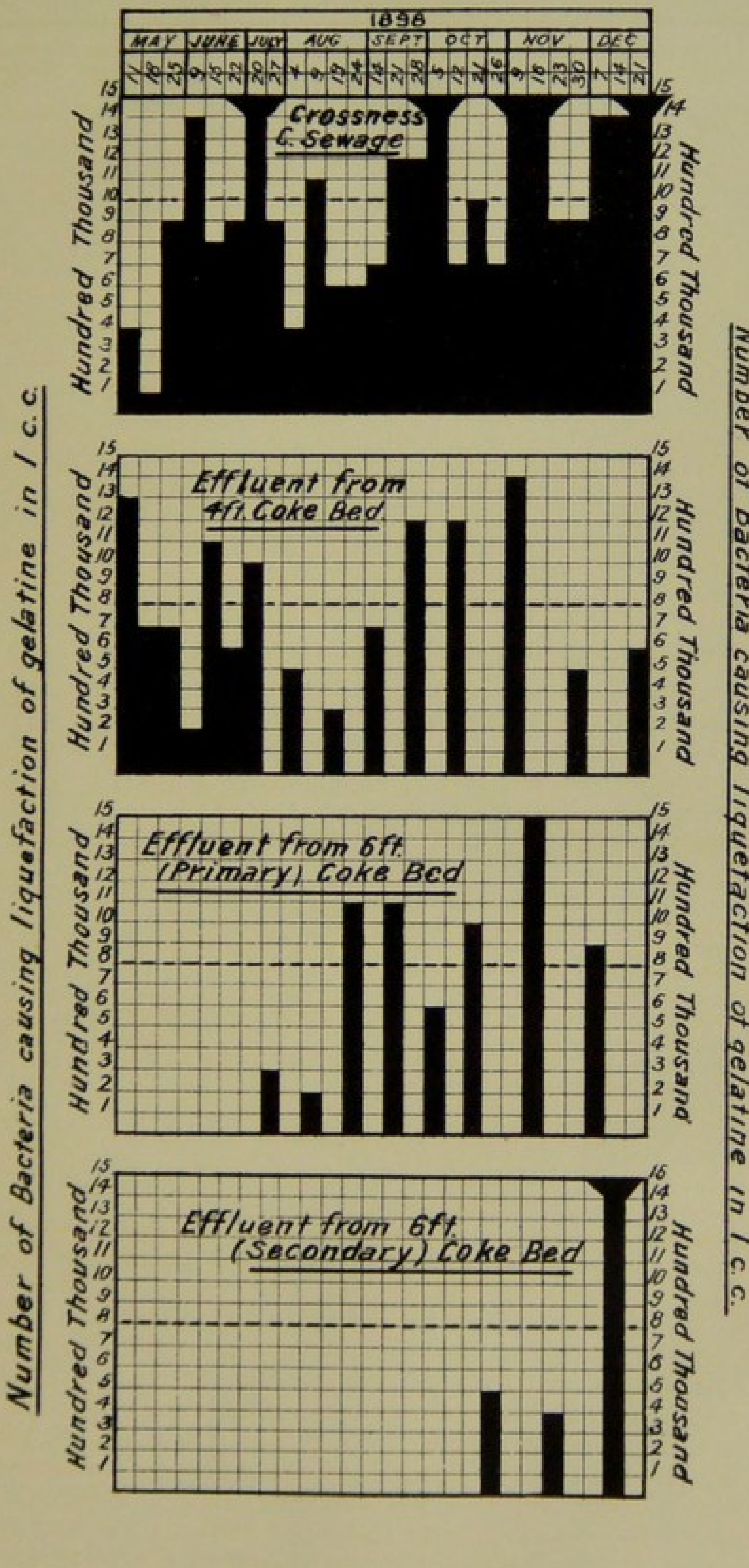
Certainly, however, it is a point worth noting that in soils the ratio of spores to bacteria is commonly more than 1 : 10 and in sewage less than 1 : 10,000. Waters, it may be added, differ rather widely in this respect, but they always approximate much more closely to the ratio found in sewage than that found in soil.

TABLE III. Number of bacteria per 1 c.c. causing liquefaction of gelatine.

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke-bed.	Effluent from 6-foot secondary coke-bed.
1898.				
May 11	400,000	1,300,000		
„ 18	100,000	700,000		
„ 25	900,000	700,000		
June 9	1,400,000	200,000		
„ 15	800,000	1,100,000		
„ 22	900,000	600,000		
July 20	1,700,000	1,000,000		
„ 27	900,000	...	300,000	
August 4	400,000	500,000		
„ 9	1 100,000	...	200,000	
„ 19	600,000	400,000		
„ 24	600,000	...	1,100,000	
September 14	700,000	700,000		
„ 21	1,200,000	...	1,100,000	
„ 28	1,200,000	1,200,000		
October 5	2,400,000	...	600,000	
„ 12	700,000	1,200,000		
„ 21	1,000 000	...	1,000,000	
„ 26	700,000	...	...	500,000
November 9	1,900,000	1,400,000		
„ 16	1,600,000	...	1,500,000	
„ 23	900,000	...	...	400,000
„ 30	900,000	500,000		
December 7	1,400,000	...	900,000	
„ 14	1,400,000	...	...	1,600,000
„ 21	2,200,000	600,000		
Averages	1,076,923 (26 samples)	806,666 (15 samples)	837,500 (8 samples)	833,333 (3 samples)
Percentage reduction (as compared with the raw sewage)		25 per cent.	22 per cent.	22 per cent.
Average number of liquefying bacteria in the raw sewage where the samples were comparative with the samples obtained respectively from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds.	986,666 (15 samples corresponding to 4-foot samples)	806,666 18 per cent. reduction.		
	1,275,000 (8 samples corresponding to 6-foot primary samples)	... ...	837,500 34 per cent. reduction	
	1,000,000 (3 samples corresponding to 6-foot secondary samples)	... ...	... ...	833,333 16 per cent. reduction.

The table shows that the number of liquefying bacteria in the crude sewage (26 samples) in the effluent from the 4-foot coke-bed (15 samples), in the effluent from the 6-foot primary coke-bed (8 samples), and in the effluent from the 6-foot secondary coke-bed (3 samples) averaged 1,076,923, 806,666, 837,500, and 833,333 per c.c. respectively. The percentage reduction in the number of liquefying bacteria in the effluents being respectively 25, 22, and 22. The average number of liquefying bacteria in the 15 samples of crude sewage corresponding to the 4-foot coke-bed effluents was 986,666. In the 8 samples corresponding to the 6-foot primary coke-bed effluents the average was 1,275,000, and in the 3 samples corresponding to the 6-foot secondary

DIAGRAM 3.


1898
MAY
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NOV
DEC
11 18 25 9 15 22 20 27 4 9 19 24 14 21 28 5 12 21 26 9 16 23 30 7 14 21
Crossness C. Sewage
Effluent from 4ft. Coke Bed
Effluent from 6ft. (Primary) Coke Bed
Effluent from 6ft. (Secondary) Coke Bed
Hundred Thousand
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of Bacteria causing liquefaction of gelatine in 1 c.c.

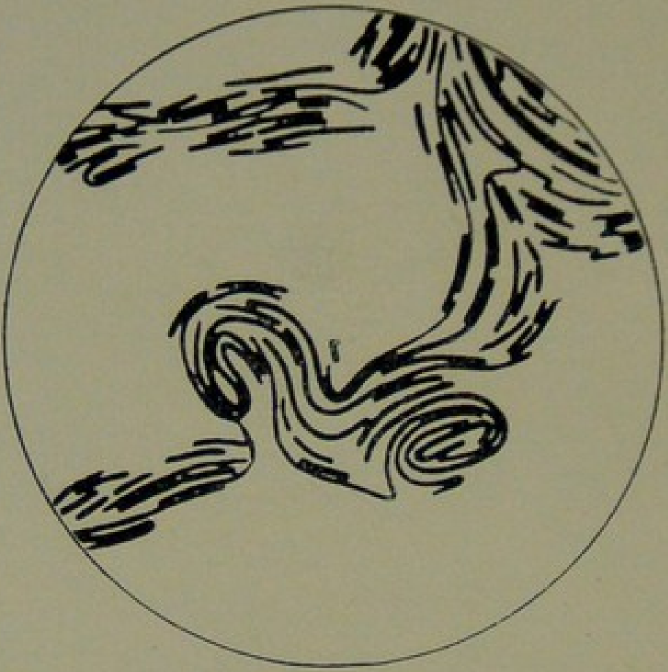

FIG. 9.—*Proteus vulgaris.* Impression preparation from "swarming islands" on gelatine 20 hours' growth at 20° C. × 1,000.

FIG. 10.—*Proteus vulgaris.* Same as fig. 9, but a different strain of proteus (isolated from Crossness crude sewage) and a higher magnification. × 3,000.

coke-bed effluents 1,000,000. Calculated from these figures the percentage reduction of liquefying bacteria was 18 as regards the 4-foot coke-bed effluents, 34 in respect of the 6-foot primary coke-bed effluents, and 16 as regards the 6-foot secondary coke-bed effluents.

Usually a rise or fall above or below the mean in the number of liquefying bacteria in the crude sewage was associated with a similar increase or decrease in the number in the corresponding effluents. Thus as regards the crude sewage and the 4-foot coke-bed effluents, in 10 out of the 15 experiments there was a correspondence, and in the case of the 6-foot primary coke-bed effluents, 5 out of the 8 samples corresponding to the crude sewage showed a similar relationship. Only 3 samples of the effluent from the 6-foot secondary coke-bed were examined; these in each case were related to the raw sewage in the above sense.

So far as may be judged from a rise or fall above or below the mean, the figures show a certain parallelism between the total number of bacteria in the crude sewage and the number of liquefying bacteria, and lastly between the number of spores and liquefiers.

As regards the 4-foot coke-bed effluents, there is evidence of a distinct relation between the total number of bacteria and spores of bacteria, the total number of bacteria and the number of liquefying bacteria, but little or none between the number of spores and number of liquefiers.

With respect to the 6-foot primary coke-bed effluents, there is no definite correspondence between the total number of bacteria and either the number of spores of bacteria or the number of liquefiers; and the spores and liquefiers show, if anything, an inverse relation.

It is to be noted that the number of liquefying bacteria was less in the effluents from the 4-foot coke-bed than in the effluents from either the 6-foot primary or the 6-foot secondary coke-beds; and the spores and liquefiers show, if anything, an inverse relation.

It is difficult to judge the exact value to be placed on the determination of the number of liquefying bacteria. At one time, it was thought that the greater the number of liquefying bacteria in a water, the more dangerous was the nature of the contamination, and the more unfit the water was for domestic use. But as many objectionable bacteria (e.g., *B. coli*) do not liquefy gelatine and many pure waters are rich in liquefying microbes of a harmless nature, this test fell into comparative disfavour. When, however, the character of the liquefying bacteria in the substance under examination is taken into consideration, the position of things is somewhat altered. Thus in 14 samples of crude sewage and effluents there were present at least 100,000 gas-forming "*sewage proteus*" per c.c. So that it may safely be said that at least one-tenth of the numerous liquefying bacteria in sewage are proteus-like in character. And as some of the *strains* of this "*sewage proteus*" isolated from the raw sewage and the effluents were found to be very virulent to rodents, it may be added that crude sewage and effluents from bacterial coke-beds are not only rich in liquefying bacteria, but that they contain in great abundance liquefying germs which are probably objectionable in kind.*

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* Microbes corresponding to the published descriptions of *Proteus vulgaris* seem much less numerous in sewage than might have been anticipated, but it must not be supposed that they are in reality absent. *See* Figs. 9 and 10. The morphological and biological characters of "*sewage proteus*" are described and illustrated at the end of this report. *See* Figs. 46, 47, 48 and 49.

In conclusion, it is worthy of note that the ratios of spores and of liquefiers to the total number of bacteria in the crude sewage and effluents respectively are approximately as follows—

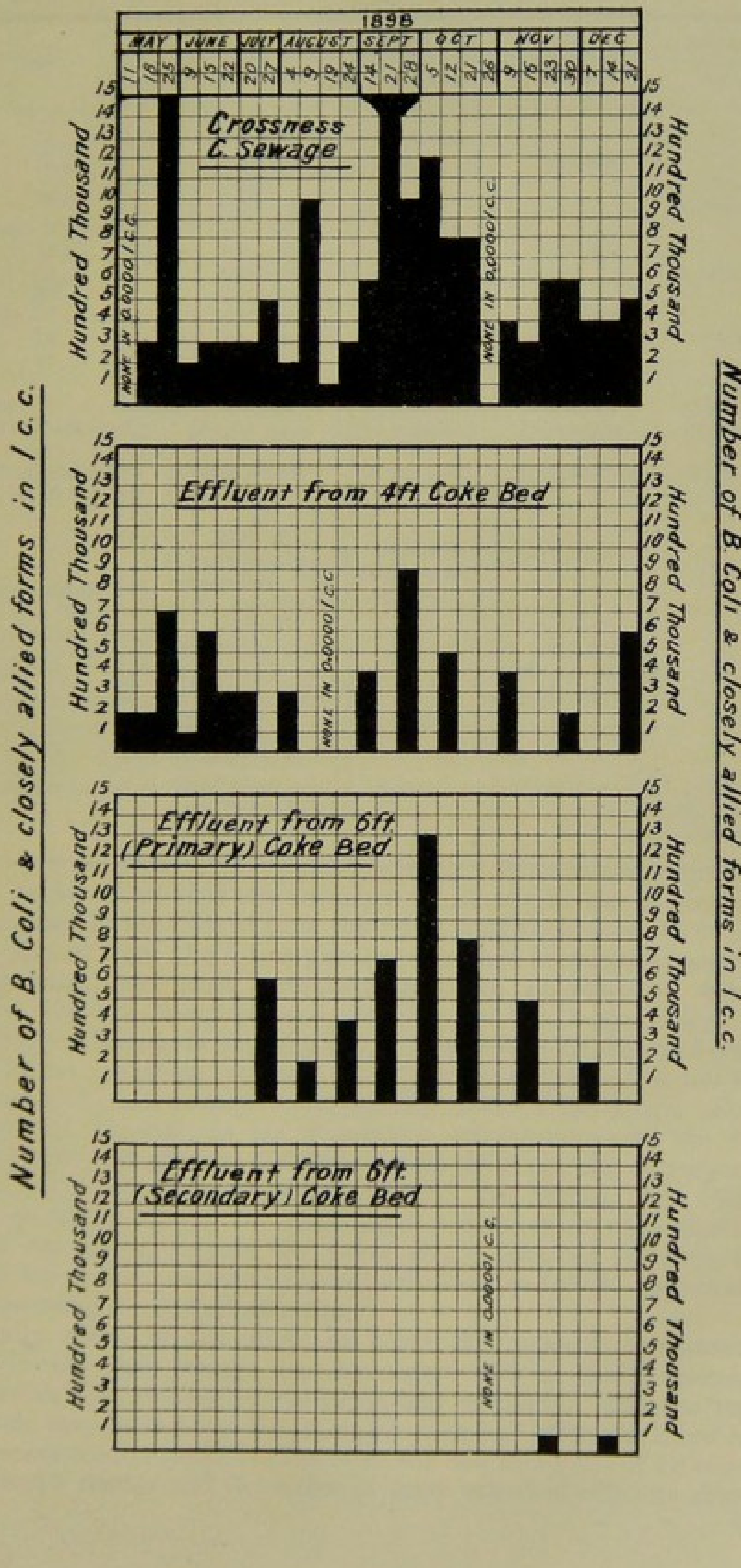
Crude sewage (26 samples)—Ratio of spores (aërobes) to total number of bacteria ... = 1 : 21,640
4-foot single coke-bed effluent (15 samples)—Ratio of spores (aërobes) to total number of bacteria ... ... = 1 : 19,709
6-foot primary coke-bed effluent (8 samples)—Ratio of spores (aërobes) to total number of bacteria ... ... = 1 : 26,513
6-foot secondary coke-bed effluent (3 samples)—Ratio of spores (aërobes) to total number of bacteria ... ... = 1 : 13,436
Crude sewage (26 samples)—Ratio of liquefiers to total number of bacteria ... ... = 1 : 6·8
4-foot single coke-bed effluent (15 samples)—Ratio of liquefiers to total number of bacteria = 1 : 6·0
6-foot primary coke-bed effluent (8 samples)—Ratio of liquefiers to total number of bacteria ... ... = 1 : 8·1
6-foot secondary coke-bed effluent (3 samples)—Ratio of liquefiers to total number of bacteria ... ... = 1 : 5·1

These results would seem to indicate that the result of the bacterial treatment of the raw sewage in the coke-beds was to effect an increase in the number of spores and of liquefiers relative to the total number of micro-organisms in the case of the 4-foot single and of the 6-foot secondary beds, and to bring about a decrease in the number of spores and liquefiers relative to the total number in the case of the 6-foot primary coke-bed. But the records are not sufficiently numerous to allow of a definite statement being made.

TABLE IV. *Number of B. coli or closely allied forms in 1 c.c.*

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke-bed.	Effluent from 6-foot secondary coke-bed.
1898.				
May 11 ...	None in 0·00001 c.c.	200,000		
" 18	300,000	200,000		
" 25	1,500,000	700,000		
June 9	200,000	100,000		
" 15	300,000	600,000		
" 22	300,000	300,000		
July 20	300,000	300,000		
" 27	500,000	...	600,000	
August 4	200,000	300,000		
" 9	1,000,000	...	200,000	
" 19	100,000	None in 0·00001 c.c.		
" 24	300,000	...	400,000	
September 14	600,000	400,000		
" 21	1,600,000	...	700,000	
" 28	1,000,000	900,000		
October 5	1,200,000	...	1,300,000	

DIAGRAM 4.


1898
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11 18 25 9 15 22 20 27 4 9 19 24 14 21 28 5 12 21 26 9 16 23 30 7 14 21
Crossness C. Sewage
NONE IN 0.0000 1 C.C.
NONE IN 0.0000 1 C.C.
Effluent from 4ft. Coke Bed
NONE IN 0.0000 1 C.C.
Effluent from 6ft. (Primary) Coke Bed
Effluent from 6ft. (Secondary) Coke Bed
NONE IN 0.0000 1 C.C.
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Hundred Thousand
Number of B. Coli & closely allied forms in 1 c.c.

TABLE IV.—*continued.*

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent rom 6-foot primary coke-bed.	Effluent from 6-foot secondary coke-bed.
1898.				
October 12	800,000	500,000		
" 21	800,000	...	800,000	
" 26 ...	None in 0·00001 c.c.	...	...	None in 0·00001 c.c.
November 9	400,000	400,000		
" 16	300,000	...	500,000	
" 23	600,000	...	...	100,000
" 30	600,000	200,000		
December 7	400,000	...	200,000	
" 14	400,000	...	...	100,000
" 21	500,000	600,000		
Averages ... ... (in round numbers)	600,000 (24 samples)	400,000 (14 samples)	600,000 (8 samples)	100,000 (2 samples)
Percentage reduction with the raw	(as compared) sewage).	33 per cent.	No reduction	83 per cent.
Average number of *B. coli* in the raw sewage where the sample corresponded with the samples obtained respectively from the 4 ft. single, 6 ft. primary, and 6 ft secondary coke-bed.	538,000 (13 samples corresponding to 4 ft. samples.)	400,000 -25 per cent. reduction		
	762,000 (8 samples corresponding to 6 ft. primary samples.)	... ...	600,000 21 per cent. reduction	
	500,000 (2 samples corresponding to 6 ft. secondary samples.)	... ...		100,000 80 per cent. reduction

The table shows that the number of *B. coli* in the crude sewage (24 samples), in the effluent from the 4-foot single coke-bed (14 samples), in the effluent from the 6-foot primary coke-bed (8 samples) and in the effluent from the 6-foot secondary coke-bed (2 samples) averaged 600,000 400,000, 600,000, and 100,000 per c.c. respectively. The percentage reduction in the effluents as compared with the crude sewage being 33, no reduction, and 83. The average number of *B. coli* in the 13 samples of crude sewage corresponding to the 4-foot single coke-bed effluent was 538,000; in the 8 samples corresponding to the 6-foot primary coke-bed effluents 762,000; and in the 2 samples corresponding to the 6-foot secondary coke-bed effluents the average was 500,000. Based on these figures the percentage reduction in the number of *B. coli* was 25 as regards the 4-foot single coke-bed effluents, 21 as regards the 6-foot primary coke-bed effluents, and 80 in respect of the 6-foot secondary coke-bed effluents.

Usually a rise or fall above or below the mean in the number of *B. coli* in the crude sewage was associated with a similar increase or decrease in the number of corresponding effluents. Thus as regards the crude sewage and the 4-foot single coke-bed effluents, there was in this respect a correspondence between the two in 10 out of 12 samples; and the raw sewage and the 6-foot primary coke-bed effluents showed a similar relation in 6 out of the 7 comparative samples. The records as regards the 6-foot secondary coke-bed effluents are too few in number to warrant a comparison being made.

So far as may be judged from the rise or fall above or below the mean, the figures show a certain parallelism between the number of *B. coli* and the total number of bacteria both in the crude sewage and in the effluents from the 4-foot single and the 6-foot primary coke-beds. The records as regards the 6-foot secondary coke-bed are too few to allow of useful conclusions being drawn.

It is to be noted that the average number of *B. coli* in the 6-foot primary coke-bed effluent was greater than the number in the 4-foot single coke-bed effluent, and, indeed, showed no difference from the raw sewage in this respect.

The ratio of the number of *B. coli* to the total number of bacteria in the crude sewage and in the effluents is aproximately as follows—

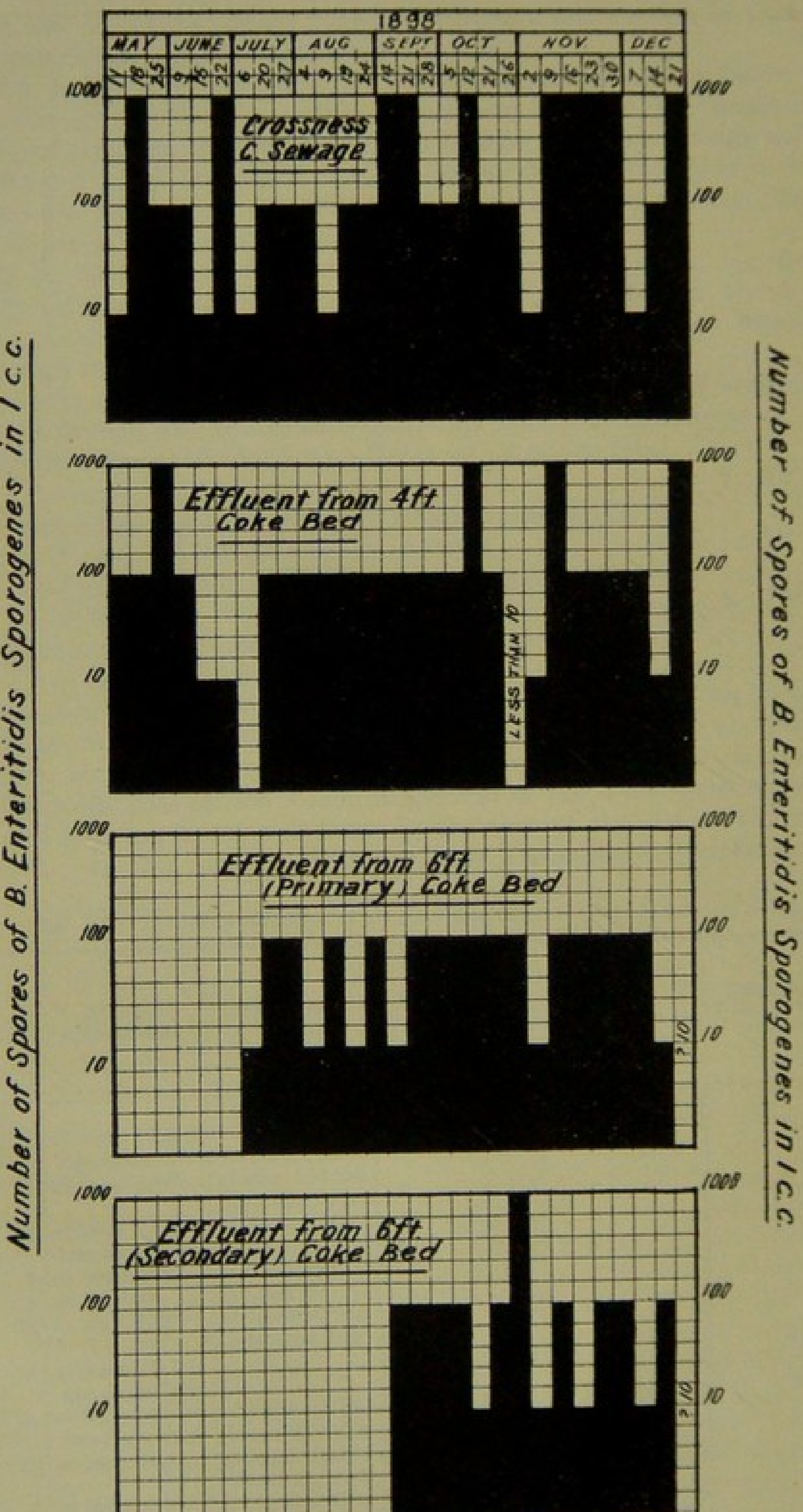
Crude sewage (26 samples)—Ratio of *B. coli* to total number of bacteria ... ... = 1 : 12
4-foot single coke-bed effluent (15 samples)—Ratio of *B. coli* to total number of bacteria ... ... = 1 : 12
6-foot primary coke-bed effluent (8 samples)—Ratio of *B. coli* to total number of bacteria ... ... = 1 : 11
6-foot secondary coke-bed effluent (3 samples)—Ratio of *B. coli* to total number of bacteria ... ... = 1 : 43

These results would seem to indicate that the results of the bacterial treatment of the raw sewage in the coke-beds was to effect no material alteration in the number of *B. coli* relative to the total number of bacteria in the case of the 4-foot single and of the 6-foot primary coke-beds and to bring about a decrease in the case of the 6-foot secondary coke-bed. In this last case, however, only 3 samples were examined.

TABLE V. *Number of spores of B. enteritidis sporogenes in 1 c.c.*

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke-bed.	Effluent from 6-foot coke-bed again passed through the laboratory vessel at Crossness.	Effluent from 6-foot secondary coke-bed.
1898.					
May 11	at least 10 but less than 100	at least 100 but less than 1,000			
„ 18	at least 1,000	at least 100 but less than 1,000			
„ 25	at least 100 but less than 1,000	at least 1,000			
June 9	at least 100 ...	at least 100			
„ 15	at least 10 ...	at least 10			
„ 22	at least 1,000	at least 10 but less than 100			
July 6	at least 10 but less than 100	...	at least 10 but less than 100		
„ 20	at least 100 but less than 1,000	at least 100 but less than 1,000	at least 100 ...	at least 100	
„ 27	at least 100 ...	at least 100 but less than 1,000	at least 100 ...	at least 10 but less than 100	
Aug. 4	at least 100 ...	at least 100 ...	at least 10 ...	at least 10	
„ 9	at least 10 but less than 100	at least 100 ...	at least 100 ...	at least 10 but less than 100	
„ 19	at least 100 ...	at least 100 ...	at least 10 ...	at least 10	

DIAGRAM 5.



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11 18 25
8 15 22
6 20 27
4 9 17 24
14 21 28
5 12 21 26
2 9 16 23 30
7 14 21
1000
100
10
Crossness C. Sewage
Effluent from 4ft Coke Bed
LESS THAN 10
Effluent from 6ft (Primary) Coke Bed
? 10
Effluent from 6ft (Secondary) Coke Bed
Number of Spores of B. Enteritidis Sporogenes in 1 c.c.

TABLE V.—*continued.*

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke-bed.	Effluent from 6-foot coke-bed again passed through the laboratory vessel at Crossness.	Effluent from 6-foot secondary coke-bed.
1898.					
Aug. 24	at least 100 but less than 1,000	at least 100 ...	at least 100 but less than 1,000	at least 10 but less than 100	
Sept. 14	at least 1,000	at least 100 but less than 1,000	at least 10 but less than 100	effluent from 6-ft. primary coke-bed now turned on to 6-ft. secondary coke-bed	at least 100
" 21	at least 1,000	at least 100 ...	at least 100 but less than 1,000	"	at least 100
" 28	at least 100 but less than 1,000	at least 100 but less than 1,000	at least 100 ...	"	at least 100
Oct. 5	at least 100 but less than 1,000	at least 100 ...	at least 100 but less than 1,000	"	at least 100
" 12	at least 1,000	at least 1,000	at least 100 ...	"	at least 10 but less than 100
" 21	at least 100 but less than 1,000	at least 100 ...	at least 100 but less than 1,000	"	at least 100
" 26	at least 100 but less than 1,000	less than 10 ...	at least 100 ...	"	at least 1,000
Nov. 2	at least 10 ...	at least 10 ...	at least 10 ...	"	at least 10
" 9	at least 1,000	at least 1,000	at least 100 ...	"	at least 100
" 16	at least 1,000	at least 100 ...	at least 100 but less than 1.000	"	at least 10 but less than 100
" 23	at least 1,000	at least 100 ...	at least 100 ...	"	at least 100 but less than 1,000
" 30	at least 1,000	at least 100 but less than 1 000	at least 100 ...	"	at least 100
Dec. 7	at least 10 but less than 100	at least 100 ...	at least 100 but less than 1,000	"	at least 10 but less than 100
" 14	at least 100 but less than 1,000	at least 10 and ? 100	at least 10 and ? 100	"	at least 100 but less than 1.000
" 21	at least 1,000	at least 1,000	? 10, less than 100	"	? 10, less than 100

In summarising these results, it is to be noted that—

(1) The number of spores of *B. enteritidis sporogenes* both in the crude sewage and in the effluents varied as a rule from 10 to 1,000 per c.c. Usually there were more than 100.

(2) The bacterial treatment did not produce any significant alteration in the number of spores of this pathogenic anaërobe, and sometimes the number of spores was greater in the effluents than in the corresponding samples of crude sewage. Possibly this may be due to the spores being stored in the coke-beds and being occasionally washed out. This hypothesis would account for the observed fact that sometimes the number of spores of aërobic bacteria in the effluents was greater than in the corresponding sample of sewage. Speaking generally, and dealing only with corresponding samples of raw sewage and effluent, and where the absence of *B. enteritidis* was established in an amount of liquid one-tenth less than the quantity in which it was found to be present, *i.e.*, a negative as well as a positive result was obtained, more cannot be said than that the number of spores of *B. enteritidis* was more often observed

to be less in the effluents as compared with the corresponding sample of crude sewage than *vice versâ*.

In view of these results, and remembering the virulence[*] to rodents of this microbe cultured in milk, and its alleged relation to certain cases of acute diarrhœa in the human subject, it is remarkable that some still assert that the effluents from bacteria-beds are free from pathogenic germs.

Another point on which there is evidently misconception is the belief that because *B. enteritidis sporogenes* is present in normal stools, the presence of this anaërobe in an effluent or in a water-supply is of no moment. It is as idle to assert that, because it may be present in normal stools, its presence in an effluent or in a water-supply is of no importance, as it would be to maintain that because *diplococcus pneumoniæ* (one of the most pathogenic micro-organisms known) may be present in normal human saliva, its presence elsewhere in nature is not fraught with any untoward significance.

Fig. 7 shows the appearances produced in sterile milk when inoculated with a minimal quantity of sewage and thereafter heated to 80° C. for ten minutes and cultivated anaërobically at blood-heat. Briefly, the casein is precipitated and torn into irregular masses by the copious development of gas, and the whey presents a nearly transparent or slightly cloudy appearance. Now, even if we forget that these characteristic changes in the milk are microbial in origin, and discard altogether the question of the pathogenicity of the micro-organisms concerned in the process, and if we regard the change in the medium merely as a special phenomenon to be associated with the introduction of certain substances as opposed to others, the test still remains extremely valuable. For the *particulate matter* in as much as from 100 to 500 c.c. of a pure water[†] does not in point of fact produce these changes when added to milk, whereas the addition of as little as $\frac{1}{100}$ to $\frac{1}{1000}$ c.c. of sewage does bring about this change. Nor do we know of any substance which is not either objectionable *per se* or which can be proved not to have been associated *at some time* with matter of undesirable sort which can effect a similar transformation in milk.

As regards polluted and cultivated soils (and their "washings") and virgin soils (and their "washings"), it may be said that the spores of *B. enteritidis sporogenes* are present in great abundance in the former and absent (or relatively so) from the latter.

The only reasonable objection that can be urged against the test is that the fact of *B. enteritidis sporogenes* being a sporing anaërobe

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[*] It is true that sometimes a milk culture showing Klein's "enteritidis change" is found to be non-pathogenic to rodents, but in these cases it is usually only necessary, in my experience, from the same series of cultures to inoculate an animal with a typically "changed" milk culture *lower* in the scale of dilutions (*i.e.*, containing more of the sewage or effluent in question) to obtain a pathogenic result. It may be difficult to determine whether in these cases we are dealing with aberrant and non-pathogenic strains of *B. enteritidis sporogenes* or with microbes of separate species (non-pathogenic but capable of producing a similar transformation in milk culture). But the "enteritidis change" in milk culture is always significant, although sometimes the curve of "the enteritidis change *plus* virulence" falls below the curve of "the enteritidis change *minus* virulence."

[†] The demonstration of the spores of *B. enteritidis sporogenes* in substances bearing no conceivable relation to water-supply is of interest; but this must not be used as an argument against the utility of the test, *as a test*, in the bacteriological examination of potable waters.

weakens somewhat its usefulness of taking its presence as an indication of recent and therefore presumably specially dangerous pollution. Of course, such a contention has little or no bearing on the experiments carried out this inquiry.

It will be noticed that the spores of *B. enteritidis* often exceeded in number the total number of spores of aërobic bacteria. The reason for this probably lies in the fact that *B. enteritidis* is an anaërobe. In nature, anaërobic micro-organisms are usually found to be present in the spore form, because doubtless it is but seldom that the conditions are favourable for their anaërobic growth, and if they were not capable of forming spores under adverse circumstances they must soon lose their vitality and die. Aërobic bacteria, on the other hand, commonly find in nature the conditions favourable for their continued growth and multiplication, and therefore are usually met with in the vegetative form. In surface soil, however, as has been already pointed out, the ratio of spores to bacteria is very high, possibly because the physical conditions are frequently most unfavourable to microbial life.

On comparing the figures as regards the total number of bacteria and number of spores of *B. enteritidis* no definite correspondence can be made out between the two sets of figures either in the case of the crude sewage or in the effluents. In not a few cases when the total number of bacteria was large the number of spores of *B. enteritidis* was small and *vice versâ*.

It might perhaps have been anticipated that both in the case of the crude sewage and in the effluents there would be some measure of correspondence between the number of *B. coli* and the number of spores of *B. enteritidis sporogenes*. On comparing the two sets of figures it would seem that this is not the case; indeed, if there is any relation at all it is an inverse one. Thus, dealing in the first place with the crude sewage only, it will be noticed that—

On ten different occasions the number of spores of *B. enteritidis* was very high, viz., at least 1,000 per c.c. On the corresponding dates the number of *B. coli* was five times below the average, only twice above, and on three occasions the average number was present.

Taking next the five samples in which *B. coli* was present in great numbers, namely, 1,000,000 or more per c.c. In the corresponding samples the number of spores of *B. enteritidis* was about the average three times, less than the average once, and above the average once.

Taking next the three samples in which *B. enteritidis* was present in small numbers, namely, at least 10 but less than 100 per c.c. On one of these dates *B. coli* was present in number exceeding one million per c.c., and in the two other samples the number of *B. coli* was below the average.

Next dealing with the 10 samples in which *B. coli* was distinctly below the average, namely, those in which the number was 300,000 or less per c.c. In three of these samples the number of spores of *B. enteritidis* was over 1,000, five samples contained the average number, and in the remaining two, the number was below the average.

Secondly, dealing with the effluents from the 4-foot single coke-bed, a similar although perhaps less well-marked discrepancy between the number of *B. coli* and *B. enteritidis* is noticeable.

The records as regards the other coke-bed effluents are not very numerous and do not lend themselves readily to comparisons of the above sort.

In general summary of these results it may be said that—

(1) Although the total number of bacteria, the number of spores of aërobic microbes, the number of liquefying micro-organisms, the number of *B. coli* and the number of spores of *B. enteritidis sporogenes* was, on an average, less in the effluents from the coke-beds than in the raw sewage, the reduction was not well marked, and frequently the number was actually greater in the effluents than in the corresponding samples of crude sewage.

(2) The 4-foot single coke-bed yielded on the whole better results than the 6-foot primary and proved nearly as efficient as the 6-foot secondary coke-bed.

(3) There was no very definite evidence, so far as may be judged from these results, of any special selective* process taking place during the bacterial treatment of the sewage in the coke-beds, since the bacterial composition of the effluents was very much the the same as that of the raw sewage.

(4) The total number of microbes, both in the crude sewage and effluents, was always more than one million, but usually less than ten million per c.c.; the number of *B. coli* and spores of *B. enteritidis sporogenes* was usually more than 100,000, and at least 100, but less than 1,000, respectively, per c.c. More than one-tenth of the total number of bacteria liquefied gelatine, and only about one in 20,000 was present in the spore form.

(5) The bacterial composition of the effluents differed only slightly from the crude sewage; so far as this could be judged by the records which have been enumerated, it cannot, in the absence of direct proof to the contrary, be safely considered that the effluents from the coke-beds are less dangerous than the raw sewage in their possible relation to disease.

B. *Further experiments with the effluents from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds at Crossness.* (Series I.)

In the early part of the year 1899 some further experiments were carried out with the effluents from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds. These took the form of comparative determinations of the number of spores of anaërobic bacteria in the raw sewage and in the effluents from the coke-beds.

Number of spores of anaërobic bacteria in Crossness crude sewage and in the effluents from coke-beds.

The effect of the bacterial treatment of the raw sewage in coke-beds was, as regards the number of spores of *anaërobic* bacteria, to a con-

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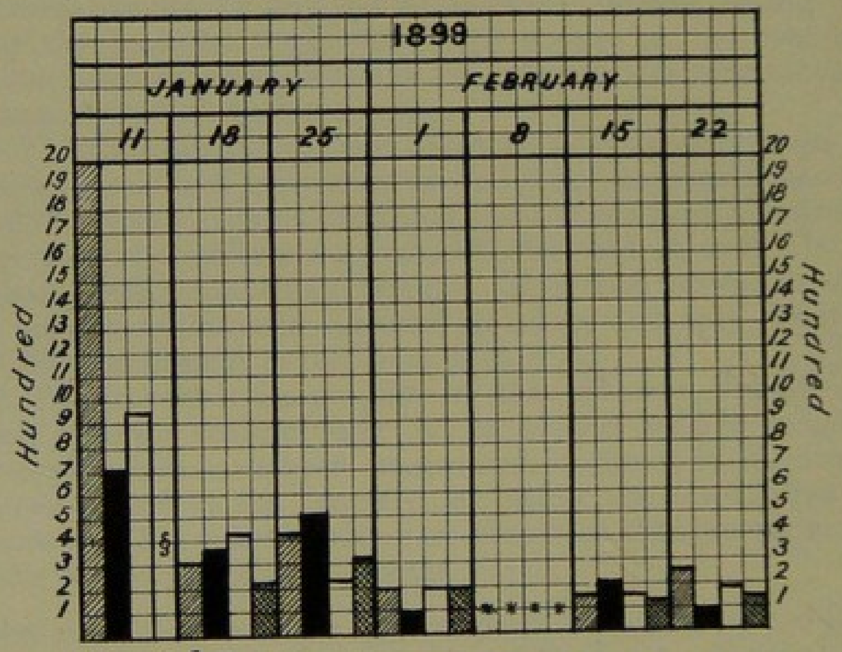
* That, however, some selective process is at work in the coke-beds can hardly be doubted. For example, raw sewage contains little or no oxidised nitrogen, whereas the effluents from the bacteria-beds contain nitrites, and nitrates often in considerable amount. This alteration in the chemical state of the liquid is brought about by nitrifying bacteria, and it is highly probable that these particular microbes multiply and accumulate in the coke-beds, and that the effluents from *mature* coke-beds contain more nitrifying organisms than the crude sewage. Some experiments of a tentative character which I have carried out seem to support this hypothesis.

DIAGRAM 6.

Number of Spores of Anaërobic Bacteria in 1 c.c. (Agar at 37° c.)



§ No record

* The growths spread over the surface of the medium, preventing accurate counting

▨ Crossness Crude Sewage

☐ Effluent from 4ft Coke Bed

■ " " 6ft (Primary) Coke Bed

▩ " " (Secondary) " "

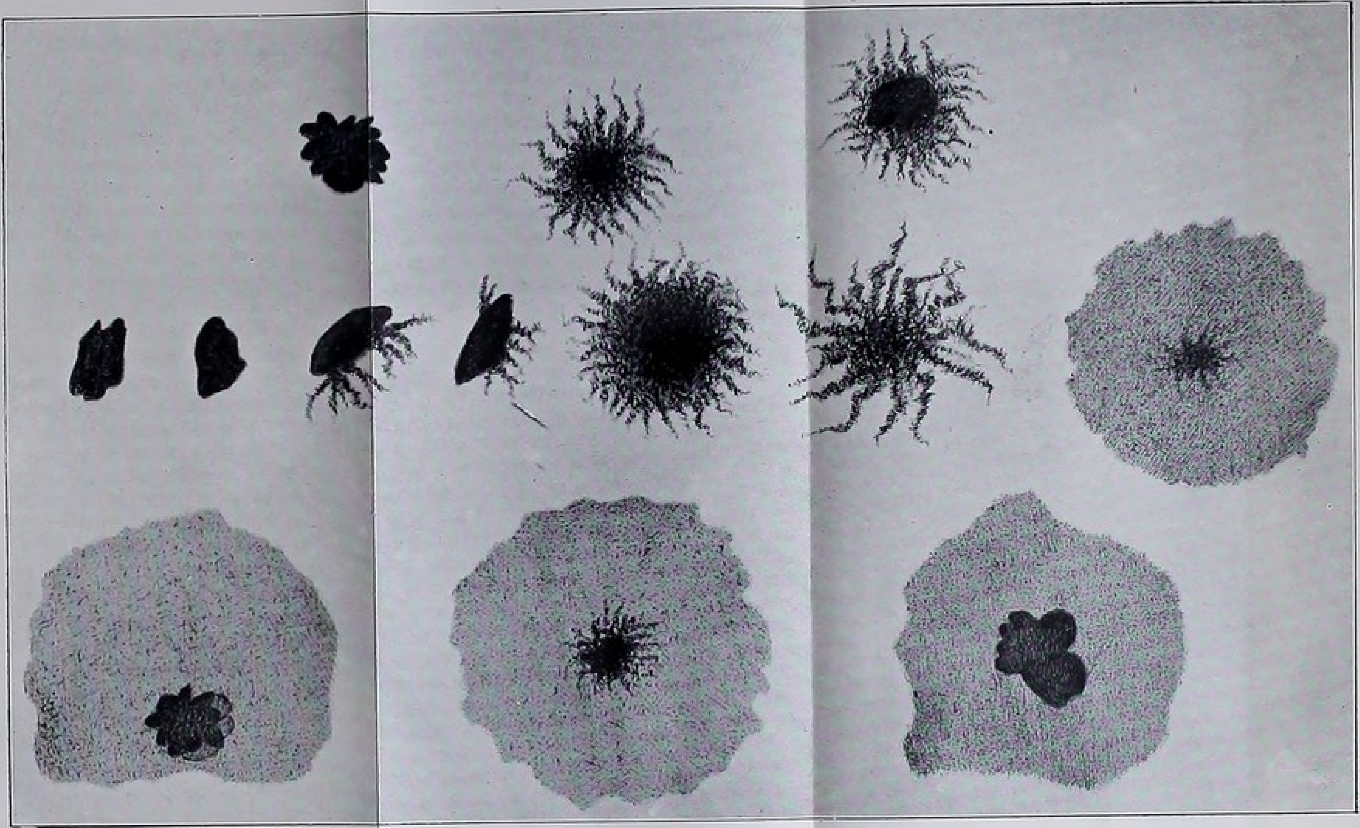


FIG. 11—(Diagrammatic.) Colonies, superficial and deep, of spore-forming anaërobes in agar plate cultures (previously inoculated with $\frac{1}{10}$ c.c. of crude sewage or of effluent, and then heated to 80° C. for ten minutes; cultivated under anaërobic conditions at 37° C.). As seen under a low power of the microscope, but not drawn to scale.

siderable extent covered by the comparative determinations of the number of spores of *B. enteritidis sporogenes* in the raw sewage and in the effluents, carried out during 1898. Nevertheless, it was considered advisable to supplement those records with a series of experiments dealing with the number of spores of anaërobic bacteria of all kinds in the raw sewage and in the effluents capable of growing at 37° C. in agar under anaërobic condition.

TABLE VI. *Number of spores of anaërobic bacteria in* 1 *c.c.* [*Agar at* 37° *C.*]

Date.	Crossness crude sewage.	Effluent from 4-foot single coke-bed.	Effluent from 6-foot primary coke-bed.	Effluent from 6-foot secondary coke-bed.
1899.				
January 11	1,988	720	920	No record
" 18	304	380	424	224
" 25	424	516	232	336
February 1	201	100	191	197
" 8	The growths spread over the surface of the medium, preventing accurate counting			
" 15	148	212	160	124
" 22	262	128	196	156

The agar tubes were boiled for half an hour, rapidly cooled to 80° C., then inoculated with the sewage or effluent, and kept for 10 minutes at 80° C. The contents were next poured into plates, which were immediately placed in an air-tight chamber containing a freshly-prepared mixture of pyrogallic acid and potassium hydrate solution.

Excluding the results obtained on January 11th, as the figures are abnormally high, and as there is no record on that date for the 6-foot secondary coke-bed, the averages are as follows—

Average number of spores of anaërobic bacteria in five samples of Crossness crude sewage, and in five comparative effluents from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds, 268; 267; 240; and 207 per c.c. respectively.

It will be seen from these results that the bacterial treatment of the crude sewage in the coke-beds did not effect any marked alteration in the number of spores of anaërobic bacteria. Indeed, the number in the effluent from the 4-foot coke-bed was practically the same as in the raw sewage, and in the case of the effluents from the 6-foot primary and the 6-foot secondary coke-beds, the reduction was only 10 and 22 per cent. respectively.

Pressure of other work for the Council made it impossible to study exhaustively the morphological and biological characters of the different kinds of anaërobic bacteria isolated in pure culture from the anaërobic agar plates; and the notes under this heading are of too fragmentary a character to make it advisable to place them on record here. So far as could be ascertained, there was no difference, as regards species of microbes, between the anaërobic cultures made from the crude sewage and those made from the effluents from the coke-beds.

The appearance presented by the colonies (superficial and deep) under a low power of the microscope is shown diagrammatically in fig. 11. So far as could be judged by observation under a low power of the microscope and by making sub-cultures, the number of spore-forming anaërobes of different species was not great. As regards growth in anaërobic milk culture, some of the microbes isolated from the agar plate cultures produced precipitation of the casein, with abundant development of gas, while the whey remained nearly transparent, or presented only a slightly cloudy appearance; others produced no visible change even after several days' incubation at 37° C.; others again gave rise to an appearance resembling slow peptonization, beginning immediately below the surface, and gradually extending downwards in cylindrical fashion.

A rise or fall above or below the mean in the number of the spores of anaërobic bacteria in the crude sewage was usually associated with a similar increase or decrease in the number of spores of anaërobes in the effluents from the 4-foot single, 6-foot primary, and 6-foot secondary coke-beds.

In conclusion, and as an addition to the records of the bacterial composition of Crossness crude sewage, it may be worthy of note that the number of spores of anaërobic bacteria (agar at 37° C.) in Crossness crude sewage is usually between 200 and 300 per c.c.

C.—*Experiments with the effluents from the 13-foot coke-bed at Crossness.*[*]

The chief results obtained will be given under the following headings—

(*a*) Total number of bacteria (gelatine at 20° C.).
(*b*) Number of *B. coli* or closely allied forms.
(*c*) Number of spores of *B. enteritidis sporogenes* (Klein).
(*d*) Number of bacteria capable of growing in agar at 37° C.

(*a*) *Total number of bacteria (gelatine at 20° C.).*

The results as regards the total number of bacteria are given in the following table—

TABLE VII. *Showing the total number of bacteria in 1 c.c.*

Date.		Crossness crude sewage.	Effluent from the 13 ft. coke-bed at Crossness.
1899.			
March	22	5,000,000	2,000,000
May	11	4,600,000	3,000,000
July	5	7,200,000	16,000,000
August	2	4,110,000	8,000,000
September	1	2,240,000	1,940,000
"	7	3,910,000	1,490,000
"	13	11,170,000	5,040,000
"	19	9,580,000	6,750,000
"	27	5,000,000	4,100,000
October	4	4,300,000	5,320,000

These results are shown in graphic form in diagram 7.

It is to be noted that the average numbers of microbes in the crude sewage and in the effluent from the 13-foot coke-bed were 5,711,000 and 5,364,000 per c.c. respectively. This means a reduction of only 6 per cent., the reason being that on July 5th and August 2nd the effluent contained a much larger number of micro-organisms than the raw sewage. On all other occasions, with one exception (October 4th), the effluent contained fewer bacteria than the corresponding samples of

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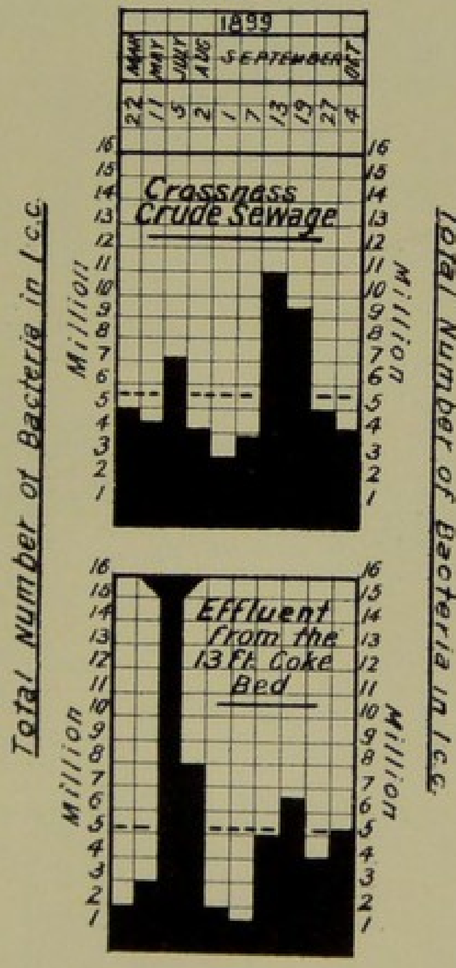
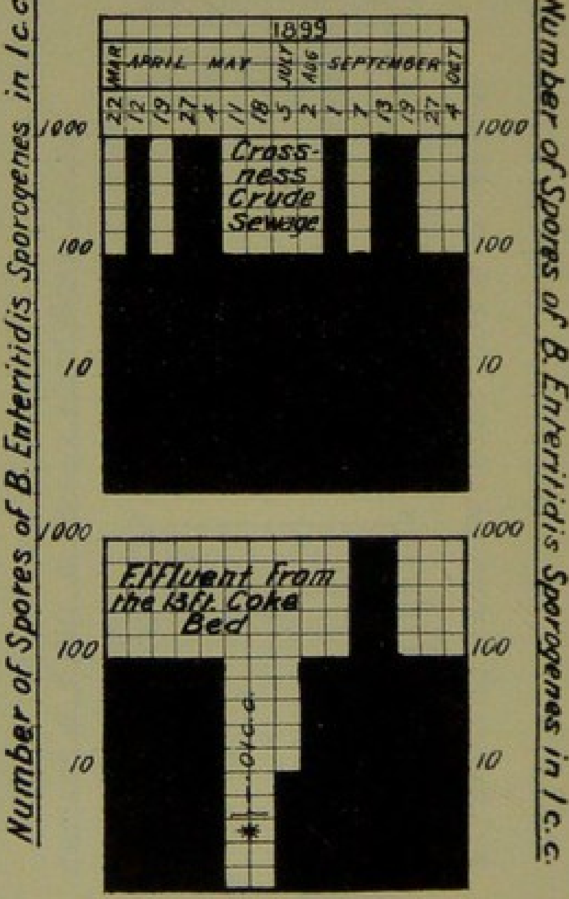
[*] A description of this bed will be found in the Chemical Division of this book.

—DIAGRAM 7—


1899
MAR
MAY
JULY
AUG
SEPTEMBER
OCT
22
11
5
2
1
7
13
19
27
4
Crossness Crude Sewage
Effluent from the 13 Ft. Coke Bed
Total Number of Bacteria in 1 c.c.
Million
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

— DIAGRAM 9. —



* Negative Result

crude sewage. In the raw sewage a rise or fall above or below the mean in the total number of microbes was, on seven occasions, coincident with a similar increase or decrease in the number of germs in the corresponding samples of effluent. In the remaining three cases, this relationship was not observed.

(*b*) *Number of B. coli or closely allied forms.*

The results, as regards *B. coli*, are given in the following table—

TABLE VIII. *Number of B. coli or closely allied forms per c.c.*

Date.		Crossness crude sewage.	Effluent from the 13 ft. coke-bed at Crossness.
	1899.		
March	22	100,000	100,000
May	11	700,000	200,000
July	5	None in 0·00001 c.c.	None in 0·00001 c.c.
August	2	900,000	400,000
September	1	400,000	200,000
"	7	300,000	100,000
"	13	500,000	900,000
"	19	1,900,000	900,000
"	27	500,000	300,000
October	4	600,000	600,000

These results are shown in graphic form in diagram 8.

The table shows that on one occasion the number of *B. coli* was greater in the effluent from the 13-foot coke-bed than in the corresponding sample of raw sewage. In nearly all the other cases, the crude sewage contained the larger number. Nevertheless, although on an average the bacterial treatment of the crude sewage effected a reduction in the number of *B. coli*, the number actually remaining in the effluents was very large—usually more than 100,000 per c.c.

(*c*) *Number of spores of B. enteritidis sporogenes* (*Klein*).

The results, as regards *B. enteritidis sporogenes*, are given in the following table—

TABLE IX. *Showing the number of spores of B. enteritidis sporogenes* (*Klein*).

Date.		Crossness crude sewage.	Effluent from the 13 ft. coke-bed at Crossness.
	1899.		
March	22	+ ·01 c.c.	+ ·01 c.c.
April	12	+ ·01 and ·001 ; – ·0001 c.c.	+ ·01 ; – ·001 c.c.
"	19	+ ·01 ; – ·001 c.c.	+ ·01 ; – ·001 c.c.
"	27	+ ·001 ; – ·0001 c.c.	+ ·01 ; – ·001 c.c.
May	4	+ ·01 and 001 ; – ·0001 c.c.	+ ·01 ; – ·001 c.c.
"	11	+ ·01 ; – ·001 c.c.	– ·01 c.c.
"	18	+ ·01 ; – ·001 c.c.	– ·01 c.c.
July	5	+ ·01 ; – ·001 c.c.	+ ·1 ; – ·01 c.c.
August	2	+ ·1 and ·01 ; – ·001 c.c.	+ ·1 and ·01 ; – ·001 c.c.
September	1	+ ·1, ·01 and ·001 c.c.	+ ·1 and ·01 ; – ·001 c.c.
"	7	+ ·1 and ·01 ; – ·001 c.c.	+ ·1, ·01 and ·001 c.c.
"	13	+ ·1, ·01 and ·001 c.c.	+ ·1, ·01 and ·001 c.c.
"	19	+ ·1, ·01 and ·001 c.c.	+ ·1 and ·01 ; – ·001 c.c.
"	27	+ 1 and ·01 ; – ·001 c.c.	+ ·1 and ·01 ; – ·001 c.c.
October	4	+ 1 and ·01 ; – ·001 c.c.	+ ·1 and ·01 ; – ·001 c.c.

The sign + signifies the presence and the sign – the absence of the spores of *B. enteritidis sporogenes.*

These results are shown in graphic form in diagram 9.

It is to be noted that although the number of spores of *B. enteritidis sporogenes* was frequently less in the effluents from the 13-foot coke-bed than in the corresponding samples of crude sewage, the *actual* number of spores remaining in the effluent after the bacterial treatment of the sewage was very large—usually at least 100, but less than 1,000 in 1 c.c.

(*d*) *Number of bacteria capable of growing in agar at 37° C.*

On May 18th and 25th, 1898, a comparison was made between the number of bacteria in Crossness crude sewage growing (*a*) in gelatine at 20°C. and (*b*) agar at 37°C. The results were as follows—

(*a*) 3,670,000 and 6,400,000 (gelatine at 20°C.) } Bacteria in
(*b*) 1,260,000 and 1,171,000 (agar at 37°C.) } 1 c.c.

A similar experiment (May 18, 1898), carried out with the 4-foot single coke-bed effluent gave 4,100,000 (gelatine at 20°C.) as compared with 1,630,000 (agar at 37°C.) bacteria per c.c.

At the period (May, 1898) when these experiments were made, the pressure of other important work prevented a series of experiments being carried out on the above lines. It, however, was considered important to extend these observations at as early a date as possible.

The following table gives the number of bacteria (agar at 37° C.) in Crossness crude sewage and in the effluent from the 13-foot coke-bed. It also gives, for comparative purposes, the number of bacteria (gelatine at 20° C.) in the corresponding samples.

TABLE X. *Showing the number of bacteria (agar at 37° C. and gelatine at 20° C.) in seven samples of Crossness crude sewage, and seven samples of the effluent from the 13-foot coke-bed.*

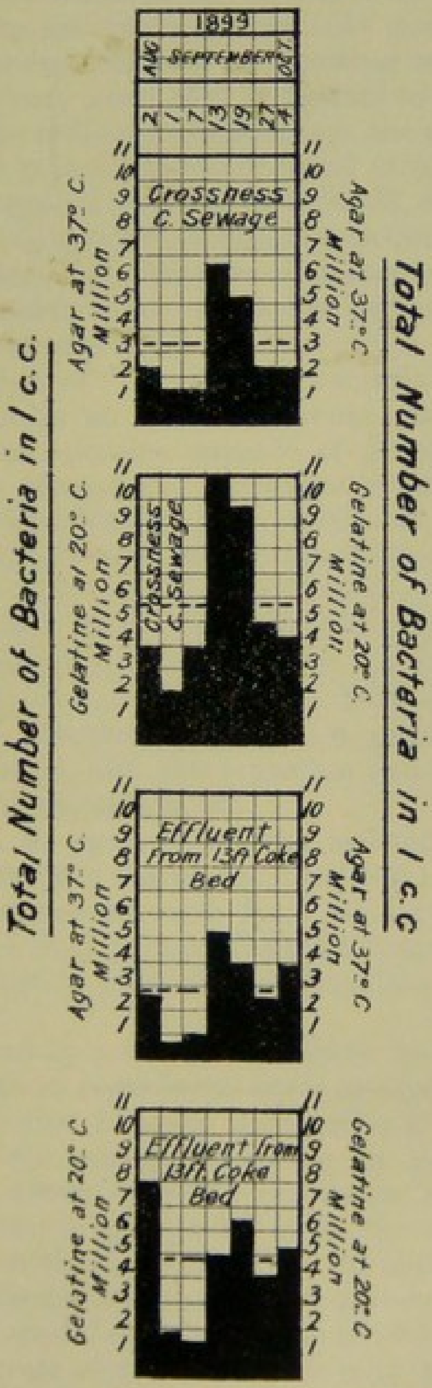
Date.	Number of bacteria in 1 c.c.			
	Crossness crude sewage.		Effluent from the 13-foot coke-bed.	
	Agar at 37° C.	Gelatine at 20° C.	Agar at 37° C.	Gelatine at 20° C.
1899.				
August 2 ...	2,660,000	4,110,000	2,540,000	8,000,000
September 1 ...	1,660,000	2,240,000	670 000	1,940,000
" 7 ...	1,530,000	3,910,000	930,000	1,190,000
" 13 ...	6,830,000	11,170,000	5,210,000	5,040,000
" 19 ...	5,270,000	9,580,000	4,020,000	6,750,000
" 27 ...	2,600,000	5,000,000	2,400,000	4,100,000
October 4 ...	2,510,000	4,300,000	3,850,000	5,320,000

These results are shown in graphic form in diagram 10.

The table shows that the average number of bacteria (agar at 37° C.) in the crude sewage and in the effluent was 3,294,444 and 2,802,857 respectively per c.c., showing a reduction of about 14 per cent. Further, that the average number of bacteria (gelatine at 20° C.) in the crude sewage and in the effluents was 5,758,571 and 4,662,857 respectively per c.c., *i.e.*, a reduction of about 19 per cent.

Comparing the figures 3,294,444 (agar at 37° C.) and 5,758,571 (gelatine at 20° C.), it is to be noted that the difference is 42 per cent.; hence more than one-half of the number of bacteria capable of growing in gelatine at 20° C. can likewise grow in agar at 37° C. When a similar comparison is made as regards the effluents from the 13-foot coke-bed, the difference is 46 per cent.

—DIAGRAM 10.—


1899
AUG
SEPTEMBER
OCT
2
1
7
13
19
27
4
Crossness C. Sewage
Crossness C. Sewage
Effluent from 13ft Coke Bed
Effluent from 13ft. Coke Bed
Agar at 37° C. Million
Gelatine at 20° C. Million
Agar at 37° C. Million
Gelatine at 20° C. Million
Total Number of Bacteria in 1 c.c.
Total Number of Bacteria in 1 c.c
1
2
3
4
5
6
7
8
9
10
11

It is evident from these results that the bacterial treatment of the sewage in the coke-beds did not effect any marked reduction in the number of organisms growing at *blood-heat;* indeed, the reduction was less as regards these germs than as regards the bacteria growing in gelatine at 20° C.

Although gelatine is doubtless a more favourable medium than agar for the growth of bacteria of all sorts, it is not the difference of nutrient medium, but of temperature which chiefly accounts for the difference in the numbers under the two sets of conditions. As a matter of fact, the number of bacteria in sewage capable of growing at 37° C. is both actually very great and is very great also in relation to the total number of microbes growing at the ordinary temperature, the reason apparently being that so many of the micro-organisms found in sewage are derived from the intestinal discharges of animals, *e.g.*, *B. coli*, which microbe has been shown to be present in numbers usually exceeding 100,000 per cc.

In pure waters, the number of "*blood-heat*" bacteria is usually small, and the ratio of these bacteria to the number of germs growing at the ordinary temperature is likewise small.

Although a large number of "*blood-heat*" bacteria is considered an unfavourable characteristic in an effluent, it must not be supposed that all the different species of microbes capable of growing at 37° C. are harmful. Many found in sewage and elsewhere in nature are, so far as we know, quite unobjectionable, *e.g.*, *B. subtilis*, *B. mesentericus*, *B. mycoides*, etc. On the other hand, others are decidedly objectionable and may be pathogenic under certain conditions, *e.g.*, *B. coli* and *B. proteus* (certain forms), and some are definitely pathogenic, *e.g.*, *B. pyocyaneus*. On one occasion *B. pyocyaneus* was isolated from a sample of Crossness crude sewage. 1 c.c. of a 24 hours' broth culture (at 37° C.) of this microbe injected subcutaneously into a guinea-pig killed the animal in less than 24 hours, and the organism was recovered in pure culture from the heart's blood, spleen, etc.

On November 1, 1899, *B. pyocyaneus** was isolated from $\frac{1}{1000}$ c.c. of the effluent from the secondary coarse bed (series A) at Barking.† A guinea-pig injected subcutaneously with 1 c.c. of a twenty-four hours' broth culture (at 37° C.) died in less than 24 hours, and the same micro-organism was isolated in pure culture from the heart's blood of the guinea-pig.

So far as may be judged by a rise or fall above or below the mean, the figures show that, both as regards the crude sewage and the effluents, there was a decided parallelism between the number of bacteria growing in agar at 37° C. and the number growing in gelatine at 20° C. Similarly, a rise or fall above or below the mean in the number of bacteria capable of growing in agar at 37° C. in the crude sewage was nearly always coincident with a rise or fall in the number of microbes in the corresponding effluents from the 13-foot coke-bed.

In conclusion, and by way of addition to the chief results which were obtained during the progress of the enquiry, it is to be noted that the number of bacteria capable of growing in agar at blood-heat in Crossness crude sewage is usually over three millions per c.c., and more than

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* See Fig. 12.

† In certain epidemics of diarrhœa occurring in human beings, *B. pyocyaneus* has been isolated from the stools of the patients and has been regarded in these cases as the causal agent.

one-half of the number of microbes growing in gelatine at 20° C. It must be admitted that the 13-foot coke-bed at Crossness yielded very unsatisfactory results from the bacteriological point of view.

Thus, although the effluents usually contained fewer bacteria and less of *B. coli* and spores of *B. enteritides sporogenes* than the crude sewage, the reduction was not well marked, and, indeed, was immaterial from the epidemiological point of view, considering the *actual* number still remaining. For, as has been already pointed out, the effluents usually contained more than one million microbes, more than 100,000 *B. coli*, and at least 100 but less than 1,000 spores of *B. enteritidis sporogenes* per c.c.

IV. THE EXPERIMENTS ON THE BACTERIAL TREATMENT OF SEWAGE AT THE NORTHERN OUTFALL WORKS (BARKING).

1. *The coke-beds and the ragstone-beds.** (Series I.)

The beds were four in number, namely, two of coke, (coarse and fine), and two of ragstone (coarse and fine).

Some of the experiments with the effluents, as regards their effect on animals, are recorded elsewhere (experiments on animals), as also are the notes on the deposit accumulating upon the coke in the coke-beds at Barking.

The effluents were chiefly examined for the presence of *B. enteritidis sporogenes*, and the results obtained in this direction are given in the form of a table. But on March 16th, 1899, a sample of Barking crude sewage, and the effluents from the fine ragstone-bed and the fine coke-bed were further examined for the total number of bacteria and number of *B. coli*. The results were as follows :—

Barking crude sewage	10,000,000 bacteria in 1 c.c.	600,000 *B. coli* in 1 c.c.
Effluent from fine ragstone-bed	4,000,000 bacteria in 1 c.c.	500,000 *B. coli* in 1 c.c.
Effluent from fine coke-bed	1,800,000 bacteria in 1 c.c.	300,000 *B. coli* in 1 c.c.

The following is a table of the results as regards *B. enteritidis sporogenes* (Klein)—

TABLE XI. *Number of spores of B. enteritidis sporogenes (Klein).*

Date.	Barking crude sewage.	Effluents from the coke and ragstone-beds at Barking.			
		Coke.		Ragstone.	
		Coarse.	Fine.	Coarse.	Fine.
1899	c.c. c.c.	c.c. c.c.	c.c. c.c.	c.c. c.c.	c.c. c.c.
Jan. 26	+ ·01 and ·001	...	+ ·01 and ·001	...	+ ·01 ; − ·001
Feb. 2	+ ·01 and ·001	+ ·01 ; − ·001	+ ·01 ; − ·001	+ ·01 and ·001	+ ·01 and ·001
" 9	+ ·01 and ·001	+ ·01 ; − ·001	+ ·01 ; − ·001	+ ·01 and ·001	+ ·01 ; − ·001
" 15	+ ·01 and ·001	+ ·01 and ·001	+ ·01 and ·001	+ ·01 and ·001	+ ·01 and ·001
Mar. 8	+ ·01	+ ·01 ...	+ ·01 ...	+ ·01 ...	+ ·01 ...
" 16	+ ·01	...	− ·01 ...	...	+ ·01 ...
Apr. 13	+ ·01	− ·01 ...	− ·01 ...	+ ·01 ...	− ·01 ...

The sign + signifies the presence and the sign − the absence of the spores of *B. enteritidis sporogenes.*

These results are shown in graphic form in diagram 11.

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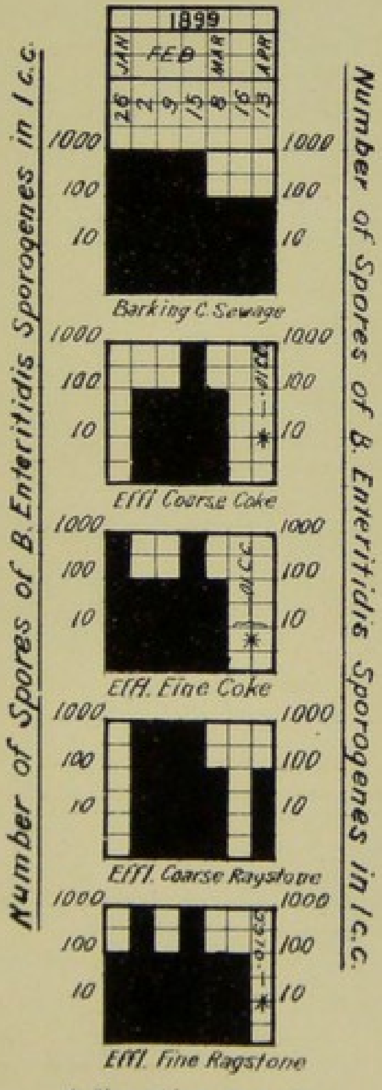
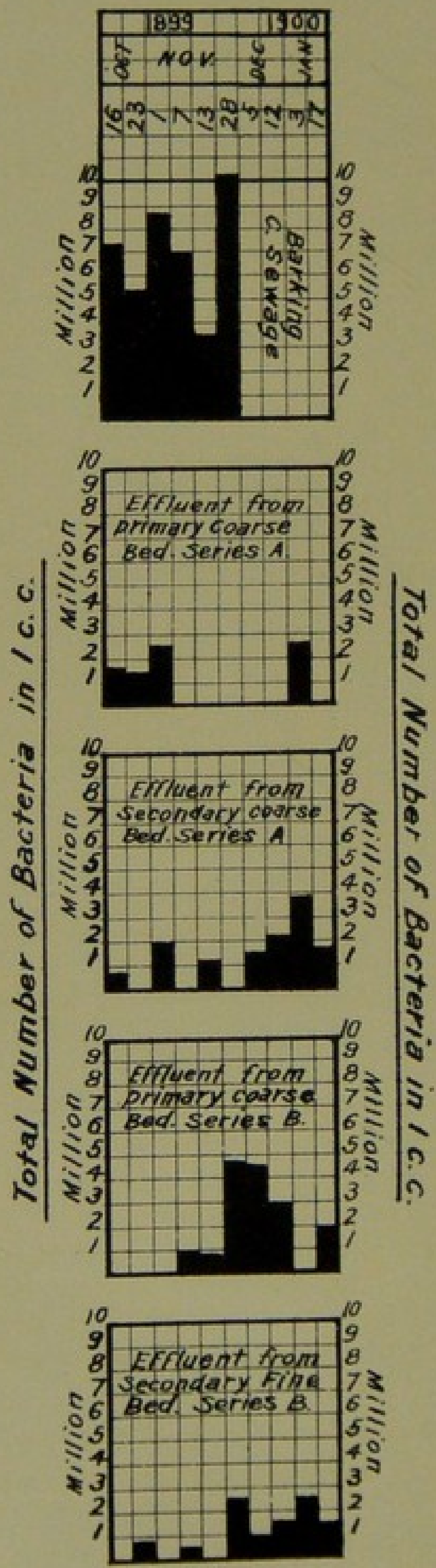
* A description of these beds will be found in the Chemical Division of the book.

DIAGRAM II.



✱ Negative Result.

DIAGRAM 12.


1899
1900
OCT.
NOV.
DEC.
JAN.
16
23
1
7
13
28
5
12
3
17
Million
10 9 8 7 6 5 4 3 2 1
Barking C. Sewage
Effluent from primary Coarse Bed. Series A.
Effluent from Secondary coarse Bed. Series A.
Effluent from primary coarse Bed. Series B.
Effluent from Secondary Fine Bed. Series B.
Total Number of Bacteria in 1 c.c.

It might have been anticipated that the fine beds would have produced a significant alteration in the number of spores of this pathogenic anaërobe. This, however, was not the case, and although the number in the effluents was usually less than in the corresponding samples of crude sewage, the reduction was not very well marked, and was not, moreover, a constant feature. There did not seem to be, as regards the number of spores of *B. enteritidis*, any striking difference between the coarse and fine beds, or between the two kinds of material (coke and ragstone).

2. *The double coke-beds.** (Series II.)

These coke-beds were known as—
The primary coarse coke-bed (A).
The secondary ,, ,, (A1).
The primary ,, ,, (B).
The secondary fine ,, (B1).

From October 10th, 1899, to January 17th, 1900, the new beds at Barking were under bacteriological observation.

The results obtained will be dealt with briefly as follows—

(*a*) *Total number of bacteria (gelatine at 20° C.)*

The number of micro-organisms in the crude sewage and effluents is given in the following table—

TABLE XII. *Total number of bacteria in 1 c.c.*

Date.	Barking crude sewage.	Effluent from primary coarse bed; series A.	Effluent from secondary coarse bed; series A.	Effluent from primary coarse bed; series B.	Effluent from secondary fine bed; series B.
1899.					
October 16	7,200,000	1,700,000	800,000		
,, 23	5,440,000	1,500,000	...	...	900,000
November 1	8,800,000	2,640,000	2,000,000		
,, 7	7,060,000	...	...	1,070,000	400,000
,, 13	3,680,000	...	1,180,000	910,000	
,, 28	10,400,000	...	...	4,800,000	2,640,000
December 5	...	...	1,480,000	4,520,000	1,000,000
,, 12	...	...	2,240,000	2,900,000	1,420,000
1900.					
January 3	...	2,880,000	3,970,000	...	2,530,000
,, 17	...	...	1,760,000	2,000,000	1,220,000

These results are shown in graphic form in diagram 12.

It is to be noted that on four occasions one or other of the effluents contained less than one million microbes per c.c., and on fifteen occasions not more than two millions. On November 7th the effluent from the secondary fine bed (series B.) contained only 400,000 microbes per c.c., as compared with 7,060,000 in the crude sewage, a reduction of over 94 per cent.

(*b*) *Number of B. coli or closely allied forms.*

The number of *B. coli* in the crude sewage and effluents is shown in the following table—

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* A description of these beds will be found in the Chemical Division of the book.

TABLE XIII. *Number of B. coli, or closely allied forms, in 1 c.c.*

Date.		Barking crude sewage.	Effluent from primary coarse bed; series A.	Effluent from secondary coarse bed; series A.	Effluent from primary coarse bed; series B.	Effluent from secondary fine bed; series B.
1899.						
October 16	...	800,000	None in ·00001 c.c.	100,000		
„ 23	...	200,000	800,000	...	...	None in ·00001 c.c.
November 1	...	1,600,000	500,000	500,000		
„ 7	...	1,200,000	...	...	200,000	None in ·00001 c.c.
„ 13	...	600,000	...	300,000	None in ·00001 c.c.	
„ 28	...	200,000	...	...	200,000	100,000
December 5	...	...	...	100 000	100,000	None in ·00001 c.c.
„ 12	...	...	...	100 000	400,000	400,500
1900.						
January 3	...	...	200,000	160,000	...	200,000
„ 17	...	...	...	None in ·00001 c.c.	100,000	None in ·00001 c.c.

These results are shown in graphic form in diagram 13.

It will be noted that on seven occasions one or other of the effluents contained no *B. coli* in ·00001 c.c. Usually, however, the effluents contained at least 100,000 *B. coli* per c.c.

Although there was evidence of a reduction in the number of *B. coli* in the effluents as compared with the crude sewage, the large number still remaining in the effluents must be regarded as very unsatisfactory from the epidemiological point of view.

(c) *Number of spores of B. enteritidis sporogenes.*

The number of spores of *B. enteritidis sporogenes* is shown in the following table—

TABLE XIV. *Number of spores of B. enteritidis sporogenes (Klein).*

Date.	Barking crude sewage.	Effluent from primary coarse bed; series A.	Effluent from secondary coarse bed; series A.	Effluent from primary coarse bed; series B.	Effluent from secondary fine bed; series B.
1899	c.c.	c.c.	c.c.	c.c.	c.c.
Oct. 16	+ ·1, ·01 and ·001	+ ·1 and ·01; – ·001	+ ·1, ·01 and ·001	...	+ ·1 and ·01; – ·001
„ 23	+ ·1, ·01 and ·001	+ ·1, ·01 and ·001	...	...	+ ·1 and ·01; – ·001
Nov. 1	+ ·1, ·01 and ·001	+ ·1, ·01 and ·001	+ ·1, ·01; – ·001	...	...
„ 7	+ ·1, ·01 and ·001	...	...	+ ·01 and ·01; – ·001	+ ·1 and ·01; – ·001
„ 13	+ ·01; – ·001	...	+ ·01; – ·001	+ ·01; – ·001	...
„ 28	+ ·1 and ·01	...	...	+ ·1 and ·01	+ ·1 and ·01
Dec. 5	...	...	+ ·C1; – ·001	+ ·01 and ·001	+ ·01; – ·001
„ 12	...	...	+ ·01 and ·001	+ ·01 and ·001	+ ·01; – ·001
1900					
Jan. 3	...	+ ·01; – ·001	+ ·01 and ·001	...	+ ·01; – ·001
„ 17	...	...	+ ·01	+ ·01	+ ·01

The sign + signifies the presence and the sign — the absence of spores of *B. enteritidis sporogenes.*

These results are shown in graphic form in diagram 14.

DIAGRAM 13.

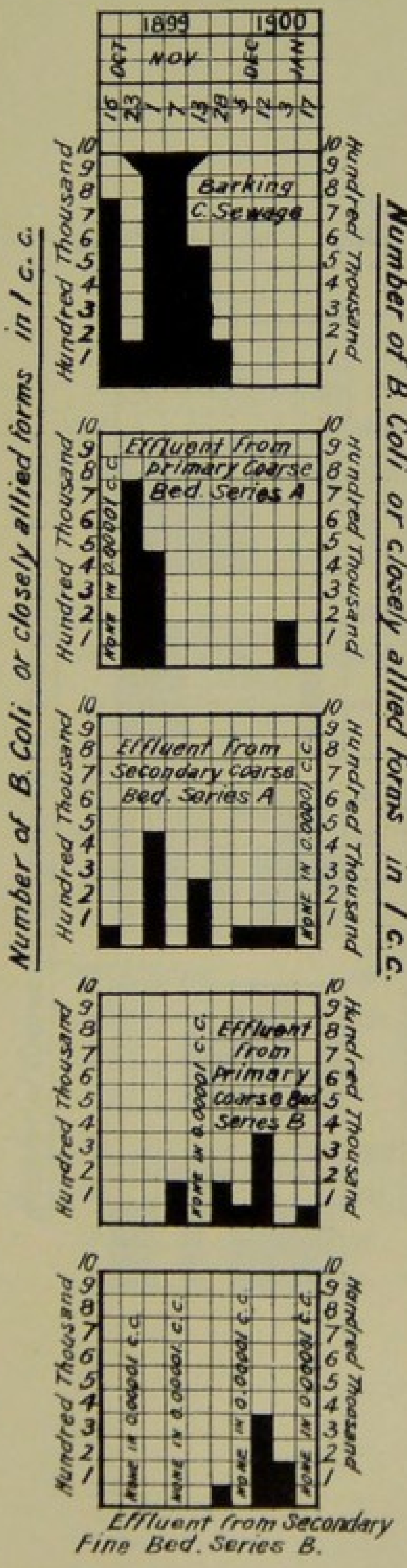
1899
1900
OCT
NOV
DEC
JAN
16
23
1
7
13
28
5
12
3
17
Barking C. Sewage
Effluent from primary Coarse Bed. Series A
Effluent from Secondary Coarse Bed. Series A
Effluent from Primary Coarse Bed Series B
Effluent from Secondary Fine Bed. Series B.
NONE IN 0.00001 C.C.
Hundred Thousand
1 2 3 4 5 6 7 8 9 10
Number of B. Coli or closely allied forms in 1 c.c.

DIAGRAM 14.

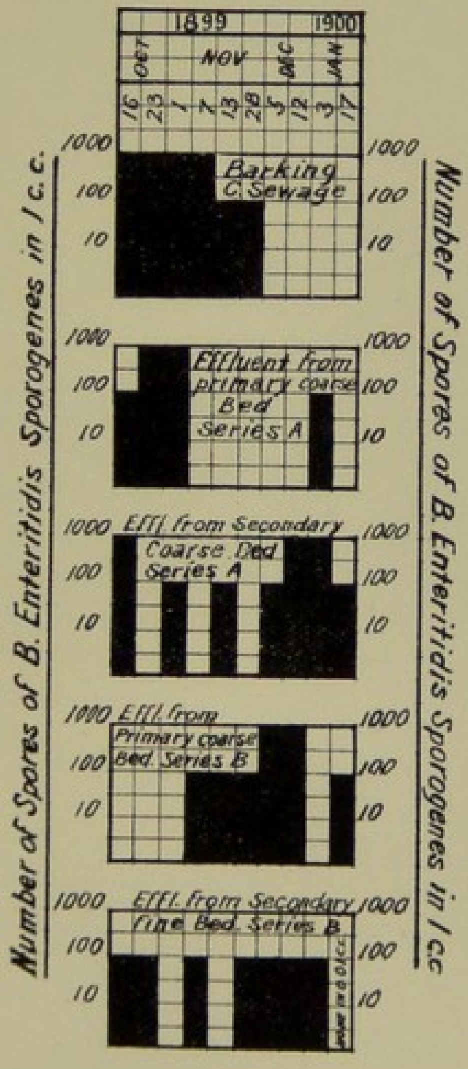
1899
1900
OCT
NOV
DEC
JAN
16
23
1
7
13
28
5
12
3
17
1000
100
10
Barking C. Sewage
Effluent from primary coarse Bed Series A
Effl. from Secondary Coarse Bed Series A
Effl. from Primary coarse Bed. Series B
Effl. from Secondary Fine Bed. Series B
Number of Spores of B. Enteritidis Sporogenes in 1 c.c.
Number of Spores of B. Enteritidis Sporogenes in 1 cc

FIG. 12.—*B. pyocyaneus*. Isolated from $\frac{1}{1000}$ c.c. of the effluent from the secondary coarse bed (A 1) at the Northern Outfall Works. × 1,000.

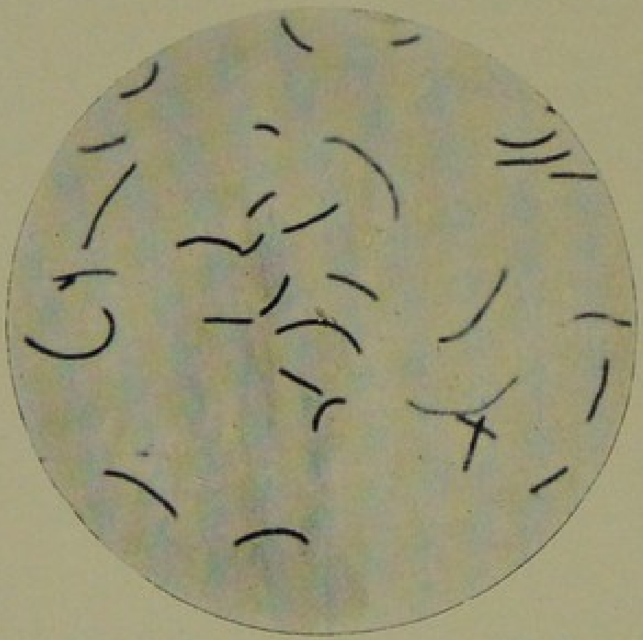

FIG. 13.—*B. thermophilus* (or allied form). Microscopic preparation from a broth culture. Isolated from Barking crude sewage. In illustration of one of the thermophilic bacteria—these microbes are abundant in the raw sewage and in the effluent from the coke-beds, and grow luxuriantly at a temperature of 60—70° C. × 1,000.

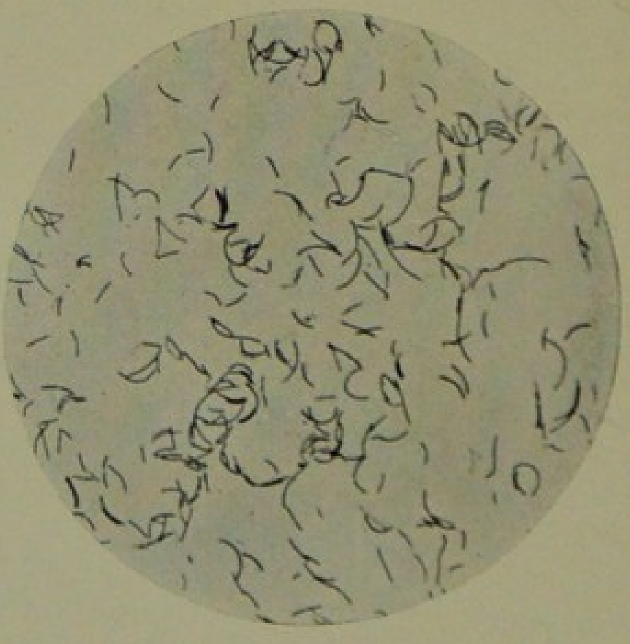

FIG. 14.—Same as fig. 13. × 500.

Although, as a rule, the effluents contained fewer spores of *B. enteritidis sporogenes* than the crude sewage, the reduction was not very well marked, and, moreover, was not a constant factor.

It cannot, therefore, be said that the biological processes at work in the coke-beds affected any significant alteration in the number of spores of this pathogenic anaërobe.

(*d*) *Concluding remarks.*

On November 1st, 1899, *B. pyocyaneus*[*] was isolated from $\frac{1}{1000}$ c.c. of the effluent from the second coarse bed (series A). The organism was very virulent, 1 c.c. of a 24 hours broth culture killing a guinea-pig in less than 24 hours. The same micro-organism was isolated in pure culture from the heart's blood, etc., of the animal.

On December 6th, 1899, three strains of "*sewage proteus*" were isolated from $\frac{1}{10000}$ c.c. of the effluent from the primary coarse bed (Series B). They all liquefied gelatine very rapidly, they were actively motile, and produced "gas" in 24 hours in gelatine "shake" cultures. One of the strains killed a guinea-pig in 24 hours (1 c.c. of broth culture); another was not so virulent, although ulceration occurred at the site of the inoculation, the animal recovered; the third produced in a guinea-pig only a slight local reaction. This last non-virulent strain of "*sewage proteus*" was used to inoculate the 13-foot coke-bed at Crossness. I had previously found that this microbe was habitually present in sewage in enormous number. Thus, on fourteen different occasions "*sewage proteus*" was isolated from $\frac{1}{100000}$ c.c. of Crossness crude sewage. But the different races of "*sewage proteus*," although they all produced rapid liquefaction of gelatine and "gas" in gelatine "shake" cultures, varied very much in some other respects, e.g., pathogenicity.

On November 1st, 1899, streptococci xix., xx., and xxi.,[‡] were isolated from $\frac{1}{1000}$ c.c. respectively of the effluent from the primary coarse bed (series A), and of the crude sewage.

During a considerable period of the enquiry, attention was directed to the study of the *thermophilic* bacteria. Dr. Gordon suggested to me that a comparison of their numbers in the crude sewage and effluents might be of value.

These micro-organisms (*B. thermophilus* and its allies) have been shown to be present in the alimentary canal of human beings and other mammals, in sewage, in sewage-contaminated waters, and in soil, but not in pure waters.

It was found that *thermophilic* bacteria[†] (capable of growing luxuriantly in broth culture at a temperature of 60—70°C.) were present in London crude sewage in abundance. They were also present, although usually in smaller proportion, in the effluents from the coke-beds.

It has been suggested that the presence in or absence of these bacteria from a water supply might be employed as a test of potability. But, in

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[*] *See* Fig. 12. This micro-organism (*B. pyocyaneus*) must not be confused with the ordinary liquefying fluorescent bacillus (*B. fluorescens liquefaciens*) of sewage, soil and water. *B. fluorescens liquefaciens* either grows not at all or very feebly, at *blood-heat*, and is not virulent; and it differs in a number of other important respects from *B. pyocyaneus*.

[†] Figs. 13 and 14 show the morphological appearance of *B. thermophilus* or an allied form. The micro-organism represented in the micro-photographs was isolated from London crude sewage; it grew luxuriantly at a temperate of 60—70° C.

[‡] *See* Figs. 16, 18, 19, and pp. 112 and 113.

my experience, *thermophilic* bacteria are present in numbers in soils *not recently* polluted and are often absent (relatively speaking) from waters known to be *freshly* contaminated with objectionable matters, waters, moreover, which, by more reliable and delicate bacteriological tests, can readily be shown to be dangerously polluted.

Certainly the presence of *thermophilic* bacteria in a water would lead one to suspect *gross* contamination, but their absence could hardly be regarded as testifying to purity or "safety."

Nevertheless, the test, as a rough indication of the probable biological quality of a liquid and as a means of comparing different liquids, e.g., crude sewage and bacterial effluents, is not devoid of value.

V. (A) EXPERIMENTS WITH THE EFFLUENTS FROM THE CHEMICAL PRECIPITATION WORKS AT THE NORTHERN OUTFALL WORKS (BARKING) AND AT THE SOUTHERN OUTFALL WORKS (CROSSNESS) AND WITH THE WATER OF THE RIVER THAMES.

(B) RESULTS OF THE PRELIMINARY BACTERIOLOGICAL EXAMINATION OF BARKING AND OF CROSSNESS CRUDE SEWAGE.

(A). *Experiments with the effluents from the chemical precipitation works at the Northern Outfall Works (Barking) and at the Southern Outfall Works (Crossness) and with the water of the River Thames.*

The following table shows the results of the bacteriological examination of samples obtained from the above sources.

TABLE A. *Showing the results of the bacteriological examination of the effluents from the Northern (Barking) and from the Southern (Crossness) Outfall Works and of the water of the River Thames.*

Experiment.	Description of samples. 1	Total number of bacteria in 1 c.c. 2	Number of spores of aërobic bacteria in 1 c.c. 3	Number of bacteria causing liquefaction of the gelatine in 1 c.c. 4	Remarks. 5
1	Effluent from chemical precipitation works at Barking, Nov. 2, 1898	5,200,000	100	1,100,000	Spores of *B. enteritidis* present in 0·1, and 0·01 c.c.; absent in 0·001 c.c. Five colonies indistinguishable from *B. coli* in phenol gelatine plate containing 0·00001 c.c. effluent (500,000 per c.c. of effluent). The plate, containing 0·1 c.c. effluent (col. 3), contained some rapidly liquefying species, so that the numbers given are only approximate.
2	Effluent from chemical precipitation works at Crossness, Nov. 2, 1898	9,800,000	300	1,000,000	Spores of *B. enteritidis* present in 0·1 and 0·01 c.c.; absent in 0·001 c.c. Twenty-six colonies indistinguishable from *B. coli* in phenol gelatine plate containing 0·00001 c.c. effluent (2,600,000 per c.c. of effluent).

TABLE A.—*continued.*

Experiment.	Description of samples. 1	Total number of bacteria in 1 c.c. 2	Number of spores of aërobic bacteria in 1 c.c. 3	Number of bacteria causing liquefaction of the gelatine in 1 c.c. 4	Remarks. 5
3	Thames water collected off Greenhithe at about 2 p.m., October 12th, 1898, on a tide which had ebbed from Crossness for about two hours. The sample was, therefore, judged to be free from admixture with recent sewage effluent (dry weather)	10,000	63	No record...	At least 1 but less than 10 spores of *B. enteritidis* per c.c. of water. No colonies of *B. coli* observed in phenol gelatine plate containing as small an amount of water as 0·001 c.c. That *B. coli* was present, however, in the water need not be doubted. There were present in the cultures numerous colonies of *B. fluorescens liquefaciens* and *non-liquefaciens*, *B. mesentericus*, *B. mycoides*, and proteus-like forms were also found.
4	Thames water, taken at low tide at Barking, and outside the influence of sewage discharge, as far as this was possible, Nov. 3, 1898 (dry weather)	34,400	89	(A surface gelatine plate culture containing 0·1 c.c. of the water was completely liquefied by the 2nd day.)	At least 1 but less than 10 spores of *B. enteritidis* per c.c. of water. A guinea-pig inoculated with 1 c.c. of the milk culture (containing 1·0 c.c. of water) which showed the typical enteritidis change, died, and presented upon post-mortem examination the usual appearances; sanguineous exudation full of bacilli, etc. Eighty-four colonies, indistinguishable from *B. coli*, in phenol gelatine plate containing 0·1 c.c. of the water. There were present in the cultures, colonies of *B. mesentericus*, *proteus zenkeri*, *B. fluorescens liquefaciens*, etc.
5	Thames water, sample taken in mid-stream between Sunbury and Hampton, just above intake of the Southwark and Vauxhall Water Co. 10.40 a.m. Nov. 15, 1898 (dry weather)	5,100	56	No record...	Spores of *B. enteritidis sporogenes* absent in 1·0, 5·0, 10·0, 100·0 c.c.; but present in 300 c.c. A guinea-pig inoculated with 1 c.c. from latter culture died in less than 24 hours, and, on post-mortem examination, presented the usual appearances—swollen belly, sanguineous exudation swarming with bacilli, etc. Forty gas-forming *B. coli* per c.c. of water. Colonies of *B. fluorescens liquefaciens* and *non-liquefaciens* and proteus-forms present in the cultures. Also a large number of colonies of *B. aquatilis sulcatus* type. The presence of *B. enteritidis* in 300 c.c. of the water was demonstrated by a special filtration process.

TABLE A.—*continued.*

Experiment.	Description of samples. 1	Total number of bacteria in 1 c.c. 2	Number of spores of aërobic bacteria in 1 c.c. 3	Number of bacteria causing liquefaction of the gelatine in 1 c.c. 4	Remarks. 5
6	Thames water, sample taken in mid-stream at Twickenham, opposite Ham house, *i.e.*, about half-way between Glover's island and Eel Pie island. 11 a.m., Nov. 22, 1898 (very wet weather)	3,000	18	No record ...	Spores of *B. enteritidis sporogenes* present in 10 c.c., 5 c.c., 1 c.c., 0·1 c.c. of the water; absent in 0·01 c.c. In a phenol gelatine plate culture containing 0·01 c.c. of the water, one colony indistinguishable from *B. coli*. Subcultures from this colony gave the following results: Gas in 24 hours in gelatine shake culture incubated at 20° C. Diffuse cloudiness in broth in 24 hours at 37° C. No indol in five days. Slight acidity but no clotting in litmus milk in 48 hours at 37° C. In 96 hours, however, the milk showed a solid clot. In an ordinary gelatine plate culture containing 0·01 c.c. of the water, one colony indistinguishable from *B. coli*. Subcultures from this colony gave the following results: Gas in 24 hours at 20° C. in gelatine shake culture; diffuse cloudiness in broth in 24 hours at 37° C.; acidity but no clotting in litmus milk culture in 24 hours at 37° C. No indol in broth culture, fourth day, at 37° C.

In the above table the results are shown of the bacteriological examination of the effluents from the Northern and from the Southern Outfall Works and of the water of the River Thames. As regards the effluents from the precipitation tanks, at both outfall works, it may be said that they were no better than average samples of crude sewage. As regards Thames water, samples were taken at Greenhithe and Barking in such a way as to avoid, as far as this was possible, the influence of sewage discharge. These samples in their bacterial composition resembled dilute crude sewage. Samples were also collected high up the river, namely (1) between Sunbury and Hampton, just above the intake of the Southwark and Vauxhall Water Company (dry weather) and (2) at Twickenham (very wet weather). The former contained 40 gas-forming *B. coli* in 1 c.c. *B. enteritidis sporogenes* was present in 300 c.c. (1 c.c. of the culture killed a guinea-pig in less than 24 hours), but not in 100 c.c. The latter contained 100 gas-forming *B coli* and at least 10, but less than 100 spores of *B enteritidis* per c.c.

Thus it will be seen that Thames water at Barking and Greenhithe was no better than very dilute crude sewage, and even as high up as near Hampton and Twickenham showed distinct evidence of pollution of the most objectionable kind.

(B). *Results of the preliminary bacteriological examination of the crude sewage at the Northern Outfall Works (Barking) and at the Southern Outfall Works (Crossness).*

At the commencement of the enquiry, the bacteria-beds at Barking and Crossness were still in course of construction. There was an advantage in this unavoidable delay, since it enabled me to devote a considerable amount of attention to the bacteriological examination of the Barking and Crossness crude sewage before studying the effluents from the bacteria-beds.

The following table gives a brief summary of the chief results obtained :—

TABLE B. *Showing the results of the bacteriological examination of London crude sewage.*

Nine samples were obtained from the Northern Outfall Works (Barking) and six samples from the Southern Outfall Works (Crossness).

Experiment.	Description of the samples of sewage. 1	Total number of bacteria in 1 c.c. of crude sewage. 2	Number of spores of aërobic bacteria in 1 c.c. of crude sewage. 3	Number of bacteria causing liquefaction of the gelatine in 1 c.c. of crude sewage. 4	Remarks. 5
1	Crossness crude sewage. Feb. 23, 1898	3,810,000	none in 0·0001 c.c.	The liquefying colonies were very numerous	Spores of *B. enteritidis sporogenes* (Klein) present in 0·1 c.c. crude sewage. A guinea pig inoculated with 1 c.c. of the whey from this milk-culture died in less than 24 hours; the post-mortem appearances were characteristic of enteritidis. *B. coli* present in 0·000025 c.c. crude sewage. Very many of the colonies were proteus-like in character.
2	Barking crude sewage. Feb. 23, 1898*	1,660,000	30,000	The liquefying colonies were very numerous	Spores of *B. enteritidis sporogenes* present in 0·1 c.c. crude sewage. Inoculation into a guinea pig produced results similar to those stated in experiment 1, column 5. *B. enteritidis* not present in anaërobic milk-cultures containing 0·0001, 0·0005, and 0·001 c.c. crude sewage. *B. coli* present in 0·000025 c.c. crude sewage. Proteus-like forms numerous.
3	Crossness crude sewage. Mar. 2, 1898	3,190,000	2,800	The liquefying colonies were very numerous	Spores of *B. enteritidis sporogenes* present in 0·01 c.c. sewage. Numerous colonies of *B. coli* in 0·01 c.c. sewage. *B. fluorescens liquefaciens*, 10,000 in 1 c.c. of sewage. Proteus-like forms very numerous.

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* In carrying out some of these experiments I had the advantage of Mr. E. Brooke Pike's valuable assistance.

TABLE B.—*continued.*

Experiment.	Description of the samples of sewage.	Total number of bacteria in 1 c.c. of crude sewage.	Number of spores of aërobic bacteria in 1 c.c. of crude sewage.	Number of bacteria causing liquefaction of the gelatine in 1 cc. of crude sewage.	Remarks.
	1	2	3	4	5
4	Crossness crude sewage. Mar. 2, 1898. (The sample was collected on the same day as the above but at a different hour)	5,290,000	500	The liquefying colonies were very numerous	Spores of *B. enteritidis sporogenes* present in 0·01 c.c. sewage. Numerous colonies of *B. coli* in 0·01 c.c. sewage. Many of the colonies were proteus-like in character.
5	Barking crude sewage. April 4, 1898	1,760,000	80	The liquefying colonies were very numerous	The colonies were counted on the third and fourth days.
6	Barking crude sewage. April 15, 1898	513,333	263	220,000	The colonies were counted on the third and fourth days.
7	Barking crude sewage. April 20, 1898	6,920,000	290	The liquefying colonies were very numerous	Spores of *B. enteritidis sporogenes* present in 1·0 and 0·1 c.c. sewage. *B. enteritidis* not present in anaërobic milk-cultures containing 0·0001 and 0·001 c.c. sewage. 40 colonies indistinguishable from *B. coli* in 0·0001 c.c. sewage. Most of the colonies rapidly liquefying proteus-like forms.
8	Crossness crude sewage. Apl. 20, 1898	2,410,000	180	The liquefying colonies were very numerous	Spores of *B. enteritidis sporogenes* present in 1·0 c.c. sewage. *Enteritidis* not present in anaërobic milk-culture containing 0·0001, 0·001, ·01, and 0·1 c.c. sewage. The milk, however, had been prepared some time previously, and this, as pointed out by Dr. Klein, appears to inhibit the growth of *enteritidis*. Most of the colonies rapidly liquefying proteus-like forms. Thirteen colonies typical of *B. coli* counted in a phenol gelatine plate cultivation containing 0·0001 c.c. of crude sewage.
9	Barking crude sewage. April 22, 1898	4,300,000	400	333,000	The colonies were counted on the third day.
10	Barking crude sewage. April 27, 1898	3,850,000	470	The liquefying colonies were very numerous	Spores of *B. enteritidis* present in 0·5 c.c. and 0·1 c.c. sewage. *Enteritidis* not present in anaërobic milk-culture containing 0·01 c.c sewage. 10 spores of *B. mycoides*, and 10 of *B. subtilis* in 1 c.c. sewage. *B. fluorescens liquefaciens*, 10,000 in 1 c.c. sewage.

Table B.—*continued.*

Experiment.	Description of the samples of sewage. 1	Total number of bacteria in 1 c.c. of crude sewage. 2	Number of spores of aërobic bacteria in 1 c.c. of crude sewage. 3	Number of bacteria causing liquefaction of the gelatine in 1 c.c. of crude sewage. 4	Remarks. 5
10	Barking crude sewage. April 27, 1898 (*continued*)				9 colonies indistinguishable from *B. coli* in surface phenol gelatine plate containing 0·00001 c.c. sewage. Several of these were tested in "gelatine shake" cultures, and showed numerous bubbles the next day. Proteus-like forms were very numerous.
11	Crossness crude sewage. Apl. 27, 1898	3,300,000	400	The liquefying colonies were very numerous	Spores of *B. enteritidis* present in 0·5, 0·1 and 0·01 c.c. sewage. *B. coli communis*, 200,000 in 1 c.c. sewage.
12	Barking crude sewage. April 29, 1898	5,200,000	120	Surface gelatine plates containing 0·00001 and 0·000025 c.c. sewage liquefied by third day	Colonies counted third and fourth day.
13	Barking crude sewage. May 3, 1898	7,260,000	3,020	270,000	Colonies counted third, fourth and sixth days.
14	Barking crude sewage. May 4, 1898	3,630,000	450	900,000	Spores of *B. enteritidis* present in 0·1, 0·01 and 0·001 c.c. sewage. *B. enteritidis* absent in anaërobic milk-culture, containing 0·0001 c.c. *B. coli* 100,000 in 1 c.c. sewage. As regards spores: 10 of *B. megaterium*, 20 of *B. mesentericus* 10 of *B. mycoides*, and 10 of *B. subtilis* in 1 c.c. sewage. *B. fluorescens liquefaciens*, 40,000 in 1 c.c. sewage. Gas-forming proteus, 100,000 in 1 c.c. sewage.
15	Crossness crude sewage. May 4, 1898	3,160,000	380	400,000	Spores of *B. enteritidis* present in 0·1, 0·01 and 0·001 c.c. sewage. *Enteritidis* absent in anaërobic milk-culture containing 0·0001 c.c. sewage. *B. subtilis* and *B. mesentericus*, 20 spores of each in 1 c.c. sewage. *B. coli communis*, 200,000 in 1 c.c. sewage. Gas-forming proteus, 100,000 in 1 c.c. sewage.

VI. STREPTOCOCCI IN THE CRUDE SEWAGE AT THE OUTFALL WORKS (BARKING AND CROSSNESS) AND IN THE EFFLUENTS FROM THE BACTERIAL COKE-BEDS.

Although attention was directed to the study of staphylococci as well as streptococci, the latter class of germs will be considered here. One reason why staphylococci are considered of relatively less importance than streptococci, in connection with the work, is that the former *as a class* are hardy germs, whereas the latter as a class are more delicate. The significance of this remark will be shown presently.

My chief reasons for considering this portion of the sewage inquiry of importance are briefly as follows:—

Speaking of streptococci *as a class* it may be said that—

(1) They are among the most *pathogenic* of all the bacteria which are at present known;

(2) They are delicate germs, and readily lose their vitality and die;

(3) They are present in the *intestinal discharges* of animals. In human fæces there may be more than 1,000 present in one gramme;

(4) They are seemingly absent from relatively large amounts of water and soil,* except in those cases where there has been *recent* contamination with sewage or other substances equally objectionable in character.

It will presently† be shown that both in crude sewage and in effluents from coke-beds streptococci are present in great abundance—usually more than 1,000 in 1 c.c.—and that the bacterial treatment of the raw sewage effected in the effluent no marked alteration in their number.

Now, if the streptococci found in such numbers in the crude sewage and in the effluents are derived from the intestinal contents of animals, and are delicate germs, and are also pathogenic, the position is a somewhat serious one.

In the first place, as regards *experiments on animals*, the records show that the streptococci were usually non-pathogenic to mice. Numerous records, not included in this book, which I have since obtained, of the effects on mice of streptococci, isolated from soil-polluted water, sewage, and sewage effluents, show that, as a rule, and when obtained from the above sources, streptococci are not pathogenic to mice. Still, it must not be lost sight of that the absence of pathogenic effect on mice does not necessarily imply the absence of disease-producing ability in other animals. Nor does it prove that the streptococci were of a non-pathogenic origin. Further, it is conceivable that some alteration in the conditions surrounding these streptococci might, granting that they had been pathogenic in the past, restore to them all their original virulence.

Speaking in general terms, however, it may be said that the streptococci found in nature outside the animal body, *e.g.*, in polluted soils and water, in sewage and sewage effluents, are not as a rule pathogenic to mice.

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* The significance of streptococci in water and soil is dealt with by me in Reports to the Local Government Board. Report of the Medical Officer, Local Government Board, 1898-9-1900.

† In this and succeeding paragraphs I purposely anticipate what follows.

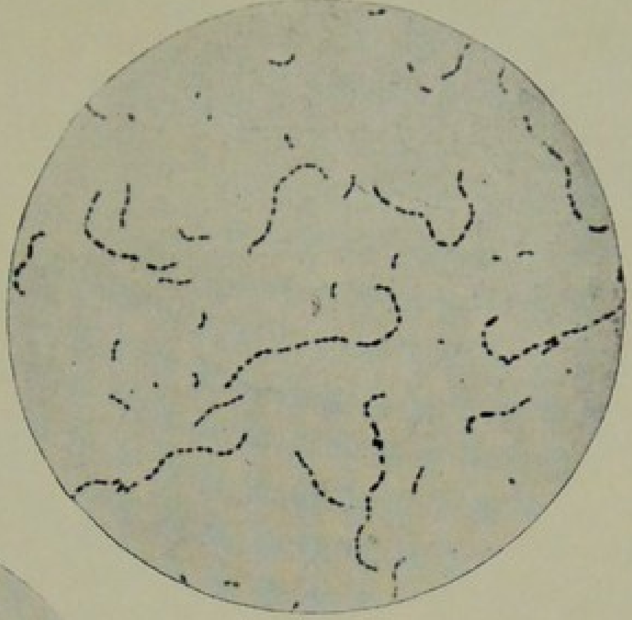

FIG. 15.—Streptococcus X. Microscopic preparation from a broth culture. Twenty-four hours' growth at 38° C. Stained by Gram's method. Isolated from $\frac{1}{1000}$ c.c. of effluent from the 6-foot secondary coke-bed at Crossness. × 1,000.

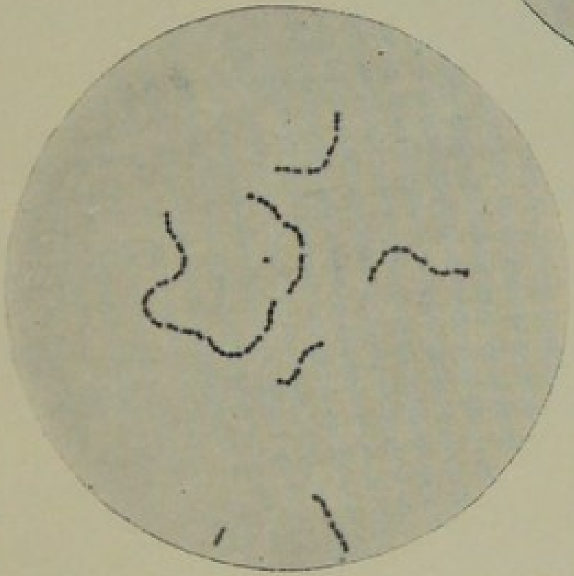

FIG. 16.—Streptococcus XIX. Microscopic preparation from a broth culture. Forty-eight hours' growth at 38° C. Stained by Gram's method. Isolated from $\frac{1}{1000}$ c.c. of effluent from the primary coarse bed A (Series II.) at Barking. × 1,000.

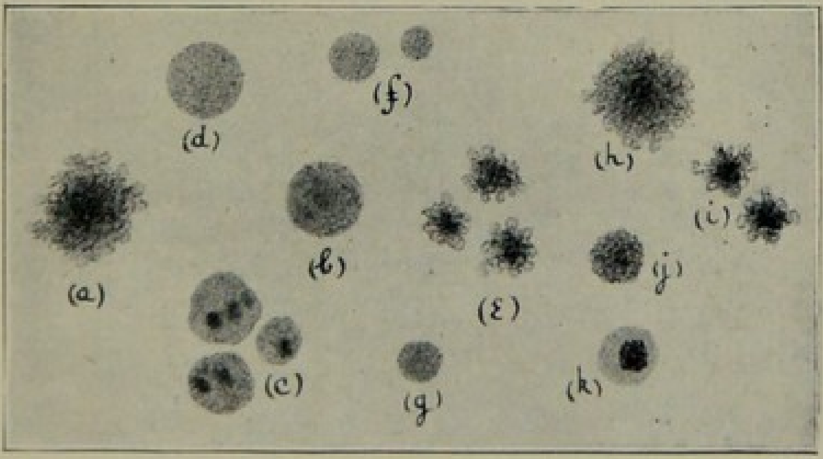

FIG. 17.—Colonies of streptococci in gelatine and agar plate cultures. Under a low power of the microscope (Leitz, 3 objective, 1 ocular).
(Diagrammatic.)

(*a*)	Streptococcus	I.	Colony in agar plate.
(*b*)	,,	II.	Colony in agar plate.
(*c*)	,,	II.	Colonies in old gelatine culture.
(*d*)	,,	III.	Colony in agar plate.
(*e*)	,,	X.	Colonies in agar plate.
(*f*)	,,	XI.	Colonies in gelatine plate.
(*g*)	,,	XII.	Colony in gelatine plate.
(*h*)	,,	XIII.	Colony in agar plate.
(*i*)	,,	XIII.	Colonies in gelatine plate.
(*j*)	,,	XIV.	Colony in gelatine plate.
(*k*)	,,	XVIII.	Colony in gelatine plate.

FIG. 18.—Streptococcus XX. Microscopic preparation from a broth culture. Forty-eight hours' growth at 38° C. Stained by Gram's method. Isolated from $\frac{1}{1000}$ c.c. of effluent from the secondary coarse bed A (Series II.) at Barking. × 1,000.

FIG. 19.—Streptococcus XXI. Microscopic preparation from a broth culture. Forty-eight hours' growth at 38° C. Stained by Gram's method. Isolated from $\frac{1}{1000}$ c.c. of Barking crude sewage. × 1,000.

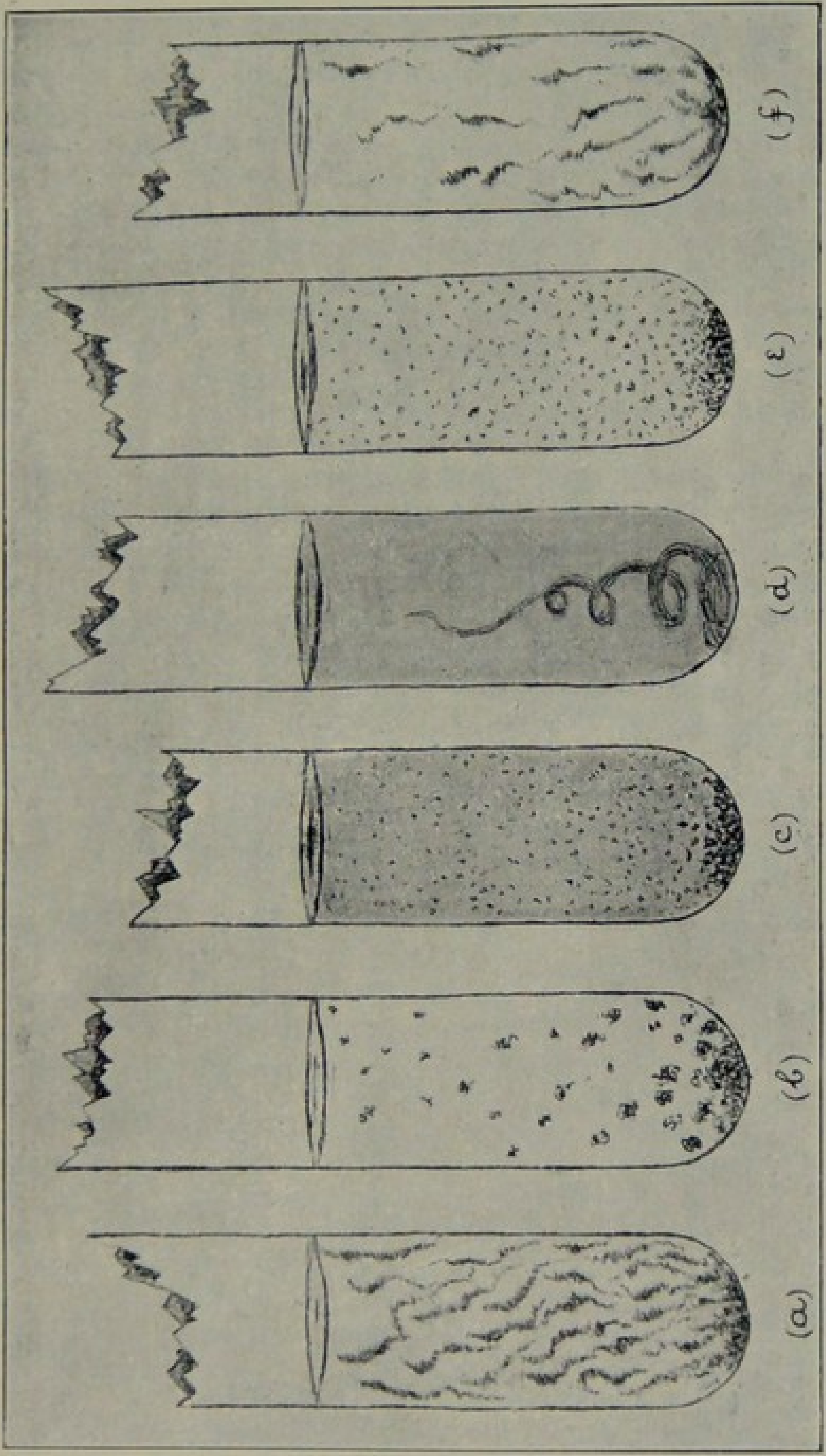

FIG. 20.—Broth and gelatine (incubated at blood heat) cultures of streptococci.
(Diagrammatic.)

(a) Streptococcus I. Gelatine culture incubated at 37° C. for two days.
(b) " I. Old broth culture (shaken up).
(c) " II. Gelatine culture incubated at 37° C. for two days.
(d) " II. Broth culture (shaken).
(e) " IV. Gelatine culture, 24 hours at 37° C.
(f) " XVII. Broth culture, 2nd day at 37° C.

Secondly, as regards the assertion that streptococci are *delicate germs* and readily lose their vitality and die, although this certainly accords with our experience of streptococci isolated from the human subject, particularly in cases of disease and septic infection, it might well be the case that some at all events of the streptococci occurring in nature outside the animal body, *e.g.*, in sewage, are hardy germs and are capable not only of resisting death, but also of multiplying under favourable conditions. This is conceivable; yet the fact is not without significance that certain of the streptococci about to be described, when subcultured in gelatine and incubated at 20° C., showed little or no appreciable growth at the end of 13 days. And some of the streptococci that I have isolated from sewage-polluted water, etc., have proved their delicacy by refusing to grow when sub-cultures were not carried out at short intervals. Thus, on several occasions, the study of a streptococcus has been prematurely cut short by death of the organisms. Still further, it has been a matter of common observation that sub-cultures made from colonies in agar plate cultures of sewage, which colonies under a low power of the microscope revealed their connection with the streptococci group by showing loops of cocci at the periphery, frequently showed *no growth*, the microbes (streptococci) having already lost their vitality. In opposition to this, it might be urged that certain of the streptococci in sewage are in reality hardy germs, but that the nutrient media ordinarily employed by bacteriologists are not the most suitable pabulum for them. It is to be noted, as possibly affording some support to this view, that, if sewage be centrifugalised and the deposit stained, the microbes taking the stain are not, as might have been anticipated, chiefly bacillary in form, but appear either as cocci or as rods, so short and rounded at their ends as to simulate cocci. Moreover, the cocci are frequently arranged in long chains (streptococci).

Nevertheless, it may be said with a fair measure of confidence that some, at all events, of the streptococci in sewage and in sewage effluents are delicate germs, and readily lose their vitality and die.

The importance to be attached to these observations is considerable. If, in the bacterial treatment of sewage, micro-organisms of presumably feeble vitality pass through the coke-beds in practically unaltered numbers, then there is every reason to fear that those microbes which are known to be distinctly pathogenic to man, and which may be either habitually or fortuitously present in sewage, and some of which are believed to be comparatively hardy germs, would likewise be unaffected by the biological processes at work in the coke-beds.

Lastly, as regards the *source* of streptococci, it has been said that they are present in the intestinal discharges of animals, and are absent (or relatively so) from waters and soils except in cases of *recent* and objectionable pollution. It might perhaps be contended that streptococci may have a wide distribution in nature, and if so, that their presence in a substance, be it soil, or sewage, or water, is of little or no significance. Against this view, it may be pointed out that if they are delicate germs, it is unlikely that they would survive, much less multiply in nature, unless the conditions were ideally favourable. Further, that although I have frequently isolated streptococci from as minute a quantity of sewage as 0·001 c.c., and of human fæces as

0·001 gramme, I have repeatedly failed to demonstrate the presence of microbes indubitably belonging to the streptococcus class in comparatively large amounts of pure water and pure soils.[||]

These facts have led me to advocate the streptococcus test as a valuable one in the bacterioscopic examination of waters.[¶] Not, indeed, that the absence of streptococci implies "safety," but that their presence affords evidence of *recent* and therefore presumably specially dangerous animal pollution.

In conclusion, I venture to assert that this test is of considerable value in judging sewage effluents from the biological point of view. If an effluent compared with a corresponding sample of sewage contains either (*a*) streptococci in practically unaltered numbers, or (*b*) even in reduced numbers where such reduction is only in the same proportion as the other microbes also present are reduced, then such an effluent is, as regards potential danger to health, seemingly with regard to (*a*) not much better than raw sewage and under (*b*) set of conditions probably no safer than crude sewage slightly diluted, but otherwise unaltered in its biological composition.

The following is a description of some of the streptococci isolated from London crude sewage and from the effluents from the bacterial beds.

1. *Name*—**Streptococcus I.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.
3. *Date*—November 16th, 1898.
4. *Morphology*—Stains well by Gram's method. The chains of cocci are usually short.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
    (*a*) *Agar* (37° C.)—Small transparent colonies showing wavy granulation. The colonies are irregular in shape, and at the edges the loops of cocci can be made out.[*]
    (*b*) *Gelatine* (20° C.)—Small transparent colonies, circular in shape, and faintly granular. The edges are *clean* and no loops of cocci are visible. No liquefaction.
6. *Streak cultures*—
    (*a*) *Agar* (37° C.)—Small transparent colonies, faintly granular.
    (*b*) *Gelatine* (20° C.)—A white transparent film-like growth, which on close observation is seen to be made up of separate colonies. No liquefaction occurs.
7. *Gelatine at* 37° C.—No diffuse cloudiness. Flocculent little masses with cirrhus-like extensions.[†]
8. *Broth cultures* (37° C.)—The broth remains quite transparent. Flocculent masses with cirrhus-like extensions are formed in the fluid. Old broth cultures show at the foot of the tube a white granular mass, the medium itself being quite transparent. On shaking the tube, granular masses of various sizes rise in the clear liquid and rapidly subside again to the bottom.[‡]
9. *Litmus milk cultures* (37° C.)—Strong acidity and solid clot in 24 hours.
10. *Remarks*—A mouse inoculated subcutaneously with 1 c.c. of broth culture remained apparently unaffected.

1. *Name*—**Streptococcus II.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness 6-foot primary coke-bed effluent.
3. *Date*—November 16th, 1898.
4. *Morphology*—Stains well by Gram's method. Very short chains as a rule, but occasionally a chain of medium length may be found.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
    (*a*) *Agar* (37° C.)—Small transparent circular faintly-granular colonies with *firm* edges. No loops of cocci are visible at the periphery.[§]
    (*b*) *Gelatine* (20° C.)—Small transparent faintly-granular colonies, circular in shape with *clean* edges. Old colonies may present a nucleated appearance. No appearance of separate loops of cocci at the periphery of the colonies. No liquefaction.[||]

[||] I have, however, found streptococci in abundance in waters and soils *recently* polluted with sewage.

[¶] Report of the Medical Officer, Local Government Board, 1898-9.

[*] Fig. 17 (*a*). [†] Fig. 20 (*a*). [‡] Fig. 20 (*b*).

[§] Fig. 17 (*b*). [||] Fig 17 (*c*).

6. *Streak cultures*—

(*a*) *Agar* (37° C.)—Minute transparent colonies. The colonies are situated so close together as to appear at first sight like a continuous film.

(*b*) *Gelatine* (20° C.)—Almost no growth, even after 13 days.

7. *Gelatine at* 30° C.—Granular cloudiness, with a white granular deposit at the foot of the tube.¶

8. *Broth cultures* (37° C.)—Diffuse cloudiness; at the foot of the tube white viscous growth, which on shaking the tube, rises in the form of a spiral.**

9. *Litmus milk cultures* (37° C.)—In 2 days acidity; in 4 days, strong acidity but no clot; 7th day, still no clot; 25th day, still no clot.

10. *Remarks*—A mouse inoculated subcutaneously with 1 c.c. of a 4 days' broth culture died on the 7th day. Microscopic preparations made from the kidney juice showed the presence of cocci, sometimes arranged as diplococci and showing an appearance as of a surrounding capsule. This was not very distinct, however. Agar plate cultures were made from the spleen, and a streptococcus was isolated, which differed somewhat from the one above described. It produced diffuse cloudiness in broth and diffuse granular cloudiness in gelatine at 37° C. Milk was rendered strongly acid and clotted.

1. *Name*—**Streptococcus III.**

2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.

3. *Date*—November 29th, 1898.

4. *Morphology*—Stains well by Gram's method. Chains of cocci of variable length; most of them are short.

5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—

(*a*) *Agar* (37° C.)—Minute transparent faintly-granular colonies. Most of the colonies are circular with a *clean* edge. Some are irregular in shape with a ragged edge resembling somewhat Streptococcus I.††

(*b*) *Gelatine* (20° C.)—Small transparent colonies roughly circular in shape with firm edges. The colonies are faintly granular, and show no separate loops of cocci at the periphery. No liquefaction.

6. *Streak cultures*—

(*a*) *Agar* (37° C.)—The growth appears at first sight like a continuous delicate film, but is in reality composed of numerous minute transparent and separate colonies.

(*b*) *Gelatine* (20° C.)—Colonies are somewhat large for a streptococcus: they are roughly circular in shape, and have a granular appearance. No liquefaction.

7. *Gelatine at* 37° C.—Granular cloudiness at the foot of the tube. Throughout the medium granular cloudiness and slight diffuse cloudiness as well.

8. *Broth cultures* (37° C.)—Diffuse cloudiness throughout the medium.

9. *Litmus milk cultures*—Acidity, but no clot in 24 hours. Later, strong acid but no clot (14th day).

10. *Remarks*—1 c.c. of a 2 days' broth culture injected subcutaneously in a mouse produced no apparent effect.

1. *Name*—**Streptococcus IV.**

2. *Source*—$\frac{1}{1000}$ c.c. effluent from 4-foot single coke-bed at Crossness.

3. *Date*—November 29th, 1898.

4. *Morphology*—Stains by Gram's method. Chains of cocci of variable length; usually short, however.

5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—

(*a*) *Agar* (37° C.)—Colonies very similar to Streptococcus III.

(*b*) *Gelatine* (20° C.)—As practically no growth occurred in gelatine streak cultures, no gelatine plates were made.

6. *Streak cultures*—

(*a*) *Agar* (37° C.)—Growth resembles both Streptococcus I. and Streptococcus III.

(*b*) *Gelatine* (20° C.)—Practically no growth, even after 13 days.

7. *Gelatine at* 37° C.—Granular deposit at foot of tube and granular cloudiness throughout the medium, but no diffuse cloudiness.‡‡

8. *Broth cultures* (37° C.)—Diffuse cloudiness. Deposit at the foot of the tube coherent in masses unlike Streptococcus III.

9. *Litmus milk cultures* (37° C.)—Distinct acidity, but no clot (11th day).

10. *Remarks*—1 c.c. of a 2 days' broth culture injected subcutaneously. The mouse died on 9th day. Cover glass specimens made from kidney juice, peritoneal fluid, &c., showed the presence of cocci and diplococci (appearance suggestive of surrounding capsule, but not very distinct). Agar plate cultures were made from the organs, but the plates were crowded with putrefactive bacteria, and no streptococci were isolated.

¶ Fig. 20 (*c*).

** Fig. 20 (*d*).

†† Fig. 17 (*d*).

‡‡ Fig. 20 (*e*).

1. *Name*—**Streptococcus V.**

2. *Source*—$\frac{1}{1000}$ c.c. effluent from 4-foot single coke-bed at Crossness.

3. *Date*—November 29th, 1898.

4. *Morphology*—Stains well by Gram's method. Short chains and chains of medium length.

5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—

(*a*) *Agar* (37° C.)—Appearances very similar to Streptococcus III., *i.e.*, some colonies circular and granular with *clean* edges; others more or less irregular in shape with ragged edges. Apparently, however, fewer colonies of irregular shape and ragged edges than in the cases of Streptococci III. and IV.

(*b*) *Gelatine* (20° C.)—As there was practically no growth in gelatine streak cultures, no gelatine plate cultures were made.

6. *Streak cultures*—

(*a*) *Agar* (37° C.)—Growth somewhat similar in appearance to Streptococcus III.

(*b*) *Gelatine* (20° C.)—Practically no growth (13th day).

7. *Gelatine at* 37° C.—Appearance very like Streptococcus III.

8. *Broth cultures* (37° C.)—Diffuse cloudiness.

9. *Litmus milk cultures*—Distinct acidity, but no clot (11th day).

1. *Name*—**Streptococcus VI.**

2. *Source*—$\frac{1}{1000}$ c.c. effluent from 4 foot single coke-bed at Crossness.

3. *Date*—November 29th, 1898.

4. *Morphology*—Stains well by Gram's method. Chains of cocci of variable length, but usually short.

5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—

(*a*) *Agar* (37° C.)—Small transparent granular colonies, usually circular in shape. Most of the colonies have a firm edge, but in some of them the edge has a ragged appearance.

(*b*) *Gelatine* (20° C.)—No record.

6. *Streak cultures*—

(*a*) *Agar* (37° C.)—The growth resembles Streptococcus I.

(*b*) *Gelatine* (20° C.)—By the 13th day the colonies had attained a fair size; they are granular, and at the edge have a lobed and fissured appearance. The colonies are white, but towards the centre they are yellowish-white in colour. No liquefaction.

7. *Broth cultures* (37° C.)—Diffuse cloudiness; at the foot of the tube white viscous growth, which on shaking the tube rises in the form of a spiral.

8. *Litmus milk cultures* (37° C.)—Very slight acidity, no clot (10th day).

1. *Name*—**Streptococcus VII.**

2. *Source*—$\frac{1}{1000}$ c.c. effluent from 4-foot single coke-bed at Crossness.

3. *Date*—November 29th, 1898.

4. *Morphology*—Stains well by Gram's method. Chains of cocci of variable length, but usually short.

5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—

(*a*) *Agar* (37° C.)—Small more or less circular colonies, transparent and granular. Most of the colonies have a firm edge, but in others the edge is broken up and uneven in character.

(*b*) *Gelatine* (20° C.)—As there was practically no growth in gelatine streak cultures (13th day at 20° C.), no gelatine plate cultures were made.

6. *Streak cultures*—

(*a*) *Agar* (37° C.)—No record.

(*b*) *Gelatine* (20° C.)—Practically no growth (13th day at 20° C.).

7. *Broth cultures* (37° C.)—Some diffuse cloudiness, and at the foot of the tube granular masses as in Streptococcus I.

8. *Litmus milk cultures* (37° C.)—Slight acidity, but no clot (10th day).

1. *Name*—**Streptococcus VIII.**

2. *Source*—$\frac{1}{1000}$ c.c. effluent from 6-foot primary coke-bed at Crossness.

3. *Date*—December 9th, 1898.

4. *Morphology*—Stains well by Gram's method. Chains of cocci of variable length.

5. *Agar plate cultures*, 37° C. (under a low power, Leitz, 3 objective, 1 ocular)—Small transparent granular colonies with firm edges and roughly circular in shape.

6. *Streak cultures*—

(*a*) *Agar* (37° C.)—The growth appears as a thin transparent greyish-white film, which on close examination is seen to be made up of minute separate colonies.

(*b*) *Gelatine* (20° C.)—Colonies are transparent and granular-looking. No liquefaction (13th day).

7. *Broth cultures* (37° C.)—Diffuse cloudiness; at the foot of the tube a white deposit which rises in the form of a spiral on shaking the tube.

8. *Litmus milk cultures* (37° C.)—Strong acidity, but no clot (11th day).

9. *Remarks*—1 c.c. of broth culture injected subcutaneously into a guinea-pig. The animal remained apparently unaffected.

1. *Name*—**Streptococcus IX.**
2. *Source*—$\frac{1}{1000}$ c.c. effluent from 6-foot secondary coke-bed at Crossness.
3. *Date*—December 15th, 1898.
4. *Morphology*—Stains well by Gram's method. Chains of cocci usually short, but some of medium length.
5. *Agar plate cultures*, 37° C. (under a low power, Leitz, 3 objective, 1 ocular)—The majority of the colonies are circular in shape with firm edges. They are small, granular and transparent-looking.
6. *Streak cultures*—
   - (*a*) *Agar* (37° C.)—The growth at first sight looks like a continuous white film, but on close inspection it is seen to be made up of numerous separate minute transparent colonies.
   - (*b*) *Gelatine* (20° C.)—Minute transparent colonies, more or less circular in shape. No liquefaction.
7. *Broth cultures* (37° C.)—Diffuse cloudiness; white deposit, at the foot of the tube; on shaking the tube deposit rises in the form of a spiral.
8. *Litmus milk cultures* (37° C.)—Feeble acidity in two days. Later distinct acidity, but no clot (11th day).
9. *Remarks*—1 c.c. of a 24 hours (at 37° C.) broth culture was injected subcutaneously into a mouse. The mouse died on the 5th day. Cocci present in juice of spleen and kidneys. From the spleen a pure culture of a streptococcus was obtained, forming chains of medium length, and which differed somewhat from the above. In broth the fluid remained clear, and at the foot of the tube, growth occurred as a white conglomerate mass. In gelatine at 37° C. very slight diffuse cloudiness, and at the foot of tube a loose flocculent cloudy growth. In gelatine plate cultures, colonies irregular in shape with uneven edge, wavy granulation well marked.

1. *Name*—**Streptococcus X.**
2. *Source*—$\frac{1}{1000}$ c.c. effluent from 6-foot secondary coke-bed at Crossness.
3. *Date*—December 15th, 1898.
4. *Morphology*—Stains well by Gram's method. Chains of cocci of medium length.*
5. *Agar plate culture*, 37° C. (under a low power, Leitz, 3 objective, 1 ocular)—Irregularly-shaped colonies with broken-up edge. Transparent with wavy granulation, and at edge loops of cocci can be made out.†
6. *Streak cultures*—
   - (*a*) *Agar* (37° C.)—The growth is made up of numerous minute separate transparent colonies which at first sight appear like a continuous filmy growth.
   - (*b*) *Gelatine* (20° C.)—By the 13th day colonies of varying size. They are very irregular in shape, with lobed and fissured borders and delicate filamentous extensions like fine seaweed. The colonies are white, but towards centre the colour is yellowish-white.
7. *Broth cultures* (37° C.)—Diffuse cloudiness; at foot of tube white viscous deposit which on shaking the tube rises in spiral form.
8. *Litmus milk cultures* (37° C.)—In two days distinct acidity, but no clot; 11th day still no clot.

1. *Name*—**Streptococcus XI.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.
3. *Date*—December 15th, 1898.
4. *Morphology*—Stains well by Gram's method. Chains of cocci of variable length, but usually short.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   - (*a*) *Agar* (37° C.)—Most of the colonies minute, transparent and granular with firm edge.
   - (*b*) *Gelatine* (20° C.)—The majority of the colonies are nearly circular in shape: they are transparent-looking and faintly granular with firm edge. No liquefaction.§
6. *Streak cultures*—
   - (*a*) *Agar* (37° C.)—The growth at first sight appears like a continuous film, but is really made up of separate minute transparent colonies.
   - (*b*) *Gelatine* (20° C.)—Small transparent faintly granular colonies. No liquefaction (13th day).
7. *Broth cultures* (37° C.)—Diffuse cloudiness; at the foot of the tube viscous white deposit, which on shaking the tube rises in the form of a spiral.
8. *Litmus milk cultures* (37° C.)—No visible change, even after 11 days' incubation.

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* Fig. 15. † Fig. 17 (*e*). § Fig. 17 (*f*).

1. *Name*—**Streptococcus XII.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.
3. *Date*—December 15th, 1898.
4. *Morphology*—Stains well by Gram's method. A streptococcus forming very short chains.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   - (*a*) *Agar* (37° C.)—Small circular colonies with firm edge, transparent and granular looking.
   - (*b*) *Gelatine* (20° C.)—The colonies are usually circular: they are faintly granular and transparent-looking. The edge is *clean*. No liquefaction.*
6. *Streak cultures*—
   - (*a*) *Agar* (37° C.)—The colonies are rather large for a streptococcus; they have a granular and transparent appearance.
   - (*b*) *Gelatine* (20° C.)—The mass of the growth appears as a continuous film; but at the edge and upper portion of the streak the colonies are separate and are small with a granular transparent appearance. No liquefaction.
7. *Gelatine at* 37° C.—A granular white deposit forms at the foot of the tube, and the gelatine throughout is full of minute granular specks.
8. *Broth cultures* (37° C.)—The broth is clear, but on sides of tube white cirrhus-like growth, and at foot of tube viscous white conglomerate mass.
9. *Litmus milk cultures* (37° C.)—Slight acidity, but no clot (11th day).

1. *Name*—**Streptococcus XIII.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.
3. *Date*—December 15th, 1898.
4. *Morphology*—Stains well by Gram's method. It was difficult to determine whether this microbe was a streptococcus or a staphylococcus. Finally it was classed as a streptococcus.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   - (*a*) *Agar* (37° C.)—The large colonies are roughly circular in shape and the smaller ones irregular. Wavy granulation is well marked, and at the edge of the colonies separate loops of cocci can be made out. The colonies are small and transparent-looking.†
   - (*b*) *Gelatine* (20° C.)—The colonies are very irregular in shape, and at the edge loops of cocci may be made out. They are small and transparent, and show a coarse wavy granulation.‡
6. *Streak cultures*—
   - (*a*) *Agar* (37° C.)—The growth is composed of separate colonies which are transparent and granular-looking, and are rather large for a streptococcus.
   - (*b*) *Gelatine* (20° C.)—By the 13th day the colonies have attained a fair size; they are irregular in shape and tend to run into each other. No liquefaction.
7. *Gelatine at* 37° C.—Resemble streptococcus XII.
8. *Broth cultures* (37° C.)—The cloudiness is not well marked and is somewhat granular in character. On shaking the tube gently viscous white masses with cirrhus-like extensions rise from the foot and float throughout the liquid.
9. *Litmus milk cultures* (37° C.)—Slight acidity, but no clot (15th day).
10. *Potato cultures* (37° C.)—No visible growth (8th day).

1. *Name*—**Streptococcus XIV.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.
3. *Date*—December 15th, 1898.
4. *Morphology*—Stains well by Gram's method. The chains are short and tend to cohere in masses. The cells are somewhat irregular in shape.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   - (*a*) *Agar* (37° C.)—The colonies are small, nearly circular in shape, with a fairly firm edge. They are granular and transparent-looking.
   - (*b*) *Gelatine* (20° C.)—The colonies are roughly circular in shape. Wavy granulation is well marked. The edge may have a slightly ragged appearance, but no separate loops of cocci can be made out. No liquefaction.§
6. *Streak cultures*—
   - (*a*) *Agar* (37° C.)—The colonies are separate, granular, and transparent-looking, but are of rather a large size for a streptococcus.
   - (*b*) *Gelatine* (20° C.)—Resembles Streptococcus XII. No liquefaction (13th day).
7. *Gelatine at* 37° C.—Resembles Streptococcus XII.
8. *Broth cultures* (37° C.)—The broth remains nearly transparent. At the foot of the tube the growth collects as a viscous white mass.
9. *Litmus milk cultures* (37° C.)—Distinct acidity, but no clot (11th day).

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* Fig. 17 (*g*). † Fig. 17 (*h*). ‡ Fig. 17 (*i*). § Fig. 17 (*j*).

1. *Name*—**Streptococcus XV.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.
3. *Date*—December 21st, 1898.
4. *Morphology*—Stains well by Gram's method. Chains of cocci are usually short, but some are of medium length.
5. *Plate cultures* (under a low power, Leiz, 3 objective 1 ocular)—
   (*a*) *Agar* (37° C.)—Small, transparent, circular, granular colonies with firm edge.
   (*b*) *Gelatine* (20° C.)—Small colonies of circular shape and with clean edge. They may present a nucleated appearance. They are granular and transparent-looking. No liquefaction.
6. *Streak cultures*—
   (*a*) *Agar* (37° C.)—A barely visible white film, which on close observation is seen to be made up of separate colonies (minute and transparent-looking).
   (*b*) *Gelatine* (20° C.)—Resembles somewhat Streptococcus XII. No liquefaction (13th day).
7. *Broth cultures* (37° C.)—Diffuse cloudiness. At the foot of the tube a white viscous deposit, which on shaking the tube rises in the form of a spiral.
8. *Litmus milk cultures* (37° C.)—In two days, distinct acid, but no clot; 5th day, ditto; 11th day, ditto.
9. *Remarks*—1 c.c. of a 24 hours' broth culture (37° C.) was injected subcutaneously into a mouse. The mouse died on the 5th day. Microscopic preparations were made from the peritoneal fluid, &c. Cocci were present, but also many putrefactive bacilli. Agar plates made from the spleen were overgrown with putrefactive organisms, but no streptococci could be isolated.

1. *Name*—**Streptococcus XVI.**
2. *Source*—$\frac{1}{1000}$ c.c. effluent from 4 foot single coke-bed at Crossness.
3. *Date*—December 21st, 1898.
4. *Morphology*—Stains well by Gram's method. Long chains of cocci matted together in masses.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   (*a*) *Agar* (37° C.)—Minute transparent colonies, usually of circular shape, and showing wavy granulation. No separate loops of cocci at periphery.
   (*b*) *Gelatine* (20° C.)—Small, circular, transparent and granular-looking colonies. No liquefaction.
6. *Streak cultures*—
   (*a*) *Agar* (37° C.)—Thin, delicate film, which on close examination is seen to be made up of minute separate colonies.
   (*b*) *Gelatine* (20° C.)—Resembles Streptococcus X.
7. *Broth cultures* (37° C.)—Broth remains perfectly transparent. At foot of tube white conglomerate mass.
8. *Litmus milk cultures* (37° C.)—Second day, no visible change; 5th day, slight acidity, but no clot. Later, acidity more decided. No clot 11th day.

1. *Name*—**Streptococcus XVII.**
2. *Source*—$\frac{1}{1000}$ c.c. effluent from 4 foot single coke-bed at Crossness.
3. *Date*—December 21st, 1898.
4. *Morphology*—Stains well by Gram's method. Chains of cocci short. The cells tend to cohere in masses simulating a staphylococcus.
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   (*a*) *Agar* (37° C.)—Small granular and transparent-looking colonies, nearly circular in shape. The edge of the colonies has a ragged appearance, but no separate loops of cocci can be made out.
   (*b*) *Gelatine* (20° C.)—Minute colonies of circular shape, showing faint granulation. The colonies are transparent-looking and some have a nucleated appearance. The edge is firm and no separate loops of cocci are visible. No liquefaction.
6. *Streak cultures*—
   (*a*) *Agar* (37° C.)—The growth presents no special characters worthy of note.
   (*b*) *Gelatine* (20° C.)—Resembles somewhat Streptococcus XII. No liquefaction.
7. *Broth cultures* (37° C.)—Broth remains quite transparent. On sides of tube cirrhus-like, streaky, white growth. At foot of tube, viscous white deposit.*
8. *Litmus milk cultures* (37° C.)—In two days, distinct acid, but no clot; 5th day, ditto; 11th day, ditto.

1. *Name*—**Streptococcus XVIII.**
2. *Source*—$\frac{1}{1000}$ c.c. Crossness crude sewage.
3. *Date*—December 21st, 1898.

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* Fig. 20 (*f*).

4. *Morphology*—Stains well by Gram's method. Short to medium chains.
5. *Plate cultures*—(under a low power, Leitz, 3 objective, 1 ocular)—
   (*a*) *Agar* (37° C.)—Colonies circular with firm edge; transparent and faintly granular.
   (*b*) *Gelatine* (20° C.)—Most of the colonies seem to be made up of two portions, a granular, irregularly-shaped, darker portion, and a more transparent and larger portion, which is less granular. Some of the colonies, however, appeared to be composed of a collection of delicate loops like S. longus type. No liquefaction.†
6. *Streak cultures*—
   (*a*) *Agar* (37° C.)—Resembles somewhat Streptococcus XV.
   (*b*) *Gelatine* (20° C.)—On the 13th day the growth resembled Streptococcus XII., but in a few places delicate filamentous extensions like fine seaweed may be seen. No liquefaction.
7. *Broth cultures* (37° C.)—Diffuse cloudiness, and at foot of tube viscous white deposit, which on shaking the tube rises in the form of a spiral.
8. *Litmus milk cultures*—No visible change, even after 11 days' incubation.

1. *Name*—**Streptococcus XIX.**
2. *Source*—$\frac{1}{1000}$ c.c. effluent from the primary coarse bed A at Barking.
3. *Date*—November 1st, 1899.
4. *Morphology*—Stains well by Gram's method. The chains of cocci are of medium length.§
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   (*a*) *Agar* (37° C.)—Irregularly-shaped, transparent colonies, showing well-marked wavy granulation. At the edge of some of the colonies separate loops of cocci are clearly visible.
   (*b*) *Gelatine* (20° C.)—Small transparent colonies, showing faint wavy granulation. Usually circular in shape with clean edge. No liquefaction.
6. *Streak cultures*—
   (*a*) *Agar* (37° C.)—No record.
   (*b*) *Gelatine* (20° C.)—Minute, transparent, circular colonies. No liquefaction.
7. *Broth cultures* (37° C.)—Some diffuse cloudiness, but granular cloudiness as well. On sides of tube, streaky, cirrhus-like, white growth.
8. *Litmus milk cultures* (37° C.)—In two days strong acid, but no clot; 4th day, ditto.
9. *Remarks*—A mouse inoculated subcutaneously with 1 c.c. broth culture remained apparently unaffected.

1. *Name*—**Streptococcus XX.**
2. *Source*—$\frac{1}{1000}$ c.c. effluent from the secondary coarse bed A at Barking.
3. *Date*—November 1st, 1899.
4. *Morphology*—Stains well by Gram's method. Resembles Streptococcus XIX.¶
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   (*a*) *Agar* (37° C.)—Minute transparent colonies, nearly circular in shape with clean edge. Wavy granulation very faint. Some of the colonies are more granular-looking and have a slightly frayed edge
   (*b*) *Gelatine* (20° C.)—Resembles Streptococcus XIX.
6. *Streak cultures*—
   (*a*) *Agar* (37° C.)—No record.
   (*b*) *Gelatine* (20° C.)—Very similar to Streptococcus XIX., but the colonies are more transparent-looking.
7. *Broth cultures* (37° C.)—Resembles Streptococcus XIX.
8. *Litmus milk cultures*—In two days, strong acid, but no clot; 4th day, strong acid, but no clot.
9. *Remarks*—A mouse inoculated subcutaneously with 1 c.c. of a broth culture was apparently unaffected.

1. *Name*—**Streptococcus XXI.**
2. *Source*—$\frac{1}{1000}$ c.c. Barking crude sewage.
3. *Date*—November 1st, 1899.
4. *Morphology*—Stains well by Gram's method. The chains of cocci are usually short, but occasionally long chains may be seen.*
5. *Plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—
   (*a*) *Agar* (37° C.)—Minute, transparent, faintly granular-looking colonies with clean edge. Usually circular in shape.
   (*b*) *Gelatine* (20° C.)—Small transparent colonies showing only very faint granulation. Colonies are circular with slightly wavy border. No liquefaction.

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† Fig. 17 (*k*).

§ Fig. 16.

¶ Fig. 18.

* Fig. 19.

6. *Streak cultures*—
    (*a*) *Agar* (37° C.)—No record.
    (*b*) *Gelatine* (20° C.)—Resembles Streptococcus XIX. and XX., but the colonies are smaller and more transparent-looking.
7. *Broth cultures* (37° C.)—Abundant diffuse cloudiness ; at foot of tube viscous white deposit.
8. *Litmus milk cultures* (37° C.)—Strong acidity, but no clot.
9. *Remarks*—A mouse inoculated subcutaneously with 1 c.c. of broth culture was apparently unaffected.

General Summary of foregoing results, as regards the presence of Streptococci in the crude sewage and in the effluents from the bacteria-beds.

Name.—It is apparent that many of the streptococci resembled *S. brevis* and some *S. longus.* Moreover, certain of the streptococci, if they had been isolated from a septic case in the human subject, might readily have been classed as *S. pyogenes.* In the present state of our knowledge, it has been thought best to register them merely for descriptive purposes as Streptococcus I., II., III., &c. Of course, many of them resembled each other so closely as to suggest identity of species or, at all events, close kinship. But the results seem to indicate that in sewage streptococci are not only more numerous, but that the number of different species is much greater than has hitherto been supposed. A great many microbes isolated from crude sewage and effluents from bacteria-beds are not included in the above list, because, on studying their morphological and biological characters, they seemed to resemble staphylococci more closely than streptococci. The line, however, dividing these two classes of germs is by no means sharp, and it is possible that a few microbes have been included in the above list which really ought to be placed in an intermediate position, *i.e.*, between the streptococci and staphylococci.

Source.—In each case, the streptococci were isolated from as minute a quantity as $\frac{1}{1000}$ c.c. of Barking or Crossness crude sewage, or the effluents from the coke-beds at Barking and Crossness. There did not appear to be any significant alteration in the number of streptococci as the result of the bacterial treatment of the raw sewage.

Morphology.—All stained well by Gram's method. The majority formed short chains, but in some cases the chains were of medium length, and in a few instances long chains were found. Sometimes the chains cohered together, forming masses, thus simulating staphylococci. In such cases, the biological characters of the microbes were closely studied before coming to a definite conclusion. [As a rule staphylococci grow more rapidly and produce a much more luxuriant and opaque growth on the surface of gelatine and agar than do streptococci. Further, staphylococci not uncommonly liquefy gelatine. On the other hand, streptococci do not liquefy (unless quite exceptionally) gelatine, and as a rule grow very slowly and form minute and transparent-looking colonies in agar and gelatine cultures.]

Temperature.—It is to be noted that all the streptococci grew well at blood heat.

Agar and gelatine cultures.—In most cases the colonies (when looked at under a low power of the microscope) were very small, circular in shape, transparent-looking, and faintly granular, with a *clean* edge. Sometimes, however, the colonies showed coarse, wavy granulation, and were irregular in shape with a frayed edge, or showed at the periphery separate loops of cocci. It must not be forgotten that some of the streptococci showed little or no appreciable growth when incubated at 20° C. for 13 days in gelatine streak culture.

Broth cultures.—About 50 per cent. produced diffuse cloudiness with a viscous white deposit at the foot of the tube. In about 20 per cent., the broth remained quite clear, the growth appearing either as a conglomerate mass or else as masses with cirrhus-like extensions. In about 15 per cent., the cloudiness was granular in character with streaky cirrhus-like growths. In about 10 per cent. there was diffuse cloudiness with a deposit at the foot of the tube coherent in granular masses. In about 5 per cent. a viscous white mass collected at the foot of the tube, the broth remaining transparent.

Litmus milk cultures.—About 85 per cent. produced acidity, but no clot. About 5 per cent. showed acidity and clot. About 10 per cent. produced no visible change.

Experiments on animals.—Only a limited number of experiments were carried out. Sometimes a pathogenic effect was produced in mice, but most of the animals were apparently unaffected. An absence of pathogenic effect to mice need not necessarily imply in streptococci freedom from disease-producing capability towards other animals. Moreover, some of these streptococci may have been highly virulent in the past, but have lost their pathogenic action. It is conceivable that these same streptococci might under certain conditions regain their full virulence.

It is apparent from these results that the type of streptococcus which is especially abundant in sewage is one presenting the following characters. For convenience of description, it is permissible to call this microbe "*Sewage Streptococcus.*" The following is a brief description of its chief morphological and biological character:—

1. *Name*— "Sewage Streptococcus."
2. *Source*—Barking and Crossness crude sewage and effluents from bacterial coke-beds.
3. *Abundance*—Usually more than 1,000 per c.c. of crude sewage and effluents.
4. *Temperature*—Grows well at blood heat.
5. *Morphology*—Stains well by Gram's method. The chains of cocci are usually short.
6. *Agar and gelatine plate cultures* (under a low power, Leitz, 3 objective, 1 ocular)—The colonies are small and transparent. They are nearly circular in shape with a *clean* edge. The granulation is faint. The colonies in agar are usually more granular and darker looking than in gelatine cultures. The gelatine is not liquefied.
7. *Streak cultures* (agar at 37° C. and gelatine at 20° C.)—The growth usually shows itself as a delicate white film, which on close observation is seen to be made up of numerous separate minute transparent-looking colonies. The gelatine is not liquefied.
8. *Broth cultures* (37° C.)—Abundant diffuse cloudiness. On gently shaking the tube a viscous white deposit rises from the foot of the tube in a spiral form.
9. *Litmus milk cultures* (37° C.)—Acidity, but usually no clot.
10. *Remarks*—Probably non-pathogenic to mice.

It will be understood that the above is a description not of a special micro-organism, but of the type of streptococcus most commonly present in crude sewage and in the effluents from the coke-beds.

VII. NOTES ON THE DEPOSIT UPON THE COKE IN THE COKE-BEDS.

On May 11th, 1899, samples of coke from the Barking bed were submitted to examination.

The coke was found to be coated with a black-coloured slimy deposit, which was free from objectionable smell, and almost odourless. The

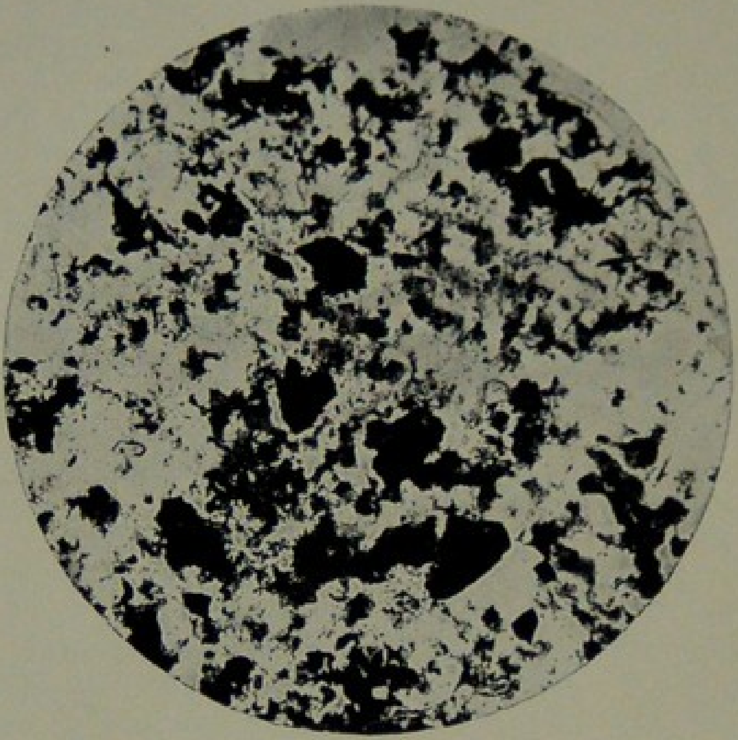

FIG. 21.—Unstained Barking coke deposit. × 85.

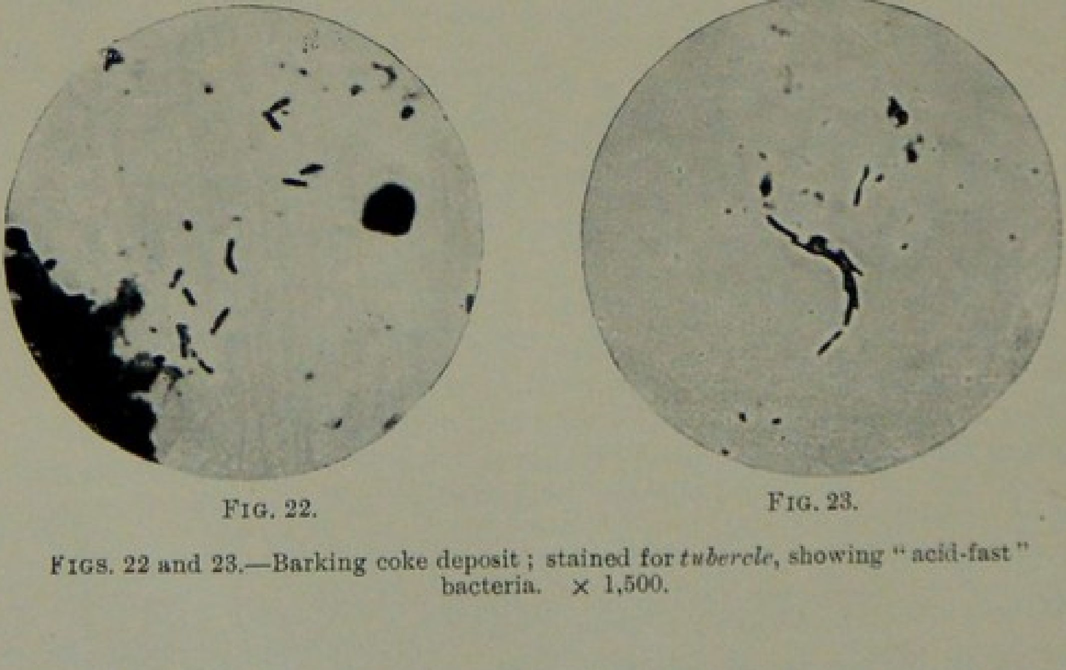

FIG. 22.

FIG. 23.

FIGS. 22 and 23.—Barking coke deposit; stained for *tubercle*, showing "acid-fast" bacteria. × 1,500.

deposit, which was readily detached from the surface of the coke, was examined. When looked at under a low power of the microscope, it was found to be composed largely of minute particles of coke and sand,* together with, apparently, imperfectly disintegrated animal and vegetable matter. This organic matter is probably of such a nature as to resist the action of bacteria for a very considerable time, if not almost indefinitely.

Infusoria, diatoms and minute worms of different kinds were present, but the sewage fungus was not observed to be present to any extent.

A portion stained with the usual aniline dyes (gentian violet, methylene blue, &c.) showed that bacteria (reacting to such stains) were not present in the number that might have been anticipated.

On diluting the deposit largely with sterile water and making cultures therefrom, it was found that the number of bacteria per gramme of deposit was 1,800,000. This number of microbes, large as it may appear, would weigh only a minute fraction of a gramme, so that it is evident that the number of *living* bacteria do not in themselves account in any way for the deposit. I made some experiments in this connexion, and found that 1,800,000 typhoid bacilli weigh only 0·0000147 gramme.

The number of spores of *B. enteritidis sporogenes* was found to be at least 10,000, but less than 100,000 per gramme of deposit.

The character of the microbes appearing in the cultures differed somewhat from those found in crude sewage. For example: There was an increase in the number of spores of *B. enteritidis sporogenes* (*Klein*), and a decrease in the number of *B. coli*. Proteus-like germs were present in abundance; many apparently being of *P. mirabilis* type. Further, *B. arborescens* and an allied form were present in considerable numbers. An organism apparently identical with *B. prodigiosus* was also isolated. It is perhaps worthy of note that a guinea-pig inoculated with some of the deposit developed an abscess at the site of inoculation, and, when this abscess was opened some weeks later, the same characteristic red-colour-forming bacillus (? *B. prodigiosus*) was among others isolated from the pus.

Two mice, inoculated subcutaneously with a small portion of the deposit, died with all the characteristic symptoms of tetanus. Microscopic cover-glass preparations were made from the seat of the inoculations: numerous bacilli showing drum-stick spore-formation, and indistinguishable from *Bacillus tetani*, were noted. A pure cultivation of the *tetanus bacillus* was not obtained, but two anaërobic microbes showing terminal spore-formation were isolated from the seat of the wound. One of these liquefied gelatine, the other did not. They appeared to be identical with two micro-organisms which I isolated by *direct* anaërobic culture from the soil in 1893.†

It has been stated that when the deposit was stained with the aniline dyes ordinarily in use only a limited number of bacteria reacted to the stain. But in addition to ordinary staining, specific staining was resorted to, and with the following results—

The deposit was mixed with sterile water, and cover-glass preparations were made. These were, after staining with hot carbol-fuchsin,

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* See fig. 21.

† Ed. Med. Journal, Nov., 1893.

thoroughly decolorised in 33 per cent. nitric acid, and counter-stained with methylene blue. It may here be explained that this is the specific staining reaction for the *tubercle bacillus*, and that other organisms than tubercle are found to be stained blue at the end of this process, the *tubercle bacillus* alone resisting decoloration with the acid, and therefore alone retaining the bright red colour of the carbol-fuchsin stain. There are, however, a few exceptions to this rule, namely, the *leprosy bacillus*, and certain other organisms (some pathogenic, other non-pathogenic) of recent discovery in milk and fatty matters, which the Germans have called "*acid-fast*" *bacteria*.

Now on staining in the above manner, a large number of cover-glass preparations of the deposit, it was found that a considerable number of bacteria retained the red stain after treatment with 33 per cent. nitric acid. Moreover, many of these bacteria were frequently arranged in small clumps and were indistinguishable morphologically from the *tubercle bacillus*, although, however, some individuals were shorter and plumper, and others took the red stain more deeply than the *tubercle bacillus*. Nevertheless, the fact remains that in specific staining reaction, in their arrangement in little clumps, and in their appearance as small thin-beaded and curved rods, *some* of the bacteria resembled the *tubercle bacillus* so closely as almost to suggest an identity of species.*

It does not follow from the above that these microbes, whatever their nature, were alive, for micro-organisms which have lost their vitality may nevertheless react to stains. Yet, on the other hand, it might well be the case that while the majority were dead some still retained their vitality, and it is conceivable, although unlikely, that they were capable not only of remaining dormant, but also of multiplying in the coke-beds.

Before proceeding to describe certain experiments carried out on animals, it is of advantage to record the results of further examinations of the coke, of the deposit from the crude sewage, and of the effluent from the coke-beds.

On May 30th, 1899, some more coke was obtained from the coke-beds at Barking, and on examination the same "*acid-fast*" *bacteria* were noted.

On May 30th, 1899, 20 c.c. of the effluent (dated 16th May) from the thirteen-foot coke-bed at Crossness were centrifugalised and the deposit stained as above. The result was negative.

On June 1st, 1899, 50 c.c. of Crossness crude sewage and 50 c.c. of the thirteen-foot coke-bed effluent were centrifugalised and stained as before. The result was negative.

On June 7th, 1899, some coke was obtained from the Crossness four-foot coke-bed (one foot from the surface). Scrapings from the surface of the coke were mixed with a little water and stained as previously. A positive result was obtained, but the "*acid-fast*" *bacteria* were for the most part shorter and plumper than the *tubercle bacillus*.

On June 7th, 1899, 1,000 c.c. of Crossness crude sewage and 1,000 c.c. of thirteen-foot coke-bed effluent were in each case placed in a sedimentation apparatus. The following day the deposit (about 4 c.c.) was, in each case, further centrifugalised and thereafter stained, as in the previous experiment. The result was negative as regards the crude

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* Figs. 22, 23; figs. 24, 25; fig. 30.

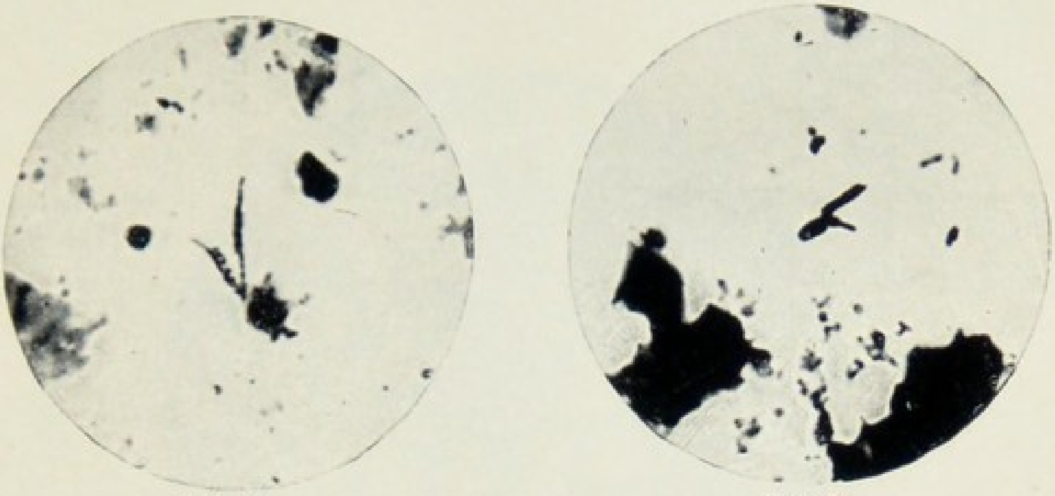

FIG. 24. FIG. 25.

FIGS. 24 and 25.—Barking coke deposit; stained for *tubercle*, showing "acid-fast" bacteria. × 1,500.

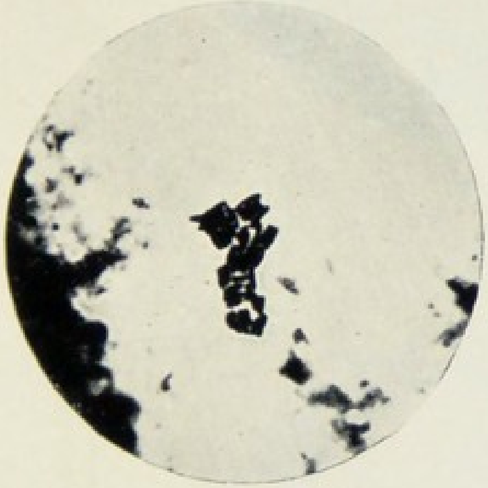

FIG. 26.—Deposit from Crossness crude sewage collected in trough at Crossness; stained for *tubercle*, showing "acid-fast" bacteria. × 1,500.

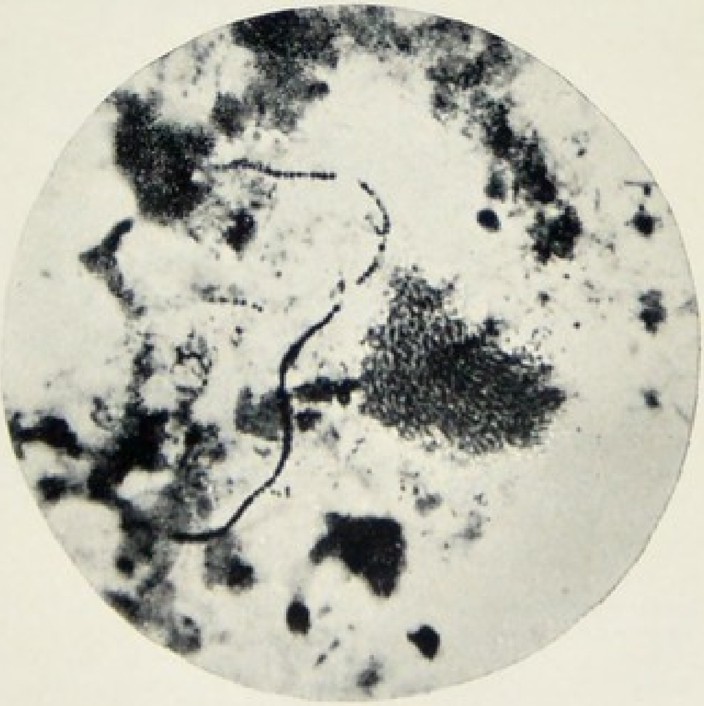

FIG. 27.—Deposit Crossness crude sewage. 50 c.c. of the raw sewage were centrifugalised and a microscopic preparation made of the deposit. This was washed in acid, then in water, and finally stained with methylene blue. × 1,000.

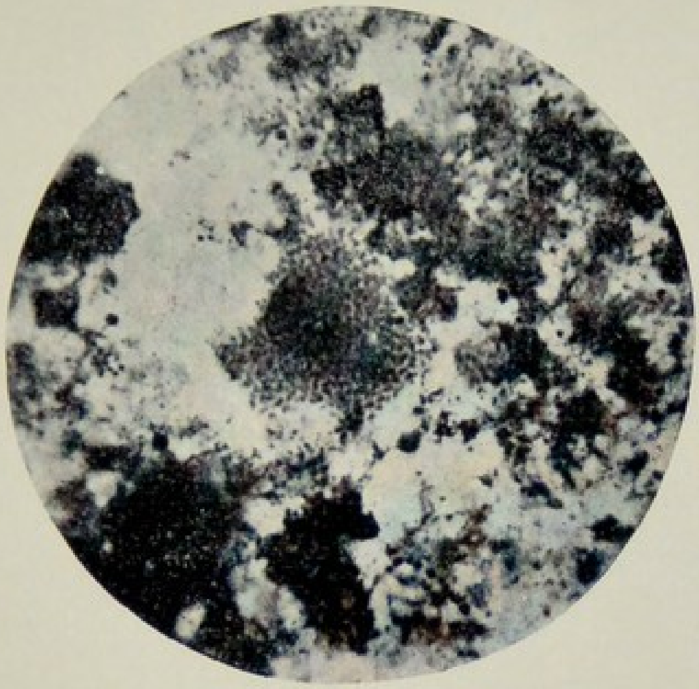

FIG. 28.

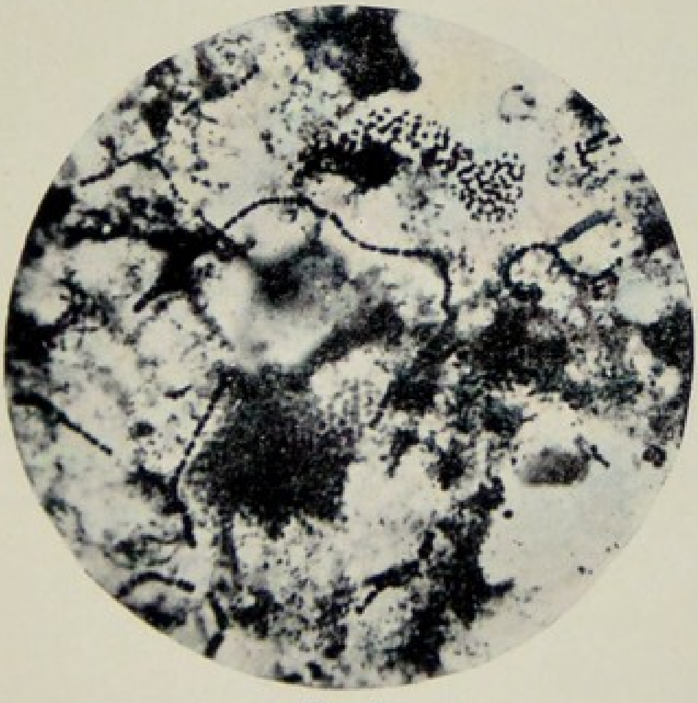

FIG. 29.

FIGS. 28 and 29.—Deposit from Crossness crude sewage. 50 c.c. of the raw sewage were centrifugalised and a microscopic preparation made of the deposit. This was washed in acid, then in water and finally stained with methylene blue. × 1,000.

[Figs. 27, 28 and 29 show the zooglœa-like masses seemingly of cocci, and also the chains apparently of cocci (streptococci).]

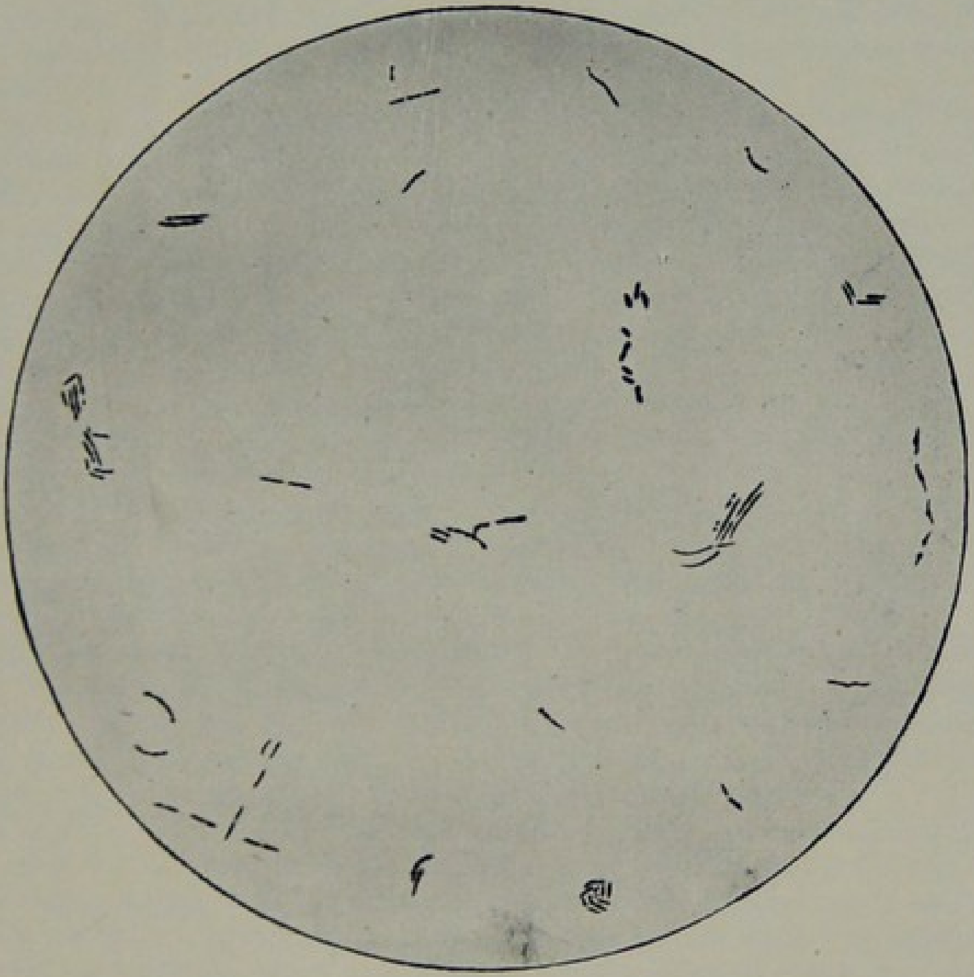

FIG. 30.—Drawings from various cover-glass preparations made from Barking and Crossness coke deposits, showing the different shapes and forms of the "acid-fast" bacteria; stained for *tubercle*. × 1,000.

sewage, but in the case of the effluent a few "*acid-fast*" *bacteria* were obtained. It may be worthy of note that the other bacteria, which, by this staining process were, as has been explained, coloured blue, were chiefly not bacillary in form. Most of them appeared as cocci, frequently arranged in zooglœa-like masses, and also as long chains of cocci (streptococci) extending often right across the field of the microscope. Numerous preparations subsequently made showed that either cocci, or rods so short and rounded at their ends as to simulate cocci, predominated in microscopic stained specimens made from sewage and effluents, and not, as might have been imagined, distinct bacillary or rod-shaped forms.*

On June 15th, 1899, samples of coke from the four-foot coke-bed (one foot from surface) and from the thirteen-foot coke-bed (six feet from surface) were examined as previously. A positive result was obtained, but the "*acid-fast*" *bacteria* were somewhat short and plump in appearance. They were usually found collected together in little clumps.

On June 23rd, 1899, some of the deposit from Crossness crude sewage, which collects in the trough close to the pumping plant, was examined as above. Here a large number of "*acid-fast*" *bacteria* were noted, many of which closely resembled the *tubercle bacillus*.†

On June 27th, 1899, 20 c.c. of Crossness crude sewage and of the thirteen-foot coke-bed effluent (dated June 20th, 1899) were centrifugalised in each case, and the deposit stained as before. In both cases "*acid-fast*" *bacteria* were found, and they were apparently more numerous in the effluent. The bacteria were usually arranged in clumps, and the short, plump forms predominated.

On June 30th, 30 c.c. of Crossness crude sewage and of the thirteen-foot coke-bed effluent (dated June 27) were centrifugalised in each case, and the deposit was stained. A negative result was recorded as regards the crude sewage, but in the preparation of the deposit from the effluent a few short, plump, red-stained rods were observed.

On July 18th, 1899, 50 c.c. of Crossness crude sewage and of the thirteen-foot coke-bed effluent were centrifugalised and the deposit was stained, as in previous experiments. In the case of the crude sewage after prolonged searching, a few short, almost egg-shaped red-stained bacteria were found. But in the effluent, little difficulty was experienced in finding "*acid-fast*" *bacteria*.

On July 26th, 50 c.c. of Crossness crude sewage and of the thirteen-foot coke-bed effluent were centrifugalised and the deposit was stained. In the effluent, red-stained bacteria were found without any difficulty, but in the case of the crude sewage the diagnosis was doubtful.

Summarising these results, it may be said that the deposit accumulating on the coke in the bacteria-beds was found to contain "*acid-fast bacteria*" in large numbers. Similarly, if a sufficient quantity of the crude sewage and of the effluents from the bacteria-beds be centrifugalised and the deposit stained as for *tubercle bacilli*, the same red-stained bacteria are found in the preparations. Particularly is this the case as regards the effluent.

As regards the experiments on animals, it is to be noted that the amount of deposit from the coke, sewage, or effluents introduced into

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* See fig. 27, and figs. 28 and 29.

† See fig. 26.

the animal was, of necessity, small, so as to avoid a rapidly fatal result from the pathogenic bacteria habitually present in the materials used. Had it been possible to employ larger quantities, different results might have been obtained.

Without entering unduly into detail, it may be said that none of the guinea-pigs died of *true* tuberculosis. It is not proposed to speak here of other diseases produced by the injections, or of such diseases as might on *incomplete examination* be judged to be tubercle.

There was, however, one notable exception, but here the deposit (which contained many "*acid-fast*" *bacteria*) was not obtained from either the Barking or Crossness coke-beds. Nevertheless, it was from a coke bacteria-bed, which had been treated with sewage for a considerable time, and worked on similar lines to those adopted at the Northern and Southern Outfall Works. Here the guinea-pig died after the lapse of some weeks, and on examination presented the usual appearance of tubercle infection. Moreover, sections of the bronchial glands, spleen, and other organs, when appropriately stained, showed the presence of numerous *tubercle bacilli*.* So that in this case at least, it is not open to doubt that some of the "*acid-fast*" *bacteria* were those of the *bacillus of tuberculosis*.

It may be concluded from these experiments that, even if some of the "*acid-fast*" *bacteria* collecting in the coke-beds are those of the *tubercle bacillus*, they have for the most part lost their infective power. Nevertheless, the single positive result here recorded tends to destroy the belief that *none* of the bacteria in question are those of tubercle, or that, being tubercle, they have entirely lost their infective power.

That some of the "*acid-fast*" *bacteria* should be those of the *bacillus of tuberculosis* is not so remarkable when the source of raw sewage is taken into consideration, and when it is remembered that each fragment of deposit collecting on the coke in the bacteria-beds probably represents the flow of hundreds of gallons of sewage.

In conclusion, no further claim is made than this :—

I. In crude sewage, in bacterial coke-beds, and in the effluent from bacteria-beds, there are certain bacteria which, after being stained with hot carbol-fuchsin, resist decolorisation with 33 per cent. of nitric acid.

II. Some of these "*acid-fast*" *bacteria* cannot, with certainty, be morphologically distinguished from the *tubercle bacillus*.

III. In one instance a guinea-pig inoculated with the deposit accumulating on the coke of a bacteria-bed died, and presented, on examination, the appearance of death from tubercle infection, and sections of its organs, when appropriately stained, showed the presence of numerous *tubercle bacilli*.

VIII. EXPERIMENTS ON ANIMALS.

Injection of crude sewage and of effluents into guinea-pigs.

The conclusions which have been arrived at as a result of the above experiments may be briefly stated as follows :—

I. The subcutaneous injection of Barking and Crossness crude sewage

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* See figs. 31, 32, 33, 34.

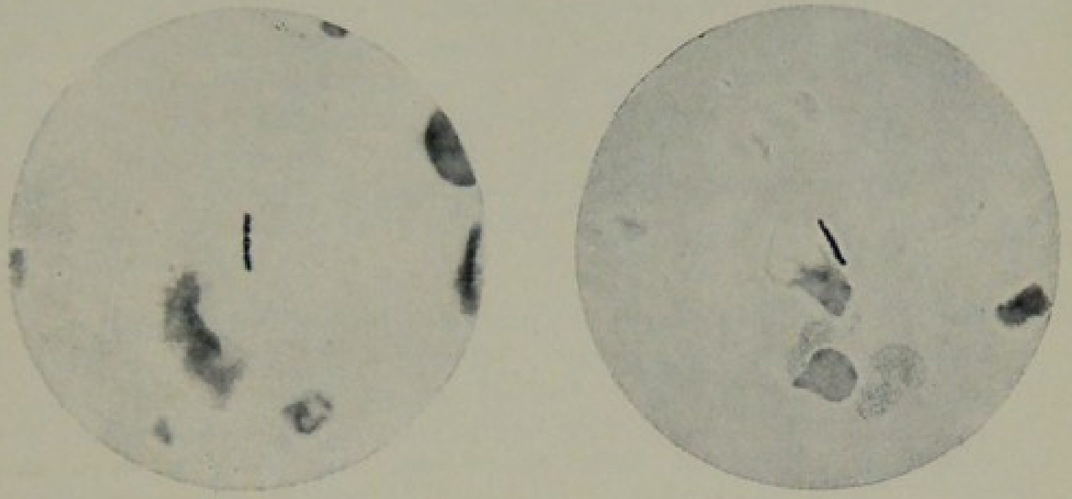

FIG. 31. FIG. 32.

FIGS. 31 and 32.—Section of bronchial gland of guinea-pig, dead of tuberculosis; stained for *tubercle*. × 1,500.

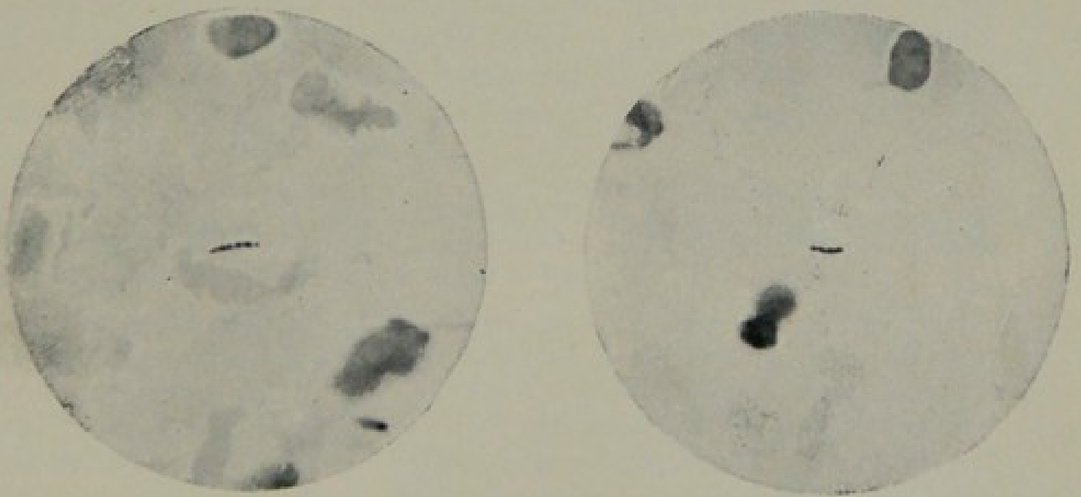

FIG. 33. FIG. 34.

FIGS. 33 and 34.—Section of spleen of guinea-pig, dead of tuberculosis: stained for *tubercle*. × 1,500.

[The guinea-pig died after inoculation with the "washings" from the deposit on the coke in a bacteria-bed.]

into guinea-pigs (about 1—3 c.c. per 200 grammes weight) always produced a local reaction, and usually death in from 24 to 72 hours. If the guinea-pigs did not die within the first few days, although suppuration and ulceration sometimes occurred at the site of the inoculation, the animals usually recovered completely. Sometimes the effluents from the coke-beds were more pathogenic than the raw sewage itself, but as a rule a somewhat larger dose of effluent was required to produce a fatal result. If the crude sewage or effluent was injected intra-peritoneally instead of subcutaneously, the animals usually died more quickly, and succumbed to a smaller dose. There were, however, exceptions to this rule.

II. If the injection of the crude sewage or effluent was not followed by fatal results within the first few days, the animal occasionally died after the lapse of some weeks, and on post-mortem examination showed appearances simulating tubercle infection; but on closer study it was found that death was really due to *pseudo-tuberculosis* (*B. pseudo-tuberculosis of Pfeiffer*).

[It will be remembered, however, that in one case a guinea-pig inoculated with a portion of coke deposit died from *true tuberculosis.* Notes on the deposit upon the coke in the coke-beds.]

III. When the animal died rapidly (24—72 hours), virulent microbes, belonging to the class of *B. coli* and *B. proteus,* were readily isolated from the blood or tissues of the animal.

IV. If the crude sewage or effluent was previously heated to 100° C. for one hour, large doses could be injected into rodents without producing a fatal result. This would seem to show that the pathogenic effect of the sewage and effluents is not directly traceable to such of the intra-cellular and extra-cellular products of microbes as are capable of resisting this temperature.

[This temperature (100° C.) would change poisonous *active albuminoids* to non-poisonous *passive albuminoids*, and would also decompose *enzymes*; but it would not necessarily destroy the poisonous substances resulting from the decomposition of putrefying albuminoids known as *ptomaines.*]

V. If the crude sewage or effluent was previously heated to 80° C. for ten minutes, a pathogenic effect could still be produced; but a much larger dose was generally required than when the liquid had not been so heated. Here death, when it occurred, was possibly due to *B. enteritidis sporogenes*, or, it may be to anaërobic micro-organisms of the *malignant œdema* group. These results would seem to indicate that the pathogenic effect of sewage and sewage effluents is not usually or primarily due to micro-organisms present in spore form, since a much larger dose is required when the liquid has been previously heated to 80° C.; unless, indeed, these microbes possess an increased pathogenic power in the presence of other germs not present as spores.

VI. If the crude sewage or effluent was filtered through a sterilised Pasteur's filter, very large doses of the filtrate failed to produce a pathogenic effect. This would seem to prove that it is not the extra-cellular products of the bacteria which by themselves produced the pathogenic result. But it is possible that filtration under the above conditions may render the bacterial products harmless where before they were noxious.

It is not proposed to give in detail the numerous experiments which have been carried out on animals; but a few experiments may be cited by way of illustration.

February 22nd, 1899.

(*a*) 1 c.c. Barking crude sewage injected subcutaneously in guinea-pig (called g.p. i).

(*b*) 1 c.c. effluent from Barking fine ragstone-bed injected subcutaneously in guinea-pig (called g.p. ii).

(*c*) 1 c.c. effluent from Barking fine coke-bed injected subcutaneously in guinea-pig (called g.p. iii).

February 23rd—g.p. i, poorly, with swollen belly; g.p. ii and iii, fairly lively, with less abdominal swelling.

February 24th—g.p. i, moribund; g.p ii and iii, in about the same condition as on the preceding day.

February 25th—g.p. i, dead. *Post-mortem examination*, showed thickening of abdominal wall and œdema, but not much sanguineous exudation.

March 1st—g.p. ii and iii, quite lively and well, except that g.p. ii, had some abdominal ulceration.

The animals (g.p. ii and iii) eventually recovered completely from the effects of the injection.

March 1st, 1899.

(*a*) 1 c.c. Crossness crude sewage injected intra-peritoneally in guinea-pig (called g.p. i).

(*b*) 1 c.c. Crossness effluent from 13 foot single coke-bed injected intra-peritioneally in guinea-pig (called g.p. ii).

March 2nd—g.p. ii, moribund, so killed.

March 3rd—g.p. i, dead.

March 29th, 1899.

(*a*) 1 c.c. Barking effluent from coarse ragstone-bed injected subcutaneously in guinea-pig (called g.p. i).

(*b*) 1 c.c. Barking effluent from coarse coke-bed injected subcutaneously in guinea-pig (called g.p. ii).

(*c*) 1 c.c. Barking effluent from fine ragstone-bed injected subcutaneously in guinea-pig (called g.p. iii).

(*d*) 1 c.c. Barking effluent from fine coke-bed injected subcutaneously in guinea-pig (called g.p. iv).

(*e*) 1 c.c. Crossness effluent from 13 foot coke-bed injected subcutaneously in guinea-pig (called g.p. v).

April 1st—g.p. i and g.p. iv, dead.

April 3rd—g.p. iii, dead.

April 4th—g.p. ii, and g.p. v, apparently quite recovered from the effects of the inoculation.

April 27th, 1899.

(*a*) 1 c.c. Crossness crude sewage injected subcutaneously in guinea-pig (called g.p. i).

(*b*) 1 c.c. Crossness effluent from 13 ft. coke-bed injected intra-peritoneally in guinea-pig (called g.p. ii).

(*c*) 1 c.c. Crossness crude sewage injected intra-peritoneally in guinea-pig (called g.p. iii).

(*d*) 1 c.c. Crossness effluent from 13 ft. coke-bed injected subcutaneously in guinea-pig (called g.p. iv).

April 29th—g.p. i, dead.

May 1st—g.p. iii, dead.

May 4th—g.p. iv, dead, g.p. ii, apparently quite recovered from the effects of injection.

November 28th, 1899.

(*a*) Barking effluent from B1 coke-bed, heated to 80° C. for ten minutes. Two c.c. injected subcutaneously in guinea-pig (called g.p. i). The animal remained apparently unaffected.

December 1st, 1899.

(*a*) 3 c.c. Barking crude sewage injected subcutaneously in guinea-pig (called g.p. i).

(*b*) Same as (*a*), but crude sewage previously heated to 80° C. for ten minutes (called g.p. ii).

The dose was apparently too large, as both g.p. i, and g.p. ii, died, but the former died first.

December 12th, 1899.

(*a*) 1 c.c. Barking crude sewage injected subcutaneously in guinea-pig (called g.p. i).

(*b*) Same as (*a*), but sewage previously heated to 80° C. for ten minutes, and 2 c.c. injected (called g.p. ii).

(*c*) Same as (*a*), but sewage previously heated to 100° C. for one hour, and 4 c.c. injected (called g.p. iii).

(*d*) Same as (*a*), but sewage first filtered through a sterilised Pasteur's filter, and 10 c.c. of the filtrate injected.

All the animals recovered from the effects of the injection except g.p. i.

IX. (A) THE VITALITY OF THE CHOLERA BACILLUS, B. PRODIGIOSUS, AND STAPHYLOCOCCUS PYOGENES AUREUS IN THE CRUDE SEWAGE AT THE SOUTHERN OUTFALL WORKS (CROSSNESS).

(B) THE INOCULATION OF THE THIRTEEN-FOOT COKE-BED AT THE SOUTHERN OUTFALL WORKS (CROSSNESS) WITH A SPECIAL SEWAGE MICROBE.

(C) EFFECT, AS REGARDS THE RESULTANT QUALITY OF THE EFFLUENTS FROM THE BACTERIA-BEDS, OF THE ADDITION OF CERTAIN CHEMICAL SUBSTANCES TO THE CRUDE SEWAGE AT THE NORTHERN OUTFALL WORKS (BARKING).

(A). *The vitality of the cholera bacillus, B. prodigiosus, and Staphylococcus pyogenes aureus in the crude sewage at the Southern Outfall Works (Crossness).*

The sewage was not sterilised, as sterilisation greatly alters the chemical composition of sewage, and the object of the experiments was to ascertain broadly whether these particular bacteria survive for any length of time in competition with the numerous other micro-organisms normally present in raw sewage.

(*a*) Vitality of the cholera bacillus in the crude sewage at the Southern Outfall Works (Crossness).

Experiment 1, *October* 24*th*, 1898.

Ten c.c. of Crossness crude sewage were poured into a sterile test-tube, and the tube was plugged with sterile wool. The contents of the tube were next inoculated with a platinum loopful of the cholera bacillus taken from a young gelatine culture. The tube containing the crude sewage (+ the cholera bacillus) was kept in a dark cupboard at the room temperature. In seeking to determine the viability of Koch's cholera vibrio the following plan was adopted. From time to time a loopful of the sewage was transferred to a tube containing sterile peptone solution (peptone 1 per cent.; NaCl 0·5 per cent.). The peptone tube was incubated at 37° C., and about twenty-four hours later a loopful of the liquid was taken from near the surface of the liquid in order to make stained cover-glass preparations for microscopic examination. A number of such preparations were made, and these were examined microscopically for the presence of Koch's vibrio.

The results obtained are shown in the following Table—

Date of inoculation of peptone solution from the tube containing the sewage *plus* the cholera vibrio.	Date of examination of peptone culture.	Descriptive number of cultures.	Remarks. Results of the examination of the peptone cultures.
1898 October 24 ... ... (Immediately after the inoculation of the sewage with Koch's vibrio)	1898 October 25	(1)	Cholera vibrios present in great abundance and almost in pure culture
October 25	„ 26	(2)	Vibrios could only be found after prolonged search
„ 26	„ 27	(3)	No difficulty was experienced in finding vibrios
„ 27	„ 28	(4)	Vibrios present in abundance
„ 28	„ 29	(5)	A positive result was with difficulty obtained
„ 31	November 1	(6)	„ „ „
November 1	„ 2	(7)	„ „ „
„ 2	„ 3	(8)	„ „ „
„ 3	„ 4	(9)	„ „ „
„ 4	„ 5	(10)	A doubtfully positive result
„ 9	„ 10	(11)	Only a few vibrios, but these were typical
„ 18	„ 19	(12)	Many vibrios, but most of them larger (longer and thicker) than normal
„ 24	„ 25	(13)	? Positive
December 5	December 6	(14)	Quite negative

It is to be noted that in culture (1) Koch's vibrio was present almost in pure culture, but in (2) it was demonstrated only with great difficulty. In (3) and (4), however, vibrios were present in abundance. In (5), (6), (7), (8), (9) cultures a positive result was arrived at only with great difficulty, and in (10) the result was only doubtfully positive. In (11) and (12) cultures, the diagnosis was more certain, but in the latter culture the microbe seemed to have become slightly altered, morphologically. In (13) there was a considerable element of doubt, and in (14) the result was quite negative.

The apparent rise and fall in the vitality of the vibrio during the progress of the experiment is of interest.

It is evident that the cholera vibrio is able to exist in Crossness crude sewage in competition with the numerous other microbes also present and under laboratory conditions of experiment for a considerable time.

Experiment 2, *October 26th*, 1898.

The experiment was a repetition of experiment 1, except that a much greater number of cholera germs was added to the sewage, viz., the whole of the surface growth from an oblique agar culture which had been incubated at 37° C. for three days. Indeed, the number of vibrios added was greatly in excess of the total number of micro-organisms in the sewage.

The results obtained were as follows—

Date of inoculation of peptone solution from the tube containing the sewage *plus* the cholera vibrio.	Date of examination of peptone cultures.	Descriptive number of cultures.	Remarks. Results of the examination of the peptone cultures.
1898	1898		
October 26 ... ... (Immediately after the inoculation of the sewage with Koch's vibrio)	October 27	(1)	Cholera vibrios present in great abundance
October 27	,, 28	(2)	A positive result was obtained only with difficulty
,, 28	,, 29	(3)	Vibrios found without difficulty
,, 31	November 1	(4)	,, ,,
November 1	,, 2	(5)	Only a few vibrios could be found
,, 2	,, 3	(6)	A positive result was obtained without much difficulty
,, 3	,, 4	(7)	Vibrios found without any difficulty
,, 4	,, 5	(8)	A positive result was obtained, but only after prolonged search
,, 9	,, 10	(9)	The result was negative
,, 18	,, 19	(10)	,, ,,
,, 24	,, 25	(11)	,, ,,
December 5	December 6	(12)	,, ,,

In this experiment, as in experiment 1, there was a difficulty experienced in finding the cholera bacillus in the peptone culture number (2), made only the day after inoculation. Yet in both experiments, no difficulty was experienced in arriving at a positive diagnosis as regards number (3) peptone culture. Notwithstanding the enormous number of vibrios added to the sewage, they appeared to die out much sooner than in the preceding experiment.

Speaking in general terms and dealing with both experiments, it may be said that under the above conditions of experiment the cholera vibrio may lose its vitality in less than a fortnight (experiment 2) or remain viable for nearly four weeks (experiment 1) when added to Crossness crude sewage.

(*b*) Vitality of *B. prodigiosus* in the crude sewage at the Southern Outfall Works (Crossness).

Experiment 3, *October* 24*th*, 1898.

In this experiment 10 c.c. of Crossness crude sewage were inoculated with *B. prodigiosus* (platinum loopful from a young agar culture). Although this micro-organism is occasionally met with in sewage, it is very rare in London raw sewage, and is therefore to be regarded as being in a sense an intruder. The tube containing the raw sewage (+ *B. prodigiosus*) was kept in a dark cupboard at the room temperature.

In seeking to determine the viability of this microbe in the sewage, the following plan was adopted—From time to time, a loopful of the sewage (+ *B. prodigiosus*) was taken and rubbed over the sloping surface of oblique agar tubes. These were kept at the room temperature, and the presence of *B. prodigiosus* was readily detected by the bright red colour produced by the growth of this microbe in agar cultivations.

The results obtained are shown in the following table—

Date of inoculation of the oblique agar tubes from the tube of sewage *plus B. prodigiosus.*	Descriptive number of cultures.	Results. As regards red growth on oblique agar tubes.
1898		
October 24 (Immediately after the inoculation of the sewage with *B. prodigiosus*)	(1)	Positive
October 25	(2)	"
" 26	(3)	"
" 27	(4)	"
" 28	(5)	"
" 29	(6)	"
" 31	(7)	"
November 1	(8)	" (only a few colonies)
" 2	(9)	" "
" 3	(10)	" "
" 4	(11)	" "
" 5	(12)	" (only 3 colonies)
" 7	(13)	" (only 1 colony)
" 9	(14)	" "
" 12	(15)	Negative
" 14	(16)	"
" 16	(17)	"
" 18	(18)	"
" 25	(19)	"
December 3	(20)	"

It is to be noted that *B. prodigiosus* retained its vitality in the crude sewage for sixteen days. Afterwards, it could not be found in any of the cultures. During the sixteen days *B. prodigiosus* remained alive, it was noted that, whereas at the start an abundant red growth showed itself in the agar cultures, towards the end of this period the number of red colonies developing was very small, and in cultures (12), (13), and (14), the number of red growths was only three, one, and one respectively. Speaking in general terms, it may be said that the number of *B. prodigiosus* decreased rather rapidly, and usually each successive culture showed less red growth than the one immediately preceding it.

Experiment 4, November 2nd, 1898.

This experiment was a repetition of experiment 3, 10 c.c. of Crossness crude sewage being inoculated with a platinum loopful of a recent growth of *B. prodigiosus* on agar.

The results obtained are shown in the following table—

Date of inoculation of the oblique agar tubes from the tube of sewage *plus B. prodigiosus.*	Descriptive number of cultures.	Results. As regards red growth on oblique agar tubes.
1898		
November 2 (Immediately after the inoculation of the sewage with *B. prodigiosus*)	(1)	Positive
November 3	(2)	"
" 7	(3)	"
" 9	(4)	" (only one colony)
" 12	(5)	" "
" 14	(6)	Negative
" 16	(7)	"
" 18	(8)	"
" 24	(9)	"
December 3	(10)	"

In this experiment, the *B. prodigiosus* remained alive for 10 days, but was not discoverable on the 12th, 14th, 16th, 22nd, or 31st day after inoculation.

Speaking of both the experiments, it may be said that under the above laboratory conditions of experiment *B. prodigiosus* in Crossness crude sewage either dies, or becomes so reduced in numbers as no longer to be capable of being readily isolated within a period varying from 10 to 16 days.

It would seem from these experiments as if the cholera bacillus were capable of existing in sewage for a longer time than the *B. prodigiosus.* This is assuming, of course, that the two different methods used for detecting these microbes were of equal delicacy, which is probably not actually the case.

(*c*) Vitality of *staphylococcus pyogenes aureus* in the crude sewage at the Southern Outfall Works (Crossness).

Experiment 5, *November 9th*, 1898.

In this experiment, 10 c.c. of Crossness crude sewage were inoculated with a platinum loopful of a young agar culture of *staphylococcus pyogenes aureus.* This pathogenic microbe has been described as being occasionally present in raw sewage. My own experience leads me to believe that it is only very rarely present in sewage. Certainly, it is to be regarded as a microbe foreign to the bacterial flora of ordinary sewage.

The tube containing the raw sewage (+ *St. pyogenes aureus*) was kept in a dark cupboard at the room temperature.

In seeking to determine the viability of this micro-organism in the sewage, the following plan was adopted. From time to time, a loopful of the sewage from the tube was taken and rubbed over the sloping surface of oblique agar tubes. These were incubated at 37° C., and the presence of *St. pyogenes aureus* was readily ascertained by observing the golden orange-yellow colour produced by the growth of this germ in agar cultures.

The results obtained are shown in the following table—

Date of inoculation of the oblique agar tubes from the tube containing sewage *plus St. pyogenes aureus.*	Descriptive number of cultures.	Results. As regards presence or absence of characteristic coloured growth of *St. pyogenes aureus.*
1898		
November 9 ... ... (Immediately after the inoculation of the sewage with *St. pyogenes aureus*)	(1)	Positive (decided growth)
November 10	(2)	„ „
„ 11	(3)	„ „
„ 12	(4)	„ „
„ 14	(5)	„ „
„ 17	(6)	„ „
„ 24	(7)	„ „
December 3	(8)	„ „
„ 14	(9)	Negative
„ 17	(10)	Positive (one colony)

In cultures made subsequent to December 17th, no colonies of *St. pyogenes aureus* could be found.

It is to be noted that up to the twenty-fourth day after the original inoculation, the presence of *St. pyogenes aureus* was easily demonstrated. But a negative result was obtained in the case of culture (9)—thirty-fifth day. Nevertheless, in culture (10) a single colony was discovered, *i.e.*, on the thirty-eighth day subsequent to inoculation. Later, the microbe was no longer discoverable in cultures made from the sewage.

From this experiment, it would seem that *St. pyogenes aureus* is capable of retaining its vitality in Crossness crude sewage for a considerable time.

In conclusion, and speaking in general terms of all the experiments, it may be stated that the cholera vibrio (pathogenic), *B. prodigiosus* (non-pathogenic), and *St. pyogenes aureus* (pathogenic) are capable of retaining their vitality for a considerable time in Crossness crude sewage notwithstanding competition with the very numerous bacteria normally present in the liquid. But it must be insisted upon that the conditions prevailing in laboratory test-tube experiments are widely different from those in operation in biological coke-beds. Nevertheless, when looking at the subject from the point of the epidemiologist, these experiments are far from reassuring, and, indeed, would seem to indicate that the antagonism of the saprophytic bacteria normally present in sewage would not suffice for the complete destruction of pathogenic species either in the sewers or, later, in the bacteria-beds. The bacteria-beds being purposely constructed so as not to hold back mechanically the suspended matters, it is to be feared, judging from the results of these experiments that the biological processes at work in the coke-beds would not rapidly destroy the life of pathogenic microbes; although they might inhibit the multiplication of pathogenic germs accidentally introduced into the crude sewage, it appears that the effluents from the beds ought to be regarded as doubtfully more safe in their possible relationship to disease than the raw sewage itself. It must be remembered, however, that the number of the pathogenic germs added to the sewage in these experiments was vastly greater than could conceivably take place under natural conditions, and that, notwithstanding the enormous number introduced, there was definite indication of a somewhat rapid decrease in their numbers.

For records relating to the passage through the bacteria-beds of pathogenic germs habitually or occasionally present in crude sewage, reference must be made to other sections of this book.

(B) *The inoculation of the 13-foot coke-bed at the Southern Outfall Works (Crossness) with a special sewage microbe.*

Most observers who have had any practical experience of the so-called biological treatment of sewage are agreed as to the necessity of treating *new* bacteria-beds, until they have become thoroughly *matured*, with small but gradually increasing doses of raw sewage. Further, it is generally believed that a *mature* bed is one which has become by a natural process of selection *charged* with the special bacteria concerned in the work of purification. By varying the conditions in a number of ways, changes, favourable or the reverse, may readily be induced. For example, by overtaxing the coke-beds with sewage a change commonly spoken of as "*sickening*" may set in when in the effluent the chemical results will no longer be satisfactory. In such a case, it may be conjectured that the wrong kind of bacteria have gained the ascendency. Conversely, by greatly diminishing the amount of sewage to be "*treated*," a conspicuously good effluent may often be obtained. Here presumably the special bacteria are able to multiply abundantly and to exercise their specific qualities to the best advantage. The precise kind of bacteria which are directly beneficial as distinct from those which act as intruders is not yet clearly known, although the broad fact that putrefactive and nitrifying germs are necessary has long been established. Nor is it properly understood under what conditions the special bacteria should be placed, in order to allow them to exercise their beneficial qualities to the best advantage. Bacterial processes so widely different as those which aim at encouraging the growth of aërobic micro-organisms and those which are esentially or largely anaërobic in character, have been put in operation by different workers. And each observer claims for his own process peculiar advantages. But it will be gathered from what has been said that probably all the bacterial processes in practical operation at the present time aim at allowing certain bacteria or groups of bacteria to gain the ascendency by a *natural process of selection*.

Although this is certainly a rational method of "*treating*" sewage, it is conceivable that the future of the biological treatment of sewage may possibly lie in the direction of a real or apparent interference with nature's methods. In the absence of absolute knowledge as to the exact conditions under which sewage should be placed, so as either in one or a succession of stages to foster the growth of the bacteria directly concerned in the work of purification and to inhibit the growth of unnecessary or harmful germs, it is possible that the addition (continuously or intermittently) of pure cultures in large amount of selected microbes might exercise a beneficial effect. The kinds of bacteria suited for this purpose and the conditions under which they should be added cannot safely be affirmed in the present state of our knowledge. The experiments, which might occupy several stages, should be conducted so as to aid or co-operate with nature rather than with the object of interfering with or upsetting the natural order of things. Further experiments might be carried out in connection with bacteria-beds already for some time in operation; or new beds might be sown with special bacteria previous and preparatory to the application of sewage. It is conceivable that they might be divided into two stages—the first aërobic or semi-anaërobic, the bacteria used belonging to the class of putrefactive aërobes and facultative anaërobes; the second stage purely aërobic, the micro-organisms involved in the process being those of nitrification; or, preliminarily to the above, and as an initial stage, anaërobic bacteria might be employed. Lastly, the experiments might be conducted from the epidemiological point of view rather than with the sole object of obtaining an effluent chemically pure. For as it is known that certain micro-organisms are antagonistic to others, the special bacteria selected might be saprophytes, the products of whose growth act as bactericidal agents to pathogenic germs.

Of course, it will be argued that nature's own methods are the best, and that any interference with the natural course of events is not to be recommended, and that it would be wise first to determine more accurately the precise functions of the different bacteria concerned in the work of the purification of sewage before proceeding to add special bacteria to a liquid or to a bacterial bed already harbouring all the known microbes of putrefaction and nitrification.

Such contentions are certainly justifiable, but it is to be thought of that the path to knowledge does not always lie along the most direct route, and accident has before now revealed the truth where experiments conducted on apparently sound lines have entirely failed.

Although, as regards the so-called biological treatment of sewage, the results obtained in the past have been most encouraging, at all events, from the chemical point of view, it is now clearly established that all the different processes which have been tried, present serious limitations which at the present time seem almost insuperable in character.

It is conceivable that both from the practical and epidemiological point of view, a solution of the problem of sewage disposal may lie in one or other of the directions that has been indicated.

The stress of work involved in the periodical examination of the crude sewage and effluents from the coke-beds made it impossible to carry out any prolonged research of the above nature.

Nevertheless, one experiment was tried, and although attended with apparently negative results, its description will not be out of place.

It will be remembered that in previous Reports it was shown that a gas-forming proteus-like germ which rapidly liquefied gelatine was present in London crude sewage in numbers usually exceeding 100,000 per c.c. This microbe was also found to be present in the effluents in very large numbers. Its ability to form gas, its rapid peptonising action and its abundance seemed to indicate that it was possibly a microbe specially concerned in the work of purification. Accordingly, it was determined to isolate a strain of this micro-organism from an effluent, to cultivate it on a large scale, and to add it in great amount to the crude sewage during the ordinary process of filling a matured coke-bed.

Three strains of "*sewage proteus*"* were isolated from $\frac{1}{10000}$ c.c. of effluent from the primary coarse-bed B at Barking (December 6th, 1899). They all grew luxuriantly at blood-heat, formed gas in twenty-four hours in gelatine shake cultures, liquefied gelatine very rapidly, and were very motile. One proved virulent when injected into a guinea-pig; another produced a strong local reaction, but the animal recovered, while the third was apparently non-pathogenic. This last microbe was that used for experiment.

700 c.c. of agar were added to about 70 tubes and sterilised. The agar was allowed to solidify obliquely in the test tubes. The tubes were next inoculated with the "sewage proteus" and incubated at 20° C.

The growth from each of the tubes was transferred to sterile bouillon (1,500 c.c.), and the mixture of bacteria and broth used to inoculate the crude sewage as it flowed on to the 13-foot coke-bed at Crossness. This involved the addition of billions of *B. proteus* to the sewage.

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* The morphological and biological characters of "*sewage proteus*" are described in Section X.

The experiment was carried out in the following way—

On December 19th, 1899, the bacterial mixture (1,500 c.c.) was added to the crude sewage (about 6,000 gallons) as it flowed on to the coke-beds, the addition being made in small quantities at a time, so as to cover the whole of the period occupied in filling the bed, namely, about twenty minutes.

The bed was allowed to remain full for the usual period, namely, three hours, and it was emptied in the usual manner.

During the process of emptying, and especially during the first flow of the effluent, a number of vessels—in bulk representing approximately 30 gallons—were filled with the effluent and kept in a warm place.

When the time arrived for re-filling the coke-bed, the contents of the vessels were added to the sewage flowing on to the bed.

Further, when, after the usual period, the bed was again emptied, the vessels were again filled with the first flow of the effluent.

The above series of operations was carried out until December 22nd, *i.e.*, the crude sewage (about 6,000 gallons) as it flowed on to the coke-bed was first charged on December 19th with a mixture of *B. proteus* and broth (1,500 c.c.) (the microbes being present in number inconceivably great), and subsequently on six other consecutive occasions with the first flow of the effluent from the previous emptying of the coke-bed.

Most unfortunately at this period circumstances arose which made it impossible to test the value of the experiment from the biological point of view. This is greatly to be regretted, as it would have been of interest to have known whether *B. proteus* was more numerous in the effluent than normally, and, if so, how long such numerical superiority was maintained. Further, whether its presence exercised any inhibiting influence on any of the other bacteria usually found in the crude sewage and effluents.

Mr. Biggs, the chemist in charge at the Southern Outfall Works, kept careful notes during the above period. He was unable either from the chemical or practical point of view to arrive at any other conclusion than that the experiment yielded quite negative results. That is to say the inoculation of the coke-bed with *B. proteus* did not produce any appreciable alteration in the effluent either as regards its chemical composition or physical appearance; nor was the capacity of the coke-bed increased. The result may, nevertheless, not have been negative from the bacteriological point of view. Possibly, if the effluents had been tested bacteriologically, well-defined changes extending over a longer or shorter period might have been observed in the bacterial composition of the liquid. It is conceivable also that if *B. proteus* had been added in still greater amounts and for a longer period, totally different results might have been obtained. To upset the biological equilibrium of a *mature* coke-bed of the large capacity of the 13-foot bed at Crossness would naturally call for the addition of an enormous number of micro-organisms.

In conclusion, it must be insisted upon that the apparently negative character of this single experiment in no way disproves the advisability of abandoning research carried out on the lines that have been here briefly indicated.*

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* These experiments were carried out in 1899. I am less sanguine now (1903) of the possibility of success in the above directions of experiment. But I give my description of the experiment in the form in which it originally appeared.

(C). *The effect, as regards the resultant quality of the effluents from the bacteria-beds, of the addition of certain chemical substances to the crude sewage at the Northern Outfall Works (Barking).*

It is known that some species of micro-organisms act with great vigour in the presence of a large excess of certain basic substances. For example, the nitrifying germs show increased bacterial activity when grown in liquid media containing an excess of magnesium or calcium carbonate. It is supposed that the solid grains, besides neutralising the products of bacterial activity, act as what may be termed "contact points," enabling the bacteria to localise and concentrate themselves at a multitude of different spots. Further, if the liquid is in motion the grains may act as "carriers" of the microbes and their products from one place to another.

It is a matter of controversy among those who have practical concern with bacteria-beds which is the best material to use. Some assert that the actual chemical composition of the substance is of no importance, that it is the physical qualities (*e.g.*, whether smooth or jagged, pervious or impervious) of the material which is all-essential. Others believe that certain substances are preferable to all others, in virtue of their ability of exerting a basic action on the products of bacterial growth and of encouraging the active growth of special micro-organisms. However this may be, it is of interest to note that Mr. E. Brooke Pike, the chemist in charge at Barking, suggested the trial of ragstone as a better material in respect of its chemical composition than coke. This was agreed to by Dr. Clowes, and accordingly a trial was made of the comparative values of ragstone and coke bacteria-beds. The outcome of these experiments seemed to be that the ragstone coke-bed did encourage the growth of the nitrifying germs (as evidenced by an increased production of oxidised nitrogen), but that the effluents, as regards the removal of dissolved oxidisable and putrescible matter, were not so satisfactory from the ragstone as from the coke-beds.

Although it is quite conceivable that the actual chemical composition of the material in a bacteria-bed, quite apart from its physical characters, may play a definite part in influencing the biological processes at work in the bed, it is evident that the action, whatever it may be, cannot be expected to persist for an indefinite period.

With this idea in view, I suggested the trial of the artificial addition, in small amounts, of some such substance as magnesium carbonate or calcium carbonate to the sewage as it flowed on to the beds, with the object of enabling the added salt to produce a beneficial effect by its diffusion throughout the liquid in the beds and also by settling on the surface of the fragments of coke and effecting a lodgment there. It was hoped that not only would the result be immediately beneficial, but that the good effect would be maintained for a considerable period after the addition of the substance had ceased. In short, that it would only be necessary occasionally and very rarely to resort to such an artificial measure in order to obtain uniformly good results. With Dr. Clowes's permission, Mr. E. Brooke Pike was good enough to carry out some very careful experiments in this direction.

In the first series of experiments he added magnesium carbonate emulsion to the crude sewage, as it flowed on to the beds, in such strength as to correspond to 0·001 part of magnesium carbonate to every

100 parts of raw sewage.* This was done each time the beds were filled, viz., twice a day between Wednesday, 21st March, 1900, and Wednesday, March 28th, 1900, both days inclusive.

The results as regards oxidised nitrogen and oxygen absorbed from permanganate were as follows—

Oxygen absorbed from permanganate in four hours at 80° F.

Parts per 100,000.

	Crude sewage.	Effluent from primary coarse bed; series A.	Effluent from secondary coarse bed; series A.	Effluent from primary coarse bed; series B.	Effluent from secondary fine bed; series B.
Average of determinations made on March 7, 8, 9, 10, 12, 13, 14, 16, 19, 20, 1900					
Before the addition of magnesium carbonate	6·740	3·410	2·280	3·420	1·780
Purification	...	49·4 per cent.	66·2 per cent.	49·3 per cent.	73·6 per cent.
Average of determinations made on March 21, 22, 23, 24, 26, 27, 28, 1900.					
During the addition of magnesium carbonate	7·343	3·460	2·429	3·343	1·886
Purification	...	52·9 per cent.	66·9 per cent.	54·5 per cent.	74·3 per cent.
Increase in purification ...	...	3·5 per cent.	0·7 per cent.	5·2 per cent.	0·7 per cent.

Nitrogen as nitrates.

Average of determinations made on March 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 19, 20, 1900.					
Before the addition of magnesium carbonate	...	·3726	1·2113	·3334	2·0238
Average of determinations made on March 21, 22, 23, 24, 26, 27, 28, 1900.					
During the addition of magnesium carbonate	...	·4469	1·1854	·4439	2·3935
Increase in amount of oxidised nitrogen	...	+ 19 per cent.	− 2 per cent.	+ 33 per cent.	+ 18 per cent.

It will be noted that none of the beds showed an appreciable improvement as regards removal of dissolved oxidisable matter, as the result of the magnesium carbonate treatment.

The figures as regards oxidised nitrogen were more encouraging. Thus, with the exception of the secondary coarse bed (A), where there was a decrease equal to 2 per cent., all the other effluents showed a definite increase of nitrates amounting to 19, 33, and 18 per cent. respectively as regards the effluents from the primary coarse bed (A), the primary coarse bed (B), and the secondary fine bed (B).

In a sense, there was a double gain as a result of the treatment, because the effluents contained a slightly smaller amount of putrescible matter and also carried with them into the river a greater amount of an oxidising substance.

But while the results are of considerable interest from the scientific point of view as affording some confirmation of theoretical considerations, it can hardly be said that they are of equal importance from the practical point of view. They do not, in short, indicate the advisability of continuing the addition of magnesium carbonate as a measure of *practical utility*.

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* This minimal quantity (·001 per cent.) was used as a preliminary, as it did not seem desirable to increase materially the suspended matters in the sewage.

In the second series of experiments Mr. E. Brooke Pike added, as well as magnesium carbonate, a like quantity (viz. 0·001 per cent.) of sodium carbonate.

Without entering into detail, it may be said that the results were no longer satisfactory, and indeed showed a general decrease in respect of nitrate production and of removal of dissolved oxidisable matter. The amount of sodium carbonate added was presumably too small to inhibit bacterial growth, and it is difficult to explain the falling off in the results, unless it be assumed that the sodium carbonate actually increased the vital activity of the micro-organisms in general, but in particular of the de-nitrifying germs and those specially concerned in producing putrefactive changes.

In conclusion, it may be said that further and more prolonged experiments seem desirable with magnesium carbonate and calcium carbonate, as well as with other substances. These might be tried in varying amounts and added continuously or intermittently. The experiments, of course, which have been described were merely of a tentative character. They may serve, however, to indicate a line of inquiry, which has hitherto been neglected, and is not devoid of scientific interest and possibly of practical importance.

X. DESCRIPTION OF SOME OF THE BACTERIA FOUND IN THE CRUDE SEWAGE AND IN THE EFFLUENTS FROM THE COKE-BEDS.

1. B. coli.
2. B. mesentericus.
    - Sewage Variety E.
    - Sewage Variety I.
3. Sewage Proteus.
4. B. frondosus.
5. B. fusiformis.
6. B. subtilissimus.
7. B. subtilis.
    - Sewage Variety A.
    - Sewage Variety B.
8. B. membranceus patulus.
9. B. capillareus.

1. *B. coli.*

[An aërobic (facultative anaërobic) non-chromogenic, motile, non-liquefying bacillus.]

Source.—The excreta of human beings and many of the lower animals. Very abundant in London crude sewage; usually more than 100,000 per c.c. of sewage.

*Morphology.**—Small bacilli with rounded ends, sometimes hardly longer than broad, at other times cylindrical in shape.

Motility.—Very variable. Sometimes only feebly motile, but many strains of *B. coli* isolated from crude sewage are actively motile.

Spore formation.—No spores are formed.

Flagella.—Dr. M. H. Gordon gives the flagella average as 1 to 3. But multi-flagellated coli-like microbes are not uncommon.

Temperature.—Grows best at 37° C., but also very well at the ordinary temperature.

Gelatine plate cultures.†—The colonies develop in from 24 to 48 hours at 20° C. The deep colonies are not characteristic, the surface colonies peculiarly so, appearing as delicate, slightly granular films, of an irregularly circular shape, which are bluish-white by reflected and of an amber colour by transmitted light; they are transparent, and sometimes iridescent, especially towards the periphery, but at the centre and over the entire surface in old cultures an opacity due to a greater thickness of the bacterial growth is observed; later these surface colonies may become marked by concentric, or radiating, or irregular markings. The surrounding gelatine frequently acquires a dull, cloudy, faded appearance. The gelatine is not liquefied.

Gelatine "stab" culture.—The growth on the surface is like a surface colony in a plate culture, but tends to be more luxuriant, due to the greater thickness of the medium. A white growth extends to the foot of the stab, and gas fissures frequently appear in the gelatine. The gelatine, as already stated, is not liquefied.

Gelatine "streak" culture.—The growth is like an elongated surface colony in a gelatine plate culture, but is, perhaps, more luxuriant. Briefly, a delicate faintly granular film forms, with transparent and irregular margins. Down the centre, longi-

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* Fig. 35.

† Fig. 36; also fig. 37.

tudinally, the growth is more opaque. Sometimes the film shows iridescence, and in old cultures it may become irregularly thickened. The gelatine, which is not liquefied, often becomes clouded. The growth, which is bluish-white by reflected light, has a yellowish amber colour by transmitted light.

Potato-gelatine plate, "stab" and "streak" cultures.—The growth is somewhat similar in appearance to the above, but tends to be more circumscribed, is slower, and of a characteristic brown colour.

Proskauer and Capaldi media (I. and II.).—Medium I. Positive both as regards growth and acidity. Medium II. Positive as regards growth, but no definite acidity. Yet it is probable that varieties of *B. coli* exist which may yield anomalous results.

Neutral-red tinted media.—Greenish-yellow fluorescence, but some varieties of *B. coli* fail in this respect.

*Gelatine "shake" cultures.**—Numerous gas bubbles are formed, usually in 24 hours, at 20° C.

Agar plate cultures.—The growth is not so characteristic as in gelatine. The superficial colonies have a moist glistening white appearance.

Agar "stab" cultures.—Growth occurs all the way down the stab, and on the surface a white layer is developed.

Agar "streak" cultures.—At 37° C. the growth is very rapid, and occurs as an abundant moist and white layer.

Potato cultures.—A rich yellowish-brown layer quickly developes, but some coli-like microbes give a transparent growth.

Broth cultures.—The growth is characteristic. In less than 24 hours, at 37° C., the broth is uniformly turbid. Later, a heavy bacterial deposit collects at the foot of the tube. There is no distinct pellicle formation, but sometimes an imperfect scum forms on the surface.

Litmus milk cultures.—The growth is extremely characteristic. Usually, an acid solid clotting of the milk takes place in 24 to 48 hours at 37° C. Occasionally the clotting is somewhat delayed. First of all, the bluish-purple colour changes to pink; then clotting occurs, and the milk, except at the free surface, becomes white. Later, the redness extends from the surface downwards until the whole contents of the tube are bright red in colour. Some coli-like microbes, however, do not clot milk and produce only feeble acidity. Others again produce alkali.

Blood serum cultures.—An abundant white layer is quickly developed at 37° C.; there is no liquefaction.

Indol reaction.—Indol reaction is usually well marked in broth cultures kept at 37° C. for five days. But some coli-like microbes yield a negative result.

Reduction of nitrates.—In 24 hours, at 37° C., reduction of nitrates to nitrites well marked. [Broth 5 per cent., KNO_3 0·1 per cent., water 94·9 per cent.]

Agglutination test.—The sera of patients suffering from enteric fever and of typhoid immunised animals commonly give a negative result. Nevertheless, some coli-like microbes yield a positive result.

Glucose (1 *per cent.*), *peptone* (2 *per cent.*), *litmus cultures.*—In 24 to 48 hours at 37° C., gas formation and acid production.

Lactose (1 *per cent.*), *peptone* (2 *per cent.*), *litmus cultures.*—In 24 to 48 hours at 37° C. gas formation and acid production. Some coli-like microbes yield negative results.

Cane-sugar (1 *per cent.*), *peptone* (2 *per cent.*), *litmus cultures.*—The results are variable. Some coli-like microbes produce gas and the medium presents a bleached appearance. The majority, however, of typical *B. coli* yield negative results.

Dulcit (1 *per cent.*), *peptone* (2 *per cent.*), *litmus cultures.*—The results are variable Some coli-like microbes ferment dulcit, others yield negative results.

Litmus-whey cultures.—In four days, at 37° C., the majority of *B. coli* produce acid in amount equivalent to over 30 c.c. $\frac{N}{10}$ Na_2CO_3 per 100 c.c. of culture medium.

Lactose (1 *per cent.*), *peptone* (2 *per cent.*), *milk* (20 *per cent.*), *sodium carbonate* (0·1 *per cent.*), *litmus cultures.*—The great majority of *B. coli* produce gas, acid and clotting of the medium in 24 to 48 hours at 37° C.

Remarks.—*B. coli* is one of the most abundant and most characteristic of sewage bacteria. In this book it has been shown that its number may exceed 100,000 per c.c. of London crude sewage. It has likewise been shown that *B. coli* survives the processes at work in the bacteria-beds at the Outfall Works. Apart from its alleged function as one of nature's scavengers, *B. coli* is of great importance from the point of view of the bacterioscopic examination of water.

It has been asserted that *B. coli* is abundant everywhere, that it multiplies outside the animal body, that it is present in the intestinal contents not only of human beings but of the higher mammals and birds, and that, therefore, its value as an indication of pollution of water of possibly dangerous sort is *nil*. The fact remains that in crude

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* Fig. 38.

sewage *B. coli* is present in numbers exceeding 100,000 per c.c., and is absent (or relatively so) from waters free from suspicion of animal pollution. Moreover, if *B. coli* multiplies outside the animal body under favourable conditions, it also loses its vitality under unfavourable conditions, and we have yet to learn that the excrement of healthy, much less of diseased, mammals and birds is altogther harmless to man.

B. coli may be pathogenic, but can hardly be considered pathogenic in the ordinary sense of the term. Its presence serves rather as an index of the possible presence of other and more objectionable kinds of bacteria.

It will be noted that not only the presence of *B. coli* in the various samples of crude sewage and effluents has been determined, but also that a record has been kept of its relative abundance. Until such records are obtained, not only as regards *B. coli*, but as regards many other species of micro-organisms, the usefulness of bacteriology is restricted.

2. *Bacillus Mesentericus.*

	Sewage Variety E.	Sewage Variety I.
	[An aërobic, non-chromogenic, actively motile, slowly liquefying bacillus.]	[An aërobic, non-chromogenic, motile, rapidly liquefying bacillus.]
Source.	London crude sewage; gelatine plate cultures heated to 80° C. for 10 minutes.	London crude sewage; gelatine plate cultures heated to 80° C. for 10 minutes.
Morphology.	Long bacilli, with rounded ends; in pairs and long chains.[*]	Medium-sized bacilli, with rounded ends; solitary,[†] in pairs and chains.
Motility.	Actively motile.	Exceedingly rapid movement.
Spore formation.	Readily forms spores.	Readily forms spores.
Flagella.	A multi-flagellated organism.[‡]	A multi-flagellated organism.[§]
Temperature.	Grows well at the room temperature, and exceedingly rapidly at 37° C.	Grows very rapidly at the room temperature, and with great rapidity at 37° C.
Gelatine plate cultures.	The growth is not very rapid. The deep colonies have a somewhat starlike appearance; the superficial colonies appear as bluish-white, delicate, granular films, which are almost coli-like in character. These surface colonies are somewhat irregular in shape, and from the wavy, transparent edge irregular processes are given off. Under a lower power of the microscope, the deep colonies show a central darkish yellow spot, from which root-like processes are given of. The surface colonies are transparent, granular, and striated, and from the spreading edge delicate processes are given off, which spread over the surface of the gelatine, forming often curious and intricate patterns. The colonies do not attain a large size, and liquefaction only slowly sets in.	The growth is characteristically rapid. The deep colonies quickly reach the surface, to form large areas of liquefied gelatine, which become saucer-shaped, and are greyish-white in colour and almost translucent.[‖] From the edge of these saucer-shaped surface colonies, processes may be given off which are almost of the nature of "swarming islands." These almost translucent areas of liquefied gelatine are rendered greyish-white by the presence of innumerable bacteria, and these bacteria may be gathered together in clumps so as to give rise to a mottled appearance. A thin bacterial film tends to form on the surface of the liquefied gelatine. In a very few days the whole plate is completely liquefied. Under a low power of the microscope, the deep colonies are dark in colour and granular. The surface colonies at first may be almost completely translucent and of an irregular, star-shaped form, but soon form large circular areas of liquefied gelatine, in which the extraordinarily rapid movement of the individual bacilli can be clearly watched.

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[*] See fig. 39. [†] See fig. 41. [‡] See fig. 40.
[§] See fig. 42. [‖] See fig. 43.

Gelatine "stab" cultures.

The growth at the surface is slow, and resembles the growth of a superficial colony in gelatine plate culture. Growth takes place all the way down the stab, accompanied by slow liquefaction; delicate tuft-like filaments are given off all down the line of the inoculation. These extend more and more deeply into the solid gelatine as growth proceeds. Gradually at the surface, liquefaction sets in, showing itself at first merely by a slight central pitting of the bacterial film. Later, the liquefaction spreads, and the delicate details of growth are lost.

Rapid liquefaction takes place nearly if not quite to the foot of the stab and in funnel form.* Very soon the liquefaction spreads to the walls of the tube and increases rapidly from above downwards, as well as from the stab in on outward direction. The liquefied gelatine has a greyish-white translucent appearance, and has also a somewhat flocculent appearance due to aggregation of little masses of bacteria. Very soon the whole contents of the tube are completely liquefied and converted into a greyish-white turbid fluid.

Gelatine "streak" cultures.

A delicate granular film forms on the surface of the gelatine which is of somewhat limited extent. Liquefaction slowly sets in and shows itself as a longitudinal furrow. After some days, the film changes its appearance and shows numberless fine processes radiating outwards and upwards from the central line. Tuft-like processes also extend into the solid gelatine. As liquefaction proceeds, all the delicate details of growth becomes lost.

The growth is not characteristic, as the liquefaction is so rapid that the peptonised gelatine runs down the oblique surface to the foot of the tube, and in a few days the whole of the contents are converted into a turbid greyish-white liquid.

Gelatine "shake" cultures.

No gas bubbles are formed; the gelatine is slowly liquefied.

No gas bubbles are formed; the gelatine is rapidly liquefied.

Agar plate cultures.

In agar plate cultures at 37° C., the growth is so rapid and the colonies spread so much laterally, that frequently the whole plate is covered with a granular dirty yellowish-white film in 24 hours. The spreading edge is often broken up into processes of most varied shape, which frequently form tree-like patterns.

In agar plate cultures at 37° C., the growth is so rapid that it is difficult to obtain discrete colonies. The growth is yellowish-white, granular, and often of unequal thickness. The spreading edge has less tendency to form tree-like patterns than in the case of *B. mesentericus E.*

Agar "stab" cultures.

In 24 hours at 37° C., there is growth all down the stab, and the surface of the medium is covered with a yellowish-white granular layer, which later may become wrinkled.

In 24 hours at 37° C., there is growth all down the stab, and the surface of the medium is covered with a yellowish-white granular layer, which later may become wrinkled.

Agar "streak" cultures.

In 24 hours at 37° C., a dirty yellowish-white film has nearly covered the whole oblique surface. The spreading edge may extend as irregular processes forming leaf-like patterns. Later, the film darkens in colour and becomes wrinkled.

In 24 hours at 37° C., a dirty yellowish-white film has nearly covered the whole oblique surface. The spreading edge may be lobed or fissured and of unequal thickness. The film darkens in colour and becomes wrinkled.

Potato cultures.

The growth is extremely characteristic. At 37° C. in 24 hours, the whole surface of the potato is covered with a thin yellowish-white film, which has a characteristic folded, creased and wrinkled appearance. There is an appearance also as of blisters: these dry up, leaving deeply wrinkled skins. The substance of the potato takes on a bright pink colour. Later, the film becomes thicker, more deeply pitted and wrinkled, and the colour becomes brown.

The growth is extremely characteristic. In 24 hours at 37° C., the whole surface of the potato is covered with a thick greyish-white moist skin, which is thrown into multiple folds, creases and wrinkles.† The colour rapidly changes from greyish-white to yellow, and then to brown. The growth, if touched with a platinum needle, is found to be held to the potato by a viscous substance which can be drawn out into long threads.

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* See fig. 44.

† See fig. 45.

Broth cultures.

The growth at 37° C. is characteristic even in 24 hours. A greyish-white wrinkled film is formed at the surface, and the liquid below is almost clear. Later the film thickens and becomes deeply pitted and wrinkled.	The growth at 37° C. is characteristic even in 24 hours. A greyish-white wrinkled film is formed at the surface, and the liquid below is almost clear. Later the film thickens, and the wrinkled appearance becomes more marked. The film acquires a reddish-brown colour, and the liquid below, which remains nearly transparent, also becomes a reddish-brown colour.

Litmus milk cultures.

In 24 hours at 37° C., slight discoloration has taken place. In 48 hours, the liquid is of a dirty yellowish-white colour, with a tinge of red; no clot. In 72 hours, a weak clot has formed, and the liquid near the surface is semi-transparent. On gently shaking the tube, a pinkish tinge developes. In five days, the clot lies at the foot of the tube as a dirty white mass; above this, the liquid is transparent and of a faint yellow colour, which on shaking changes to a pink tint.	In 24 hours at 37° C., the bluish-purple colour of the milk is changed to a dirty yellowish white; no clot. In 48 hours no clot, but the milk rapidly becomes transparent. In 72 hours, the whole of the contents of the tube are semi-transparent and of a dirty yellowish colour. On gently shaking the tube, the liquid assumes a crushed strawberry colour.

Blood serum cultures.

At 37° C., and in less than 24 hours, nearly the whole of the oblique surface of the medium has become covered with a deeply wrinkled skin. Later, slow liquefaction sets in, and in about 16 days the blood serum is completely liquefied.	At 37° C., decided liquefaction takes place in less than 24 hours, and on the surface of the liquid, at the foot of the tube, a wrinkled skin is formed. Later, the blood serum is completely liquefied.

Indol reaction.

No indol is formed.	No indol is formed.

Reduction of nitrates to nitrites.

[Broth 5 per cent., KNO_3 0·1 per cent., water 94·9 per cent.]

Great reduction of nitrates to nitrites in 24 hours at 37° C.	No reduction of nitrates to nitrites in 24 hours at 37° C.

Remarks.

Resembles very closely, if it is not identical with, *Bacillus mesentericus ruber*.	The micro-organism is constantly present in sewage in the form of spores; 10, 20, 30 or more spores per c.c. of London crude sewage may be found. It is present in considerable numbers in the effluents from the bacteria-beds. It resembles closely *B. mesentericus vulgatus*, *B. mesentericus fuscus* and *B. liodermos*, and is perhaps most closely allied to, if it is not identical with, *B. mesentericus vulgatus*.

3. "*Sewage Proteus.*"

[An aërobic, non-chromogenic, actively motile, rapidly liquefying bacillus.]

Source.—Very abundant in London crude sewage; frequently as many as 100,000 per c.c. of crude sewage.

*Morphology.**—Small bacilli, with rounded ends; solitary, in pairs, or sometimes in short chains; involution forms may occasionally be seen.

Motility.—Actively motile.

Spore formation.—No spores are formed.

Flagella.†—Each rod is possessed of a single flagellum. Quite possibly, however, there may be multi-flagellated varieties otherwise practically indistinguishable from the one here described.

Temperature.—The original culture grew better at 20° C. than at 37° C., but later investigation seemed to show that most strains grow luxuriantly at blood-heat.

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* See fig. 46.

† See fig. 47.

Gelatine plate cultures.[*]—In less than 24 hours at 20° C., the surface colonies appear as delicate granular films of irregular shape. In two days, the colonies look like "punched out" circles containing liquefied gelatine, and greyish-white bacterial deposit. The masses of bacteria lying in the liquefied gelatine usually give a mottled appearance to the colonies. Viewed under a low power of the microscope, the individual bacilli can be made out, and their active movement watched; the colonies appear darkest centrally and at the circumference, and here and there darker spots may be seen in the liquefied and granular-looking gelatine. The colonies are usually exactly circular in shape with well-defined borders, and no "swarming islands" appear to be given off, as in *proteus vulgaris*. By the third or fourth day, the plate is completely liquefied, the gelatine being converted into a turbid greyish-white liquid.

Gelatine "stab" cultures.[†]—*The growth is very characteristic.*—In 24 hours at 20° C., liquefaction has occurred all the way down the path of the needle, and minute bubbles of gas may be watched rising through the turbid, greyish-white liquefied gelatine to the surface. In 48 hours, the liquefaction is very much more pronounced; numerous bubbles of gas may be seen at the surface, and also bubbles in the solid gelatine. The bacteria collect at the foot of the liquefied portion as a greyish-white deposit. In four or five days, the whole of the gelatine is converted into a greyish-white liquid. If such a culture be heated to 80° C. for 20 minutes, the bacilli are killed, but if, after cooling, a portion of the fluid be added to another tube containing solid gelatine, the gelatine in this second tube becomes liquefied.

Gelatine "streak" cultures.—The gelatine is liquefied so rapidly that all details of growth are lost.

Gelatine "shake" cultures.[‡]—In 24 hours at 20° C., numerous gas bubbles are formed, and the gelatine is liquefied near the surface.

Agar plate cultures.—The growth is not characteristic. The colonies are more or less circular in shape, they are greyish-white in colour and have a somewhat moist glistening appearance.

Agar "stab" cultures.—There is growth all down the stab; gas bubbles may form in the medium; on the surface the growth is like a surface colony in an agar plate culture. In old cultures, the surface growth becomes of a brownish colour.

Agar "streak" cultures.—The growth is rapid, but not specially characteristic. A greyish-white layer having a moist glistening appearance is formed, which may extend nearly to the walls of the tube.

Potato cultures.—The growth is not characteristic; a slimy, thin, yellowish-white growth appears on the surface of the potato.

Broth cultures.—Abundant diffuse cloudy growth in 24 hours at 20° C.

Litmus milk cultures.—The growth at 20° C. in litmus milk culture may be described as an acid change from an opaque bluish-purple coloured liquid to a semi-transparent reddish-coloured fluid. The redness is chiefly near the surface, but if the tube be shaken the whole of the contents of the tube assume a crushed strawberry tint. If clotting occurs, it is imperfect in character and possibly the clot is dissolved as soon as it is formed.

Blood serum cultures.—Rapid growth, accompanied by liquefaction.

Indol reaction.—Usually no indol is formed in broth cultures, but in one such culture, kept for twelve days, a feeble indol reaction was observed.

Reduction of nitrates.—Rapid reduction of nitrates to nitrites in 24 hours at 20° C. [Broth 5 per cent., KNO_3 0·1 per cent., water 94·9 per cent.]

Remarks.—This organism differs from *Proteus vulgaris*, and has little or no resemblance either to *Proteus mirabilis* or to *Proteus zenkeri*. It differs from *Proteus vulgaris* in many respects, for example *sewage proteus* has but one flagellum, whereas *Proteus vulgaris* is generally stated to be multi-flagellated; *sewage proteus* has smaller and shorter rods than *Proteus vulgaris*; *sewage proteus*, unlike *Proteus vulgaris*, shows no "swarming islands." This organism has been called *sewage proteus* owing to its prevalence in crude sewage, and because of its superficial resemblance to *Proteus vulgaris*, and to other members of the proteus group. It is not unlikely that this micro-organism is frequently mistaken for the true *Proteus vulgaris*. It also differs in a number of important respects from *Bacillus proteus urinae*, an organism isolated from the urine of a patient suffering from cystitis by Dr. Horton Smith, and carefully described by him in the *Journal of Pathology and Bacteriology*, December, 1896.

It must not, however, be supposed that *Proteus vulgaris* is not present in London crude sewage, but that its number is not as great as seems to be generally supposed. In figure 10, a micro-photograph is shown of the true proteus, which was isolated from a sample of Crossness raw sewage. The preparation was obtained by making a surface gelatine plate culture of this micro-organism, and then making "impressions" from the "swarming islands" produced by its growth on the surface of the gelatine in 20 hours at 20° C.

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[*] See fig. 48.

[†] See fig. 49 (*b*) (*c*).

[‡] Fig. 49 (*a*).

A culture of "*sewage proteus*" proved to be very virulent. Thus, 1 *c.c.* of a 24-hours' broth culture was injected subcutaneously into a guinea-pig. The animal was found dead on the second day, but had probably died on the preceding day. The organism was recovered from the heart's blood in pure culture. [Subsequent work yielded in some measure anomalous results. Thus, as freshly isolated from sewage, "*sewage proteus*" sometimes grew well at 37° C., and sometimes in an imperfect manner. Moreover, the cultures were in some cases virulent and in others not.]

4. *Bacillus Frondosus.*

[An aërobic, non-chromogenic, motile, slowly liquefying bacillus.]

Source.—London crude sewage; gelatine plate cultures heated to 80° C. for 10 minutes.

Morphology.—Large bacilli, with rounded ends; solitary, in pairs, and in chains of varying length.

Motility.—Motile.

Spore formation.[*]—Forms spores readily at the room temperature.

Temperature.—No growth at 37° C. Grows fairly rapidly at the room temperature.

Gelatine plate cultures[†].—The surface colonies appear as white, coarsely granular films of irregular shape, which send out curious processes of varied form. These grotesquely-shaped processes resemble bits of seaweed flattened out. Liquefaction sets in very slowly and shows itself by a slight pitting near the centre of each colony. The deep colonies are not characteristic. Under a low power of the microscope the superficial colonies have a granular and laminated appearance, and show at the spreading edge processes which are of the most varied shapes, and which often form patterns of great delicacy and beauty.

Gelatine "stab" cultures.—The growth at the surface is like a superficial colony in gelatine plate culture. The growth down the stab is not characteristic. Liquefaction slowly sets in at the surface, and eventually all the delicate details of growth are lost.

Gelatine "streak" cultures.—The growth is like an elongated surface colony in plate culture. Briefly, a white, coarsely granular film forms on the sloping surface of the medium which at its periphery shoots out processes of very irregular shape. Liquefaction first shows itself as a longitudinal and central pitting of the bacterial film.

Gelatine "shake" cultures.—No bubbles of gas are formed.

Agar plate cultures.—The colonies are white in colour; they do not grow in the same characteristic way as the colonies in gelatine plate culture.

Agar "stab" cultures.—Growth occurs all the way down the stab, and at the surface a greyish white-layer is formed of irregular shape which resembles somewhat a surface colony in gelatine plate culture.

Agar "streak" cultures.—The growth extends over the surface of the medium as a greyish-white film. The growth at the periphery in some measure simulates the corresponding growth on gelatine.

Potato cultures.—The growth is not specially characteristic as it is of a transparent colourless character.

Broth cultures.—Grows slowly; a white bacterial deposit collects at the foot of the tube, leaving the liquid above fairly clear.

Litmus milk cultures.—In milk at 20° C. No change is visible in three days. Later the milk turns slightly acid, no clotting is visible even after one month.

Blood serum cultures.—At 20° C. a greyish-white, somewhat granular and film-like growth develops in a few days. The edge is irregular. Apparently, no liquefaction takes place.

Indol reaction.—No indol is formed in broth cultures, after 6 days' incubation at 20° C.

Reduction of nitrates to nitrites.—No reduction takes place in 4 days at 20° C. [Broth 5 per cent., KNO_3 0·1 per cent., water 94·9 per cent.]

Remarks.—This micro-organism has been compared with the descriptions of all the aërobic, motile, non-chromogenic, liquefying bacteria, and it resembles none of them sufficiently closely to suggest identity. It has been called *B. frondosus* because the spreading edge of the colonies sometimes has a leafy appearance.

5. *Bacillus Fusiformis.*

[An aërobic, non-chromogenic, motile, non-liquefying bacillus.]

Source.—London crude sewage; gelatine plate cultures heated to 80° C. for 10 minutes.

Morphology.—Large bacilli, with rounded ends; solitary, in pairs, and in chains.

Motility.—Motile.

Spore formation.[‡]—Forms spores at the room temperature. These are large, and give a spindle-shaped appearance to the cells.

Temperature.—No growth at 37° C. Grows slowly at the room temperature.

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[*] See fig. 50. [†] See fig. 51. [‡] See fig. 52.

Gelatine plate cultures.—The growth is very slow. The surface colonies are circular, of an opaque porcelain-white, glistening appearance. The periphery is slightly transparent. By transmitted light, the colonies are yellowish in colour. In old cultures, the white colour takes on a yellowish tint. The deep colonies are not characteristic. Microscopically, under a low power, no delicate details of growth can be made out. No liquefaction of the gelatine takes place.

Gelatine "stab" cultures.—Tardy growth, no liquefaction of the gelatine. A white growth appears along the line of the stab, and on the surface a scanty yellowish-white layer very slowly develops.

Gelatine "streak" cultures.—A glistening porcelain-white layer is slowly formed, which is opaque, except at the margins, which are slightly transparent. By transmitted light and by reflected light in old cultures, a slight yellowish tint may be seen. The growth does not extend far from the actual line of inoculation. No liquefaction occurs.

Gelatine "shake" cultures.—No gas bubbles are formed.

Agar plate cultures.—The colonies are white and more or less circular in shape; the growth is not characteristic.

Agar "stab" cultures.—The growth is slow and imperfect. A whitish line appears along the line of the stab, and on the surface a thin white layer slowly develops.

Agar "streak" cultures.—A thin whitish layer is slowly formed; the growth is not characteristic.

Potato cultures.—A porcelain-white growth slowly develops; afterwards, the colour becomes dirty yellowish-white and the bacterial layer becomes unequally thickened.

Broth cultures.—The growth is very scanty and not characteristic.

Litmus milk cultures.—No clotting occurs, and the change in the medium is hardly visible, even after 16 days. Apparently, a feeble acidity of the milk results.

Blood serum cultures.—Little or no growth on the surface, even after the lapse of some time; some growth, however, takes place in the fluid at the foot of the tube.

Indol reaction.—No indol is formed in broth cultures.

Reduction of nitrates to nitrites.—Negative after 12 days at 20° C. [Broth 5 per cent., $K N O_3$ 0·1 per cent., water 94·9 per cent.]

Remarks.—This micro-organism has a somewhat negative character of growth in all the nutrient media ordinarily in use. It has been called *B. fusiformis* owing to the spores being spindle-shaped. So far as could be ascertained, it belongs to a new species.

6. *Bacillus Subtilissimus.*

[An aërobic, non-chromogenic, non-motile, non-liquefying bacillus (? micrococcus).]

Source.—Crude sewage.

*Morphology.**—In most cultures it appears as a large micrococcus, but if "impression" preparations be made from surface colonies in a gelatine plate, and examined microscopically it will be seen that at the spreading edge the elements are distinctly longer than broad, nearer the centre they are oval and frequently united in pairs, and at or about the centre they are perfectly spherical.

Motility.—No motility has been observed even in recent broth cultures.

Spore formation.—None.

Temperature.—Does not grow at 37° C., but grows with extreme rapidity at 20° C.

Gelatine plate cultures.—The deep colonies are not characteristic, either on naked eye examination when viewed with a hand-lens, or when examined under a low power of the microscope. The surface colonies are peculiarly characteristic, and grow so rapidly and extend so widely, that a single colony may cover nearly a whole plate in two days. The growth is film-like in character and extremely thin and transparent. It is dull grey in colour and very faintly granular. When viewed under a low power of the microscope, the appearance is not unlike *B. coli*, but the details of the growth are so much more delicate that it is difficult to preceive the slight granulation, faint creasing and delicate veining of the bacterial film. The surface colonies are usually of a more or less circular shape, but the spreading edge is nearly always markedly irregular.

Gelatine "streak" cultures.†—The growth is like an elongated surface colony. In less than 24 hours a delicate film has spread nearly to the walls of the tube. The spreading edge is very irregular, and in older cultures may present a terraced appearance.

Gelatine " shake cultures.—No gas bubbles are formed in the gelatine.

Agar "streak" cultures.—A white film is formed on the surface having a markedly irregular edge. The lateral expansion is less than in the case of gelatine cultures.

Broth cultures.—Uniform turbidity occurs in 24 hours at 20° C., and a very faint scum forms on the surface. No motility could be made out.

Blood serum.—A thin film forms of a faint yellowish-white colour. No liquefaction occurs.

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* See fig. 53.

† Fig. 54.

Litmus milk cultures.—No visible change in 48 hours at 20° C. Later the purple colour of the milk changes to a reddish purple, and later still to a buff colour. On shaking the tube gently, the liquid does not assume a red tint. There is no clotting produced and no transparency of the medium occurs even in old cultures.

Indol.—No indol is formed even after 20 days at 20° C.

Remarks.—This microbe has been called *B. subtilissimus* on account of the thin almost gauze-like character of the surface colonies in gelatine plate culture. No micro-organism hitherto described appears to correspond with the above. It must not be confused with *B. subtilis* to which microbe it bears no resemblance.

7. *Bacillus Subtilis.*

	Sewage Variety A.	Sewage Variety, B.
	[An aërobic, non-chromogenic, rapidly liquefying, spore-forming, motile bacillus.]	[An aërobic non-chromogenic, rapidly liquefying, spore-forming, motile bacillus.]
Source.	Crude sewage and effluents from coke-beds.	Crude sewage and effluents from coke-beds.
Optimum temperature.	Grows luxuriantly at 37° C., also at the room temperature.	Little or no growth at 37° C., grows luxuriantly at 20° C.
Morphology.	Large and long bacilli with rounded ends, frequently associated in long chains.	Large and long bacilli with rounded ends, frequently associated in long chains.
Spore formation.	Forms spores readily.	Forms spores readily.
Motility.	Waddling sluggish movement.	Waddling sluggish movement.
Gelatine plate cultures.	Forms in two days at 20° C. circular greyish-white areas of liquid gelatine which rapidly increase in diameter. The white masses of bacteria lying in the liquefied gelatine may present a mottled appearance, or may be arranged in stellate fashion. Under a low power of the microscope (about 80 diam.), the individual bacilli can be clearly seen in the more liquid portion, and their movements watched. At the edge of the colonies, the bacilli bore side by side into the non-liquefied gelatine in a highly characteristic way.[*]	Rapidly forms greyish-white circles of liquefied gelatine. The masses of bacteria lying in the liquefied gelatine may present a rosette or star-shaped or radiating appearance. Under a low power of the microscope (about 80 diam.), the movement of the individual bacilli can be clearly seen. The parallel arrangement of the bacilli at the periphery of the colonies is absent, or not so well marked as in the case of variety A. A skin forms on the surface of the liquefied gelatine. The growth is not so rapid as in the case of variety A. Sometimes the colonies are not exactly circular in shape.
Agar "streak" cultures.	In two days, at 37° C., an abundant creamy white layer, covering nearly the whole surface, which on close inspection shows numerous minute circular areas where the growth, instead of being opaque, is semi-transparent.	In 20 hours, at 20° C., a greyish-white layer, not specially characteristic. In 48 hours, growth somewhat dry and granular-looking. In four days, curious wrinkled appearances. Ridges, formed by the unequal rate of growth, or by the contraction of the bacterial skin, stand out from the surface of the medium about one-sixteenth of an inch, and usually are arranged in more or less transverse folds.[†]
Gelatine "stab" cultures.	In 2 days, at 20° C., liquefaction has occurred right down to the foot of the stab. White flocculent masses of bacteria sink through the liquefied and grey-coloured gelatine to the foot of the stab. The liquefaction extends rapidly from the line of inoculation outwards, as well as from the surface downwards. A scum forms on the surface, but no distinct skin is formed.[‡]	Rapid liquefaction all the way down the stab, but as the growth proceeds the liquefaction spreads in cylindrical fashion from above downwards rather than from within outwards from the region of the line of inoculation. A distinct skin forms on the surface, which eventually sinks in the liquefied gelatine.[§]

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[*] Fig. 57, B.

[†] Fig. 56.

[‡] Fig. 57, A.

[§] Fig. 55.

Liquefaction.	Rapidly liquefies gelatine and blood serum.	Liquefies gelatine and blood serum fairly rapidly.
Gas formation.	Forms no gas in gelatine "shake" cultures.	Forms no gas in gelatine "shake" cultures.
Broth cultures.	Diffuse cloudiness in 24 hours at 37° C. A scum forms on the surface which readily falls to the foot of the tube on shaking.	Diffuse cloudiness : a skin forms on the surface which is brittle and sinks on shaking the tube.
Indol.	Forms no indol.	Forms no indol.
Litmus milk cultures.	In 2 days, at 37° C., there is complete discoloration and a clot has formed ; no redness is visible. In 5 days a white clot occupies about one-third of the bulk of medium, which appears to be slowly peptonised. The liquid surrounding the clot is pale yellow in colour, and semi-transparent without pink coloration.	The purple-blue colour of the litmus milk gradually fades, but no clotting or redness occurs. In 8 days, the milk is almost transparent and of a pale dirty yellow colour ; on shaking the tube, the liquid assumes a faint pink tinge. By the 21st day, the milk has changed to a semi-transparent dirty yellow liquid ; on shaking the tube, the contents assume a reddish tint.
Potato cultures.	In 2 days, at 37° C., a dirty-white layer is formed with a yellowish tint.	A white, rather dry-looking coat is formed. Later portions of the growth become upraised, and sometimes present a worm-like appearance.
Blood serum cultures.	In 24 hours, at 37° C., a white layer develops, accompanied with liquefaction of the medium.	In 20 hours, at 20° C., a thin whitish layer is formed. In 48 hours commencing liquefaction and markedly wrinkled skin.

Remarks.—Several varieties of *B. subtilis* occur in sewage. For the purpose of description, I have named these two :—Sewage variety A, and sewage variety B. The fact, however, of the latter organism not growing at 37° C. makes it doubtful whether it should be considered a variety of *B. subtilis.*

8. *Bacillus Membraneus Patulus.*

[An aërobic, non-chromogenic, slowly liquefying, spore-forming (?), non-motile bacillus.]

Source.—Crude sewage and effluent from coke-beds.

Optimum temperature.—Grows well at 37° C., and at the room temperature.

Morphology.—A very large bacillus which forms long chains.*

Spore formation.—Old cultures of the microbe resist heating to 80° C. for ten minutes ; and the microbe has been found in cultures made from sewage which had previously been heated to 80° C. for ten minutes. A satisfactory double-stained preparation, however, has not been obtained.

Motility.—No motility could be made out, even in a 20 hours' broth culture.

Gelatine plates.—The surface colonies appear as coarsely granular greyish-white films of somewhat irregular shape. From the spreading edge of the colonies, processes extend in a tortuous fashion over the surface of the medium, often forming patterns of great delicacy and beauty. Beneath the surface film-like growth, slow liquefaction of the gelatine occurs. The growth is rapid. Under a low power of the microscope the colonies present a characteristic granular and striated appearance.†

Oblique gelatine cultures.—In less than two days, at 20° C., there is formed on the surface of the gelatine a coarsely granular film which spreads rather rapidly and may extend nearly to the walls of the tube. From the spreading edge, processes are given off which wind over the surface of the gelatine in a characteristic manner. Soon a longitudinal pitting of the bacterial film along the line of inoculation is observed, and later on, as liquefaction proceeds, the growth slips down to the foot of the tube, and all delicate details are lost. The growth is like an elongated surface colony in gelatine plate culture.‡

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* Fig. 58. † Fig. 61, F. ‡ Fig. 59 and fig. 61, E.

Oblique agar cultures.—In one night, at 37° C., the growth appears as a coarsely granular, semi-transparent, greyish-white film. By the second day, the growth is less transparent and less granular-looking. In old cultures, the surface assumes a tuberculated appearance.

Gelatine "stab" cultures.[*]—The growth varies, as sometimes there is liquefaction down the line of the stab with tuft-like processes extending into the solid medium, and at other times, there is almost no liquefaction along the line of inoculation, and the processes extend nearly to the walls of the tube, giving rise to an appearance of great beauty. The growth on the surface is like the growth of a surface colony in gelatine plate culture.

Liquefaction.—Liquefies gelatine, but not rapidly. Produces only very slight liquefaction of blood serum even in cultures kept at 37° C. for 16 days.

Gas formation.—Forms no gas in gelatine "shake" cultivations.

Broth cultures.—Grows very rapidly at 37° C. The cloudiness throughout the medium is flocculent rather than diffuse. An abundant white bacterial deposit collects at the foot of the tube. On the surface, a skin is formed, which sinks on shaking the tube, but is re-formed in one night.

Indol formation.—Forms no indol in broth cultures.

Litmus milk cultures.—In 24 hours, at 37° C., the milk has become slightly discoloured; later, a weak gelatinous clot is formed, and the medium turns faintly acid.

Potato cultures.—The growth is not characteristic; a dirty, faint yellowish-grey coloured growth in 24 hours at 37° C.

Blood serum cultures.—A granular greyish-white film is formed. Only very slight liquefaction occurs, even in old cultures.

Reduction of nitrates.—Great reduction of nitrates to nitrites in one night at 37° C. (Bouillon 5 per cent., KNO_3 0·1 per cent., water 94·9 per cent.).

Remarks.—This organism does not appear to resemble at all closely the descriptions of any of the bacteria found in sewage and elsewhere. On account of its spreading, film-like character of growth, it has been termed *B. membraneus patulus*.

9. *Bacillus Capillareus.*

[An aërobic, non-chromogenic, rapidly liquefying, spore-forming (?), motile bacillus.]

Source.—Crude sewage and effluents from coke beds.

Optimum temperature.—Grows luxuriantly at 37° C., also at room temperature.

Morphology.[†]—A large bacillus, forming long chains.

Spore formation.—Old cultures resist heating to 80° C., and this microbe commonly occurs in cultivations made from sewage which have previously been heated to 80° C. for 10 minutes. A satisfactory doubled-stained preparation, however, has not been obtained.

Motility.—This organism is motile.

Gelatine plate cultures.[‡]—The colonies in depth have a characteristic fluffy appearance. They rapidly increase in size, and reaching the surface quickly liquefy the gelatine. The growth is filamentous in depth; and on the surface from the spreading edge of the colonies, delicate film-like processes are given off, which extend over the surface of the medium to form irregular patterns. Later, the finer details of growth are lost, owing to the rapid liquefaction of the gelatine, the colonies eventually appearing as large, more or less circular, areas of liquefied gelatine with greyish white contents.

Agar "streak" cultures.—In 24 hours an opaque white growth of limited extent appears, which along the spreading edge is slightly transparent and granular-looking. Later, the growth may extend laterally to cover a wide extent of surface.

Gelatine "streak" cultures.—A longitudinal furrow appears due to the liquefaction of the gelatine, but from the edge of the furrow delicate processes may be seen extending in irregular fashion over the surface of the solid gelatine. The furrow is nearly clear as the bacteria slip down the sloping surface with the liquid gelatine, and collect at the foot of the tube. Soon all details of growth are lost, owing to the progressive liquefaction of the medium.

Gelatine "stab" cultures.—Liquefaction takes place in funnel form, and extends down the stab to an extent varying in different cultures. Along the line of the inoculation, feathery processes are given off, which extend into the solid gelatine for a short distance. The masses of bacteria gradually sink to the foot of the liquefied medium.

Liquefaction.—Liquefies gelatine rapidly, blood serum less rapidly.

Gas formation.—No gas is formed in gelatine "shake" cultures. Sometimes the colonies in "shake" cultures have a beautiful star-shaped appearance, but at other times they are globular.

Broth cultures.—In broth at 37° C., there is diffuse cloudiness with flocculent masses scattered throughout the medium. Later, a skin forms on the surface, and an abundant white bacterial deposit collects at the foot of the tube, leaving the liquid above fairly clear.

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[*] Fig. 60.

[†] Fig. 62.

[‡] Fig. 63.

Indol.—No indol is formed in broth cultures.

Litmus milk cultures.—No decided change, even after 72 hours' incubation at 37° C. In five days weak gelatinous clot, but no apparent acidity.

Potato cultures.—By the second day at 37° C., a fairly abundant creamy coating has formed on the surface of the medium, and later this coating becomes of a dirty-brown colour.

Blood serum cultures.—By the second day, at 37° C., a white-coloured growth, having no special characters. Liquefaction slowly sets in, and by the 16th day is practically complete.

Reduction of nitrates.—Reduces nitrates to nitrites.

Remarks.—This microbe has been called *B. capillareus* because of the hair-like character of its growth in gelatine plate cultures. It resembles in some respects *B. mycoides*, *B. subtilis* and *B. mesentericus*, but not sufficiently to suggest a similarity of species.

XI. CONCLUSIONS.

Before giving conclusions, from the biological point of view, as to the value of the bacterial process in use at Barking and Crossness for treating London crude sewage, it is essential to first make some remarks of a general and introductory character; otherwise, a totally erroneous impression might be formed, and it might even be considered that the deductions arrived at after two years' close study of the subject were of such a nature as to condemn the process. Thus, if no note were taken of the chemical results and the practical side of the question, and the bacteriological results were considered by themselves, and not read, as they ought to be, side by side with the chemical data, a false impression might be gained as to the amount of purification which for practical purposes is effected in the London crude sewage by the treatment.

1. *General Conclusions.*

The Thames is a tidal river, and the "intakes" for waterworks purposes are situated high up the river and are "cut off" by "locks" from the influence of the sewage discharge at the Outfall Works.*

The river water outside the influence of the discharges at the Outfall Works is already polluted and contains practically all the bacteria found in raw sewage.

The effluents from the existing works (chemical treatment) are, in a bacterial sense, grossly impure, and indeed the samples which I examined resembled in their biological composition the raw sewage before treatment.

The body of Thames water which may be supposed to be directly affected by the discharge of the effluents at Barking and Crossness is "brackish," and so could hardly be tolerated for drinking purposes even by individuals who are indifferent to the physical characters and biological composition of the water which they drink.

The bacterial coke-beds effect a reduction of at least 50, and it may be as much as 80 per cent. in the amount of dissolved oxidisable and putrescible organic matter in the raw sewage, as compared with 17 per cent. effected by the chemical treatment.

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* It is assumed that no contamination of the *underground water* in the Thames valley takes place as a result of the pollution in the lower *reaches* of the river affecting distant sources of water supply (*e.g.*, deep wells). If in the future reliable evidence, as to the possibility of such contamination occurring, should be forthcoming, then the whole question would require reconsideration.

The effluents from the coke-beds are apparently non-putrescible.[*]

The suspended matters[*] in the crude sewage are practically entirely removed as a result of the biological treatment, instead of only about 80 per cent. effected by the chemical treatment. And recent experiments seem to show that this result may be obtained without serious progressive loss of capacity in the coke-beds, if the sewage, before its application to the coke-bed, has undergone a previous process of rapid sedimentation.

In the biological treatment no chemicals are required, and less offensive sludge is produced.

Where an effluent is turned into a stream to be used for drinking purposes, the bacteriological results are manifestly of more importance than the chemical; but when, as in the present case, the river is not a potable one, and is already polluted, the converse probably holds good; *i.e.*, the chemical state of the effluent is of primary, and the biological of secondary importance. In the first case, the chief object is to guard against disease, and in the second case the fouling the river with putrescible matters to such an extent as to constitute a nuisance has to be avoided.

However desirable it may be to obtain an effluent chemically pure, and, at the same time, bacteriologically above suspicion of danger, a process which (*a*) leads to the solution of some of the suspended matters in the raw sewage, (*b*) effects a striking reduction in the amount of putrescible matters, (*c*) avoids the use of chemicals and the accumulation of offensive sludge, (*d*) yields an apparently non-putrescible effluent, and (*e*) is at the same time practicable, is one which, in that it produces such satisfactory results in view of all the requirements of the case, presents such decided advantages over chemical treatment that it would be idle, merely because it falls short of a standard of perfection, to deny the value or to attempt to minimise the usefulness of the process.

Passing next to considerations which are purely biological in character, the following points are worthy of note.

2. *Biological Conclusions.*

Although (1) the total number of bacteria, (2) the number of spores of aërobic bacteria, (3) the number of liquefying microbes, (4) the number of *B. coli*, and (5) the number of spores of *B. enteritidis sporogenes* was, on an average, less in the effluents from the coke-beds than in the corresponding samples of crude sewage, the reduction in number was not well marked; and in some cases the effluents contained more micro-

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[*] It may be suggested that further evidence is required to show that an effluent apparently non-putrescible remains so under all conditions, and also that an effluent free, or nearly so, from suspended matter remains permanently in that condition. For it is conceivable that an effluent non-putrescible in itself might yet give rise to a putrescent effect when discharged into a stream, and that substances originally in solution might pass out of solution as the result, perhaps, of secondary degeneration. Nevertheless, from actual experiments carried out by the chemists in charge at the Outfall Works, these changes would not seem likely to take place in the case of the discharge of the effluents at Barking and Crossness into the Thames. It must be distinctly understood that the apparently non-putrescible character of the effluents from the coke-beds is due *not* to the absence of putrefactive bacteria, but very largely to the satisfactory change in the chemical state of the liquid resulting from the treatment of the sewage in the bacteria-beds. Thus, on June 15, 1898, it was found that even so minute an amount as $\frac{1}{1000000}$ c.c. (but not $\frac{1}{10000000}$ c.c.) of the Crossness 4-foot coke-bed effluent when introduced into a sterile broth tube, produced an offensive smell and gave rise to indol production.

FIG. 35.—*B. coli.* Microscopic preparation from an agar culture. × 1,000.

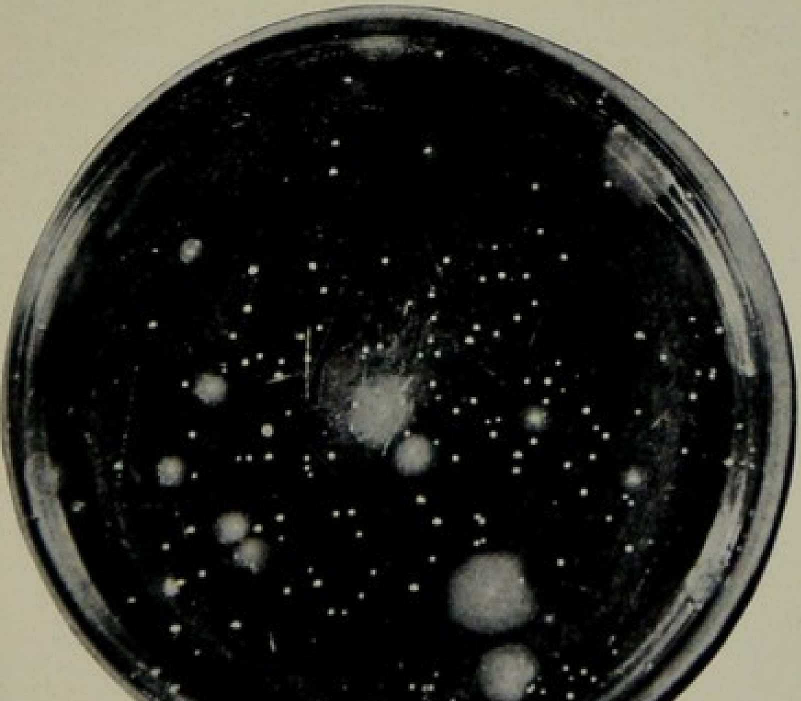


FIG. 36.—*B. coli.* Gelatine plate culture. About natural size.

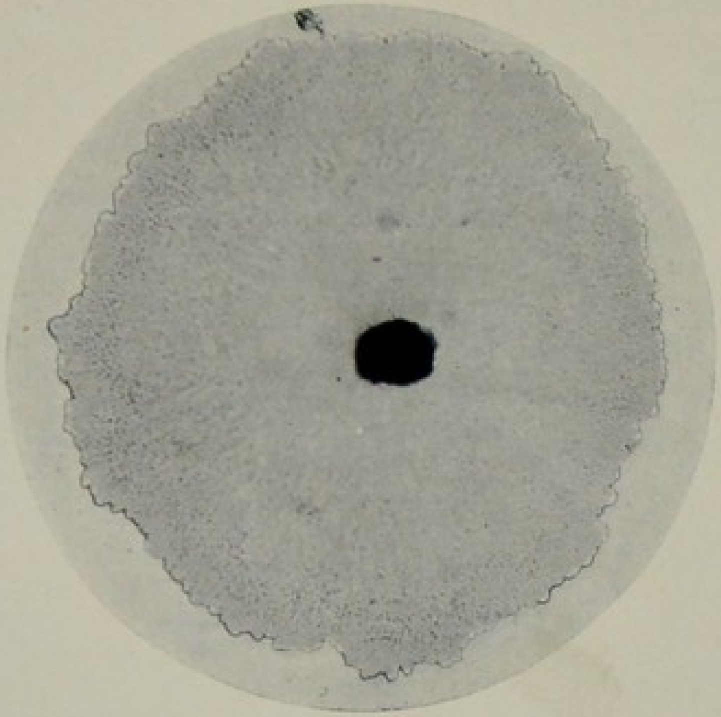


FIG. 37.—*B. coli*. Colony in gelatine plate. × 8.

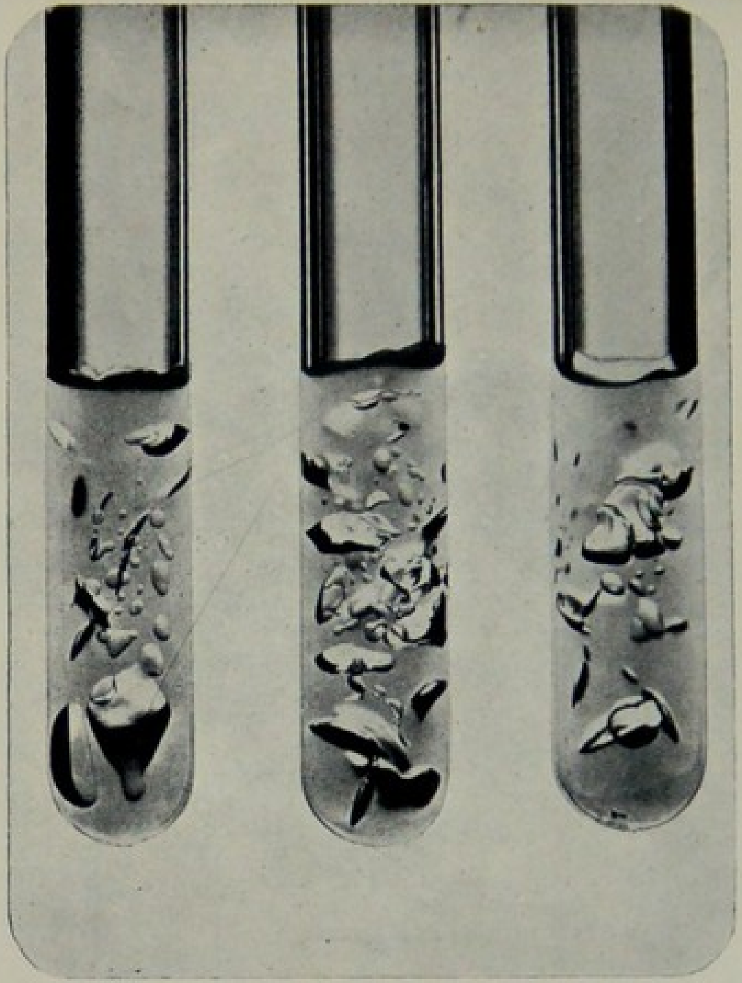


FIG. 38.—*B. coli*. Showing gas production in gelatine "shake" cultures (29 hours at 20° C.). About natural size.

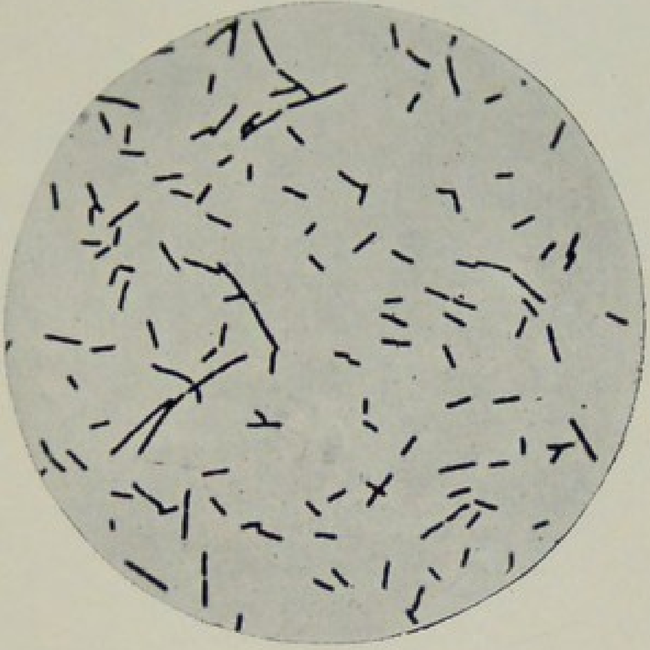


FIG. 39.—*B. mesentericus.* Variety E. Microscopic preparation from a 20 hours' agar culture at 20° C. × 1,000.

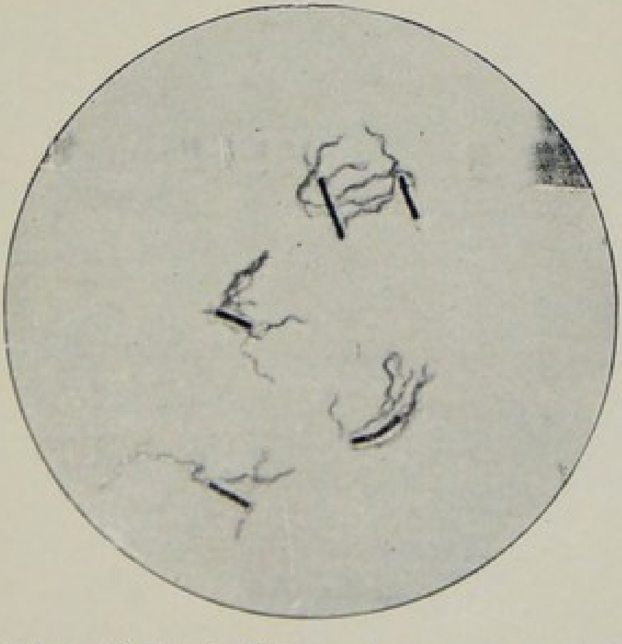


FIG. 40.—*B. mesentericus.* Variety E. Microscopic preparation stained by V. Ermengem's method, showing numerous flagella, from a 20 hours' agar culture at 20° C. × 1,000.

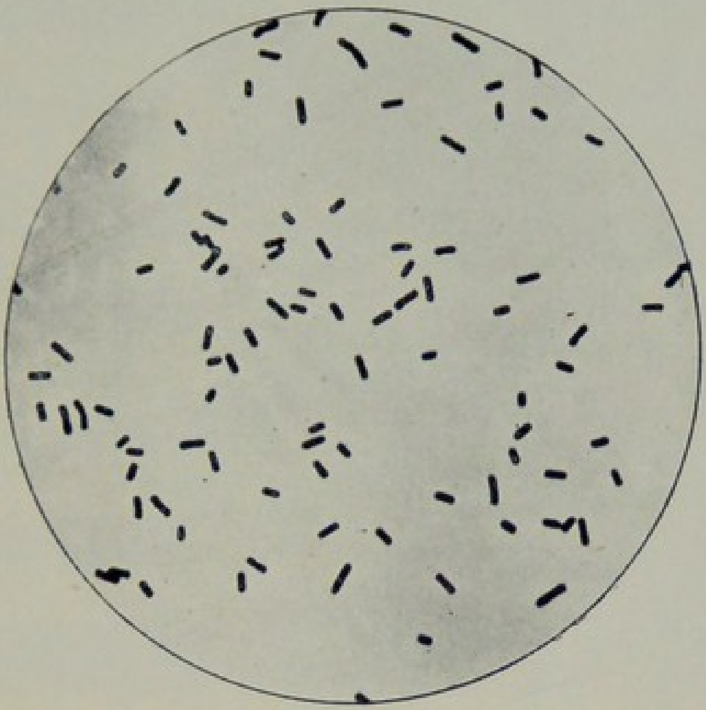


FIG. 41.—*B. mesentericus.* Variety I. Microscopic preparation from an agar culture (20 hours at 20° C.). × 1,000.

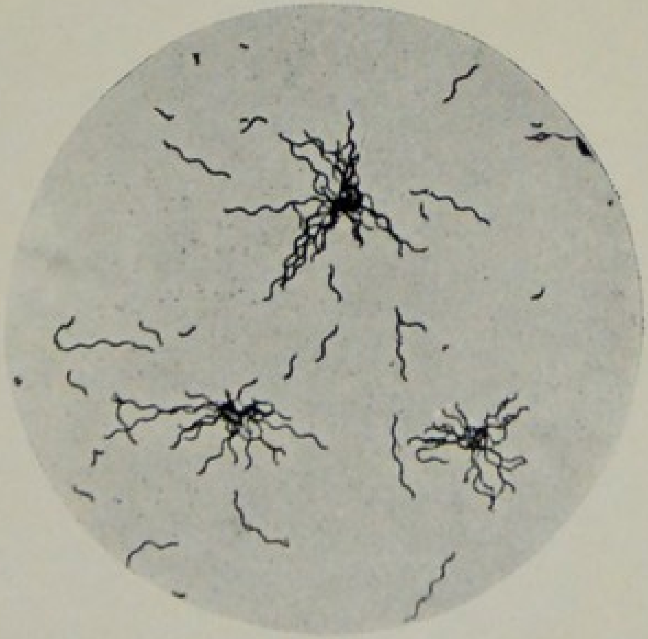


FIG. 42.—*B. mesentericus.* Variety I. Microscopic preparation stained by V. Ermengem's method, showing numerous flagella; from a 20 hours' agar culture at 20° C. × 1,000.

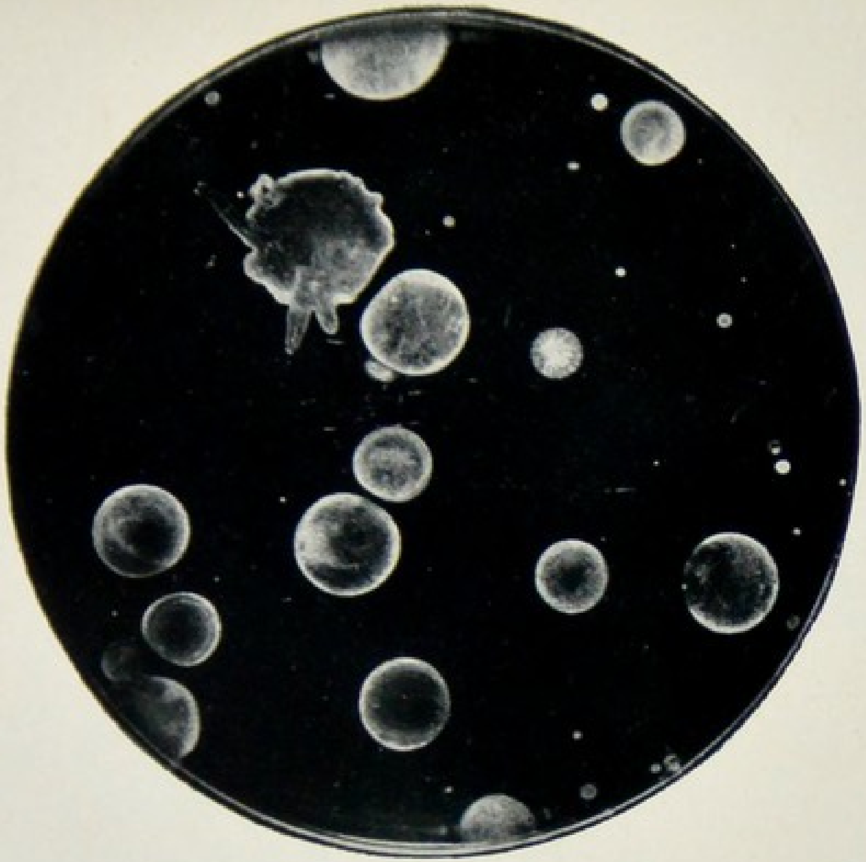


FIG. 43.—*B. mesentericus.* Variety I.
Gelatine plate culture. About natural size.

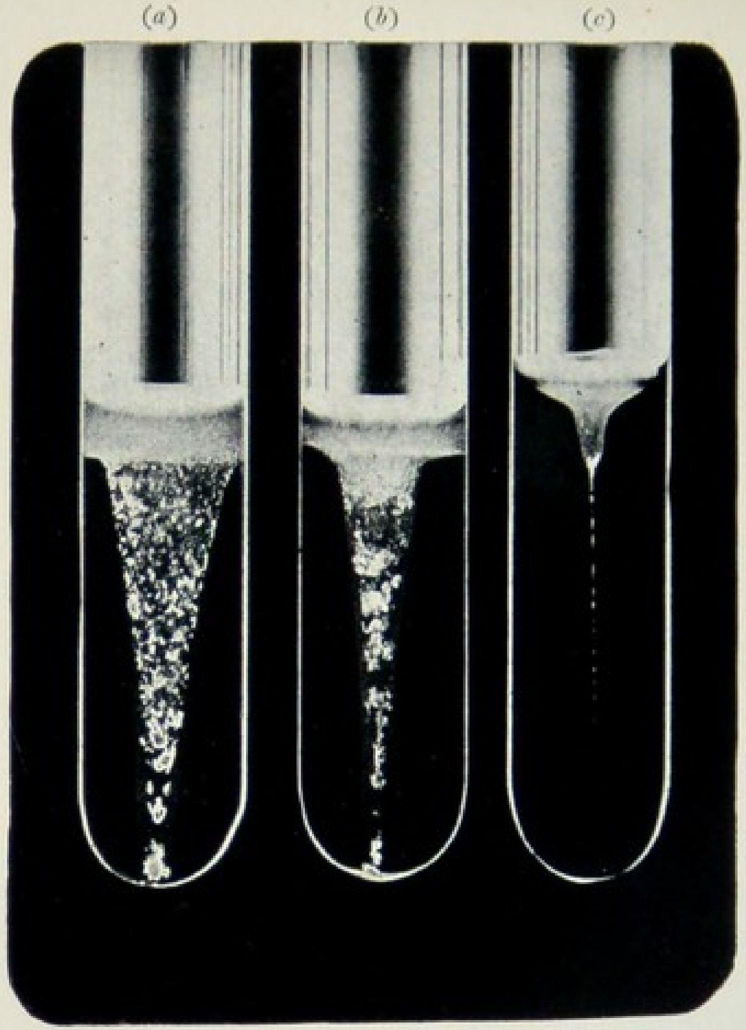


FIG. 44.—*B. mesentericus.* Sewage variety I. Gelatine "stab" cultures. About natural size.

(*a*) Three days' growth at 20° C.
(*b*) Two days' growth at 20° C.
(*c*) One day's growth at 20° C.

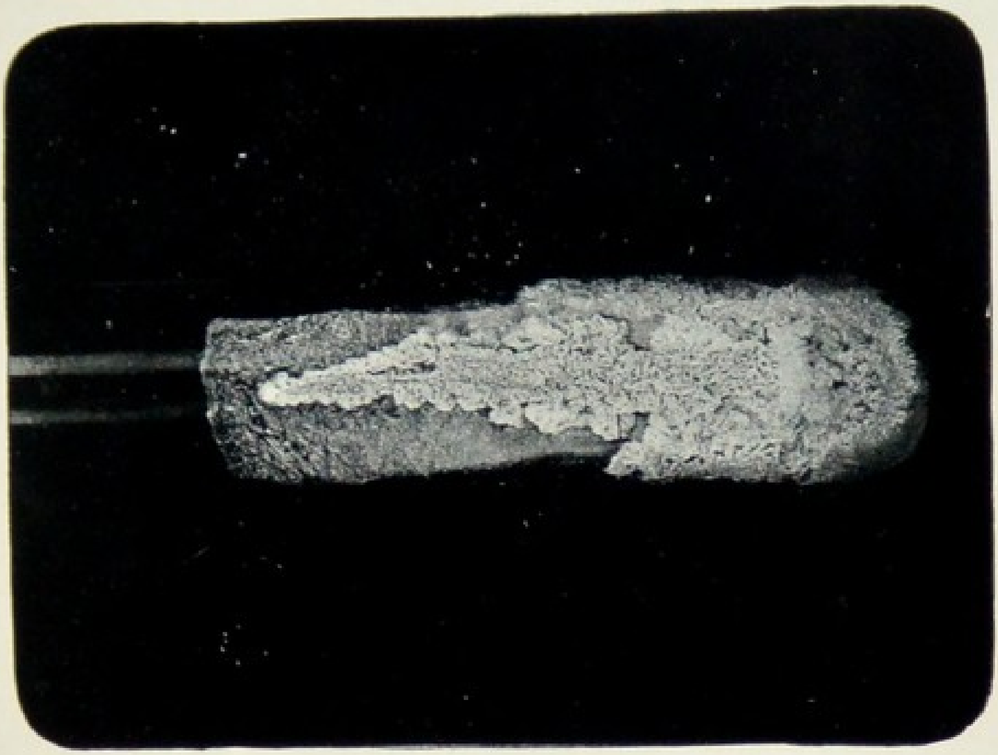


FIG 45.—*B. mesentericus.* Sewage variety I. Potato culture, one day's growth at 37° C. Very slightly enlarged.

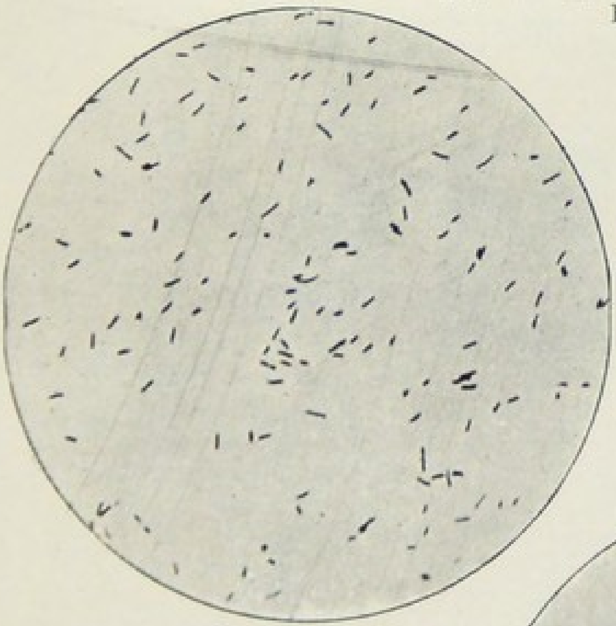
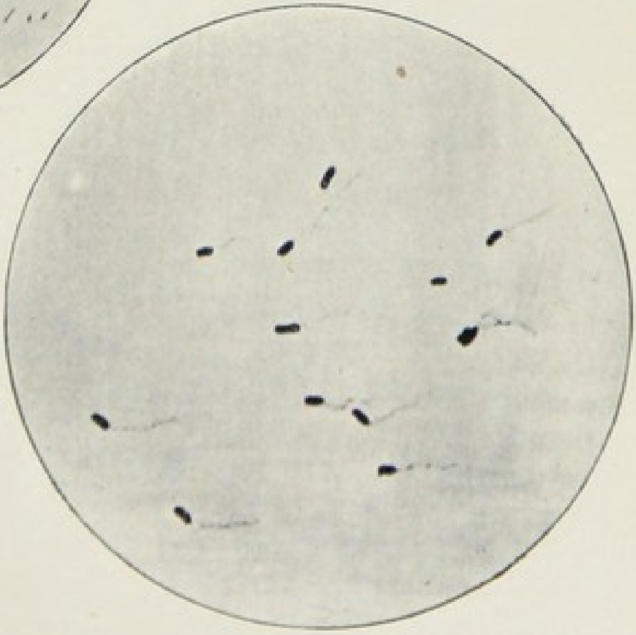


FIG. 46.—"*Sewage proteus.*" Microscopic preparation from an agar culture; 24 hours' growth at 20° C. × 1,000.

FIG. 47.—"*Sewage proteus.*" Microscopic preparation stained by V. Ermengem's method, showing one flagellum at the end of each rod; from a 24 hours' growth agar culture at 20° C. × 1,000.



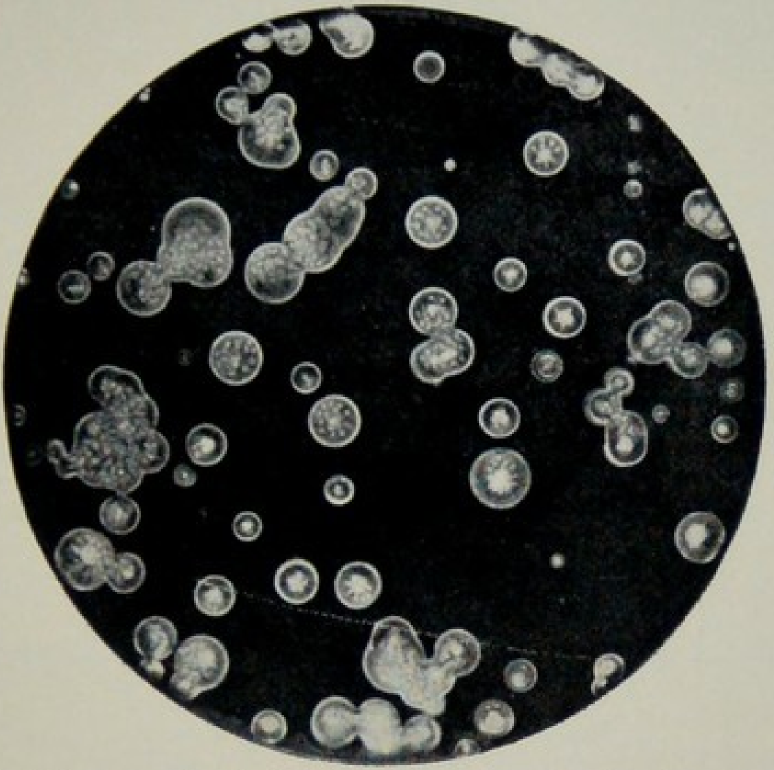


FIG. 48.—"*Sewage proteus.*" Gelatine plate culture, two days' growth at 20° C. About natural size.

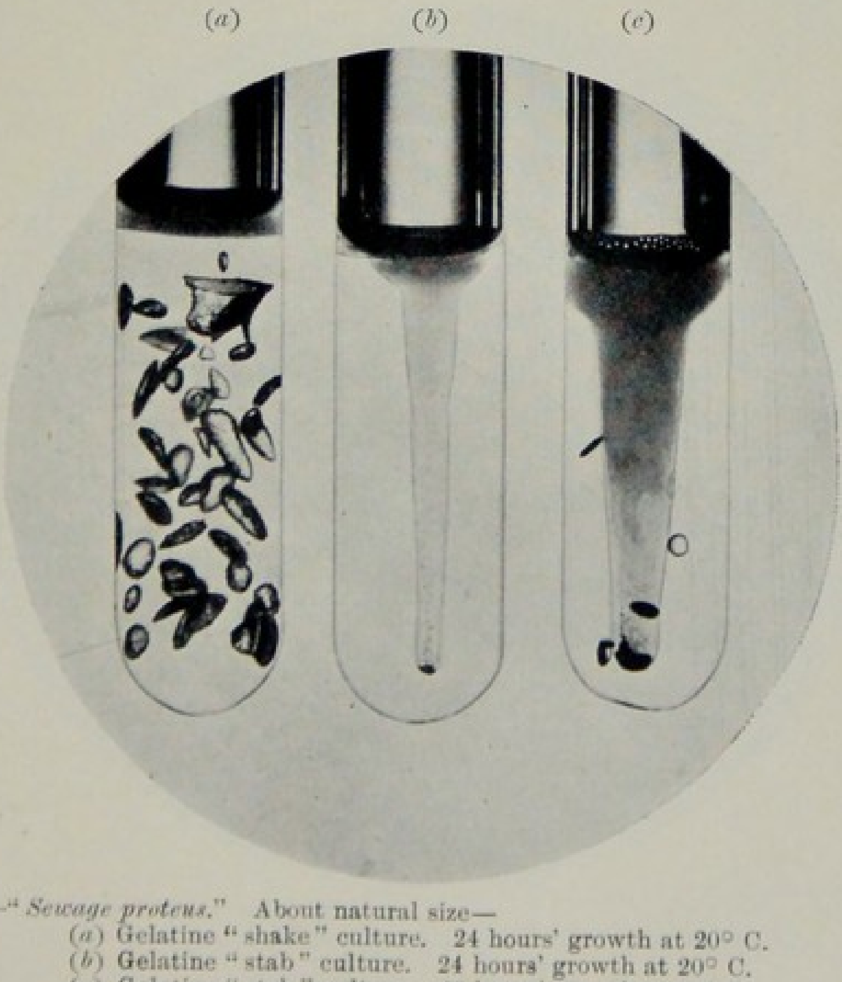


FIG. 49.—"*Sewage proteus.*" About natural size—

(*a*) Gelatine "shake" culture. 24 hours' growth at 20° C.
(*b*) Gelatine "stab" culture. 24 hours' growth at 20° C.
(*c*) Gelatine "stab" culture. 48 hours' growth at 20° C.

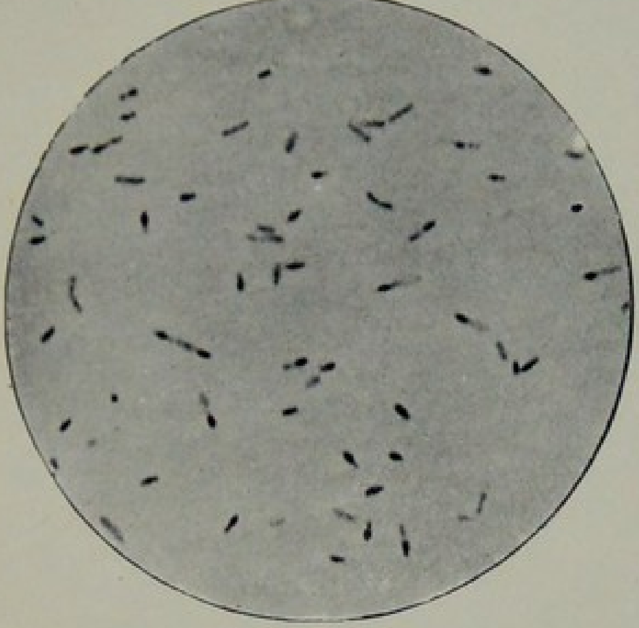


FIG. 50.—*B. frondosus.* Microscopic double-stained preparation from an agar culture, showing spores. × 1,000.

FIG. 51.—*B. frondosus.* Gelatine plate culture. About natural size.

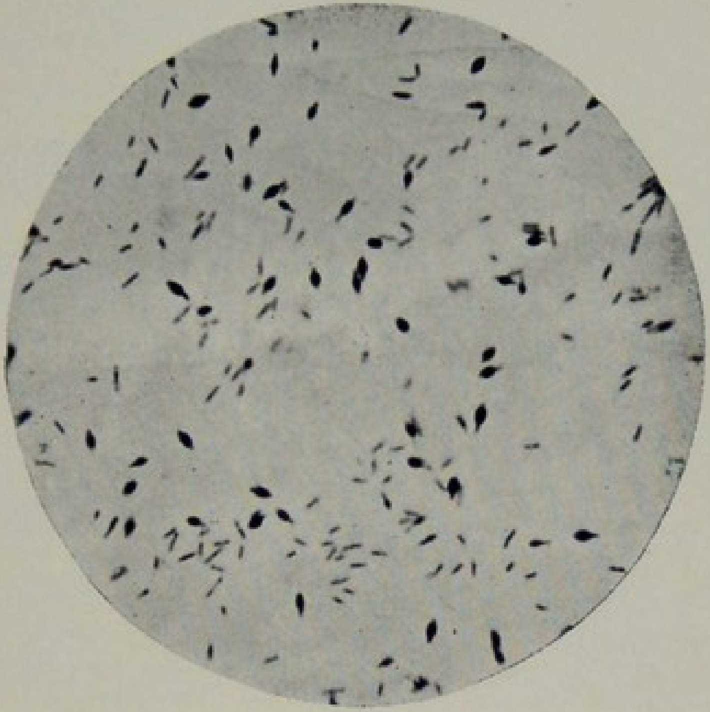


FIG. 52.—*B. fusiformis.* Microscopic double-stained preparation, showing spores. × 1,000.

FIG. 53.—*B. subtilissimus.* Impression preparation from a gelatine plate culture. × 1,000.

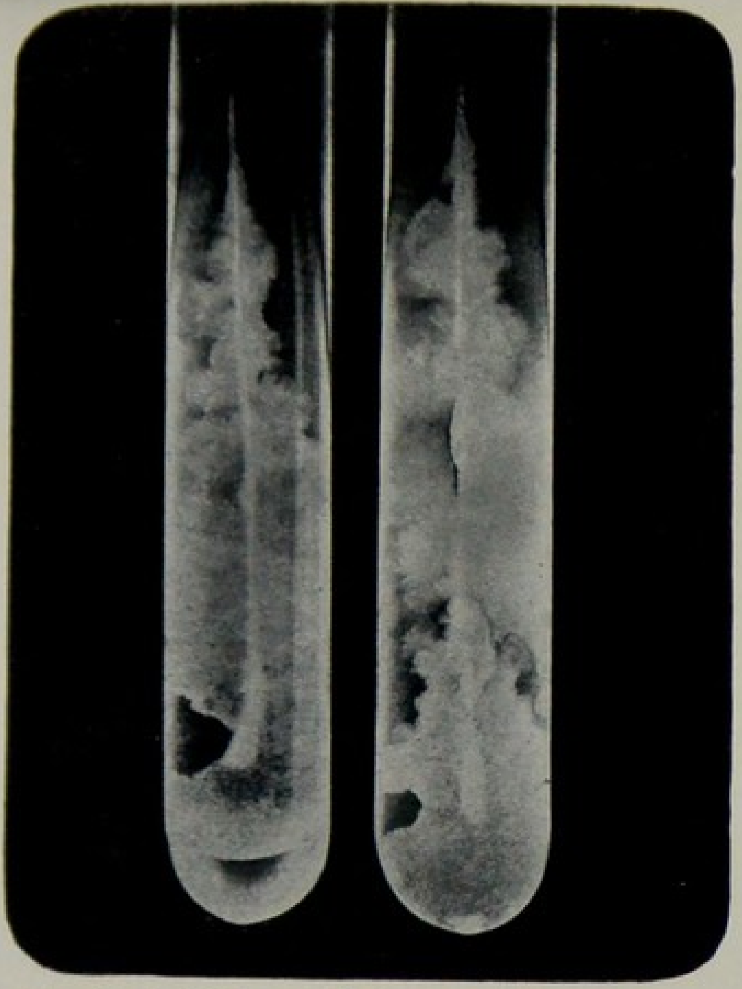


FIG. 54.—*B. subtilissimus.* Gelatine "streak" cultures, 24 hours' growth at 20° C. Natural size.

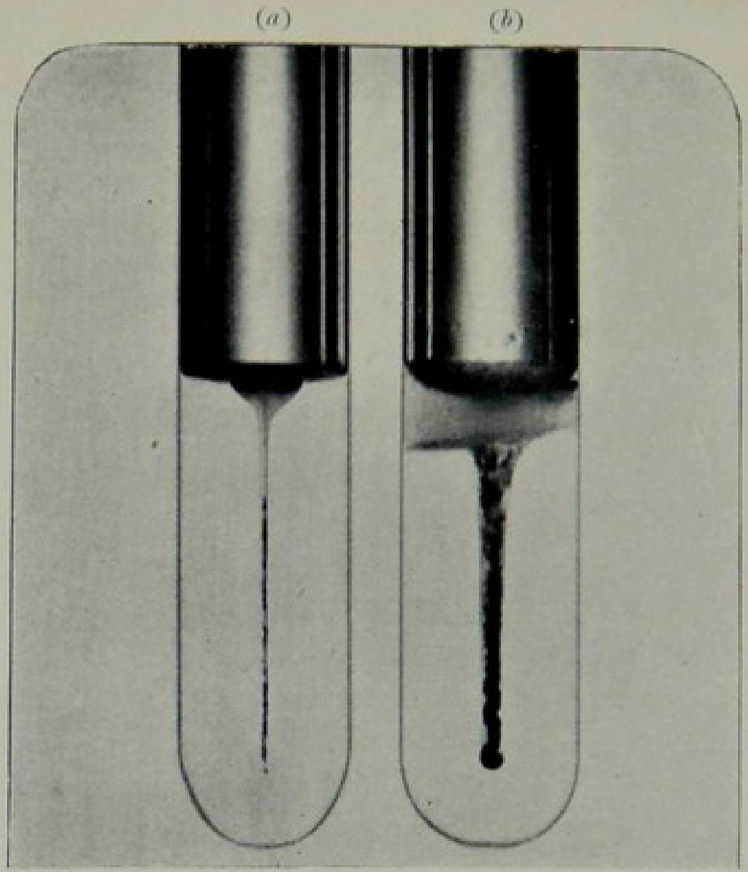


FIG. 55.—*B. subtilis.* Sewage variety B. Gelatine "stab cultures." About natural size
(*a*) One day's growth at 20° C.
(*b*) Three days' growth at 20° C.

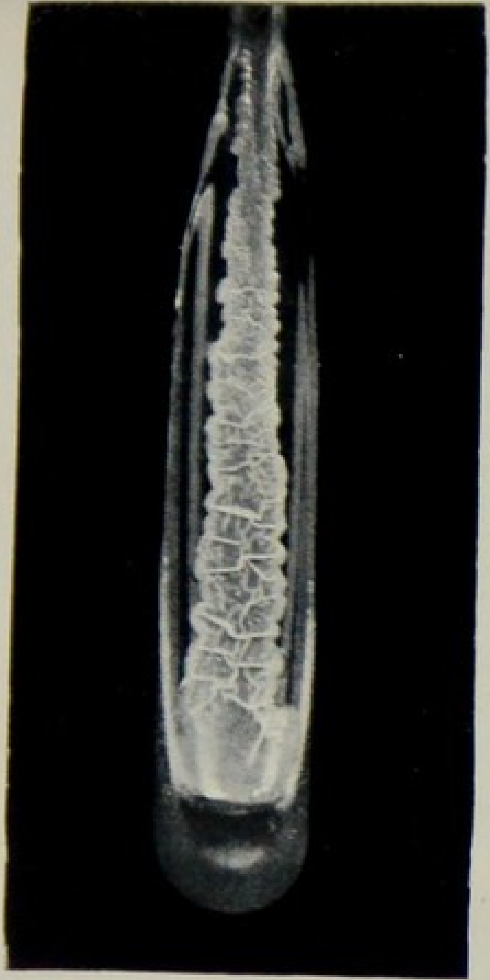


FIG. 56.—*B. subtilis.* Sewage variety B. Oblique agar culture, three days' growth at 20° C. About natural size.

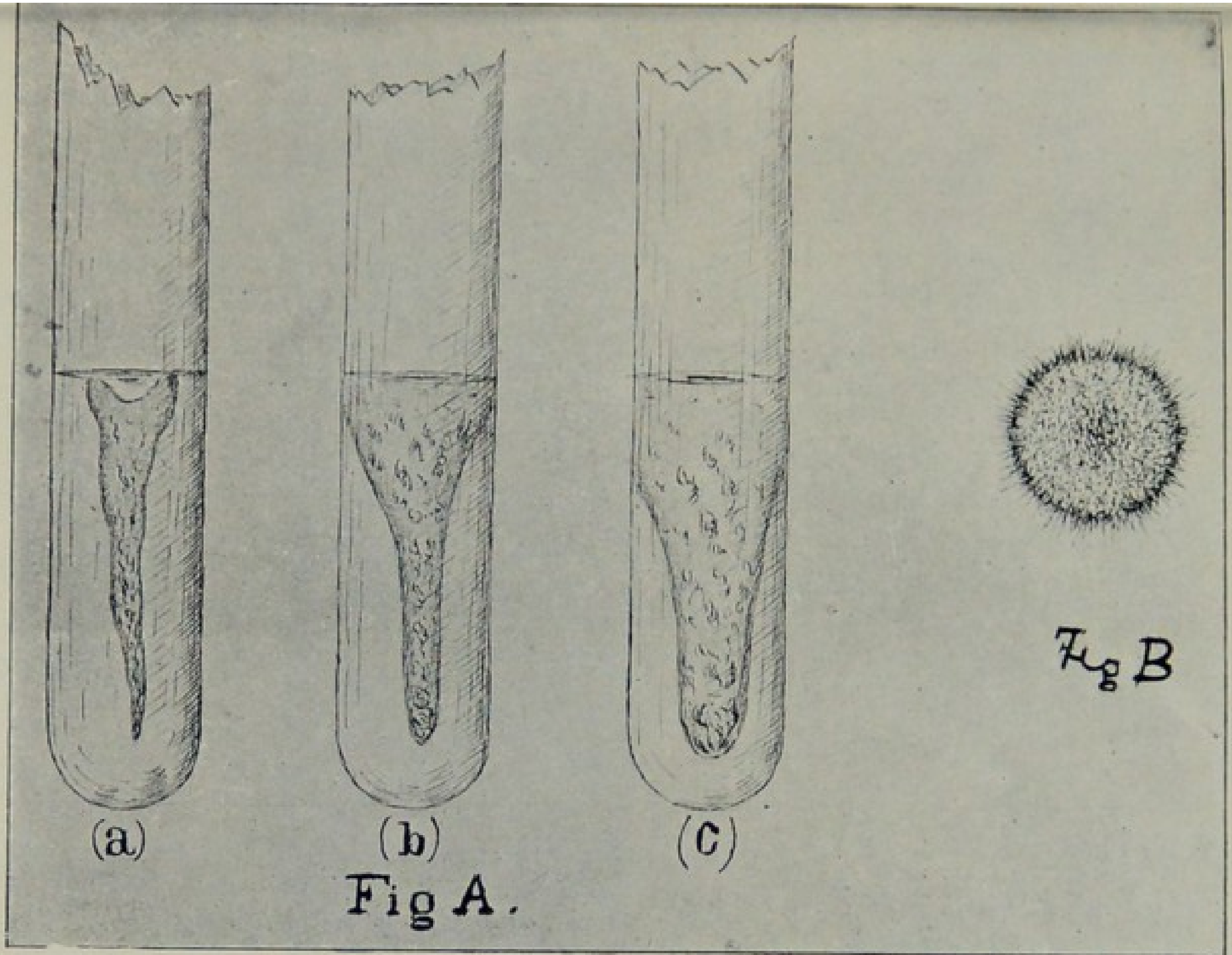


FIG. 57 (A).—*B. subtilis.* Sewage variety A. Gelatine "stab" cultures—(*a*) Two days' growth at 20° C. (*b*) Three days' growth at 20° C. (*c*) Four days' growth at 20° C.
(B).—*B. subtilis.* Sewage variety A. Colony in a gelatine plate under a low power of the microscope. Two days' growth at 20° C.
(Diagrammatic.)

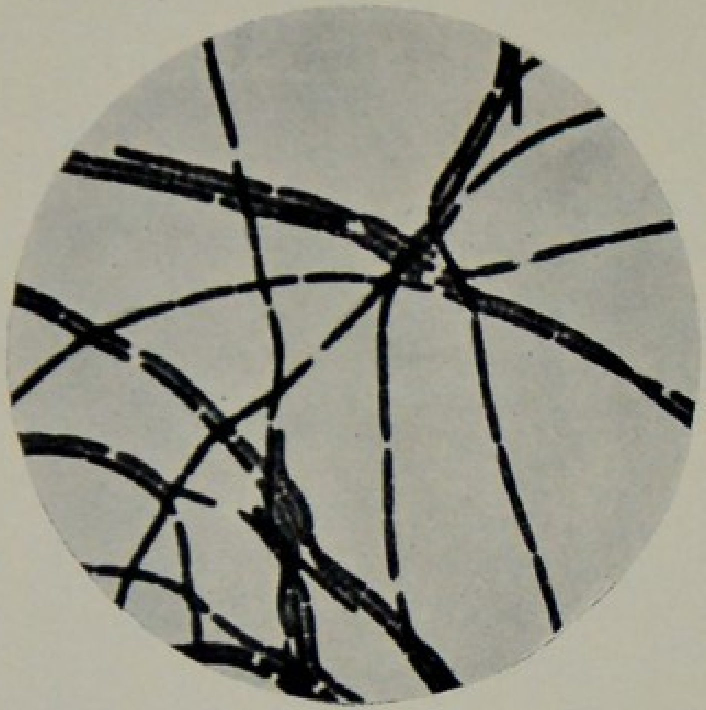


FIG. 58.—*B. membraneus patulus.* Impression preparation from a gelatine plate culture. × 1,000.

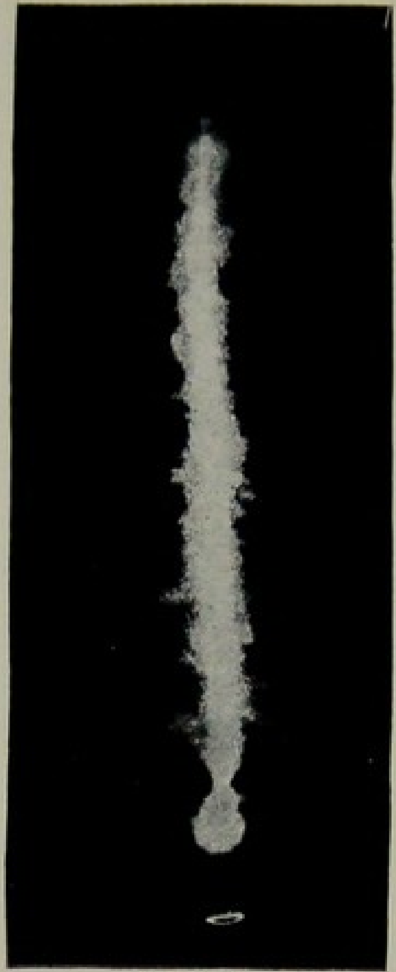


FIG. 59.

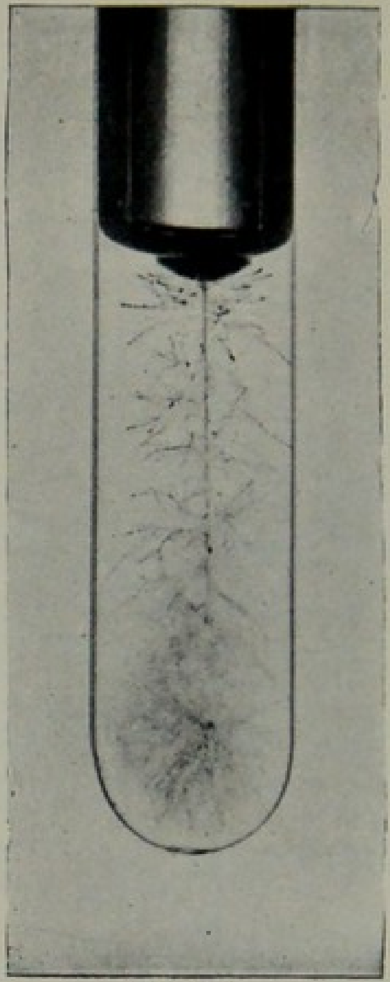


FIG. 60.

FIG. 59.—*B. membraneus patulus.* Oblique gelatine culture. About natural size.
FIG. 60.—*B. membraneus patulus.* Gelatine "stab" culture, three days' growth at 20° C. About natural size.

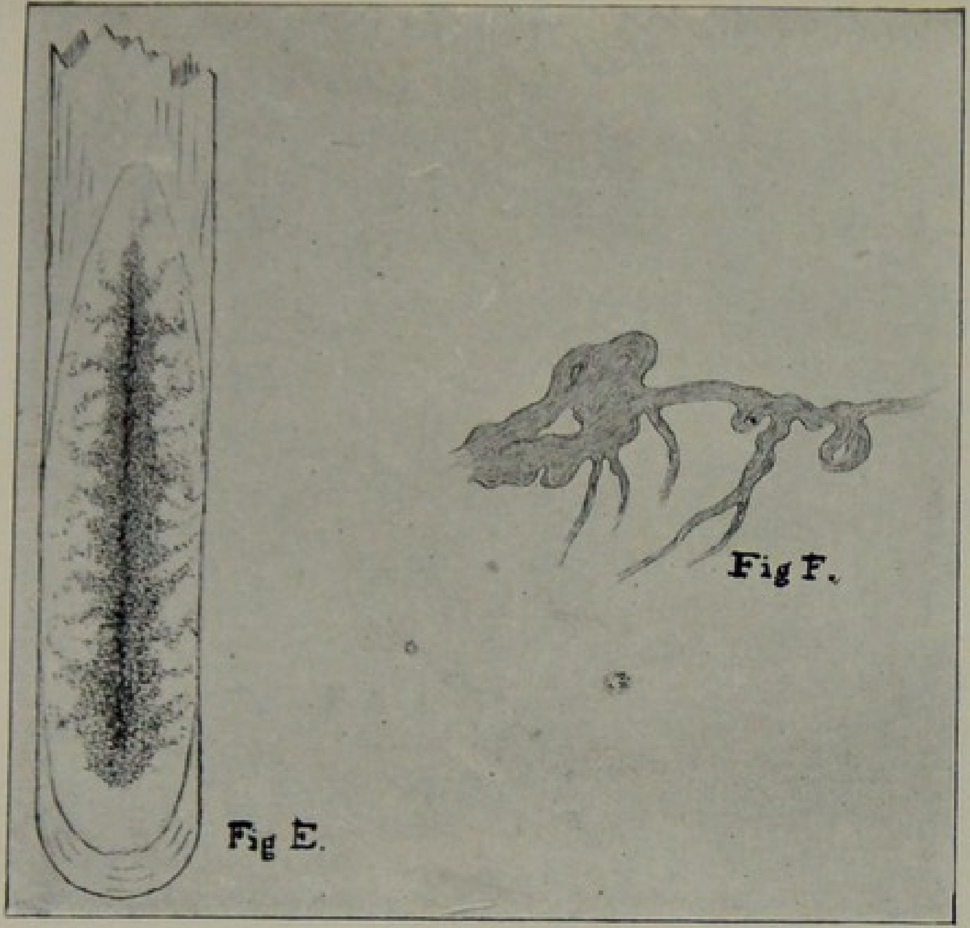


FIG. 61 (E).—*B. membraneus patulus.* Oblique gelatine culture.
(F).—*B. membraneus patulus.* Showing the appearance under a low power of the microscope, of the delicate film-like processes which extend over the surface of the medium in gelatine plate cultures.
(Diagrammatic.)

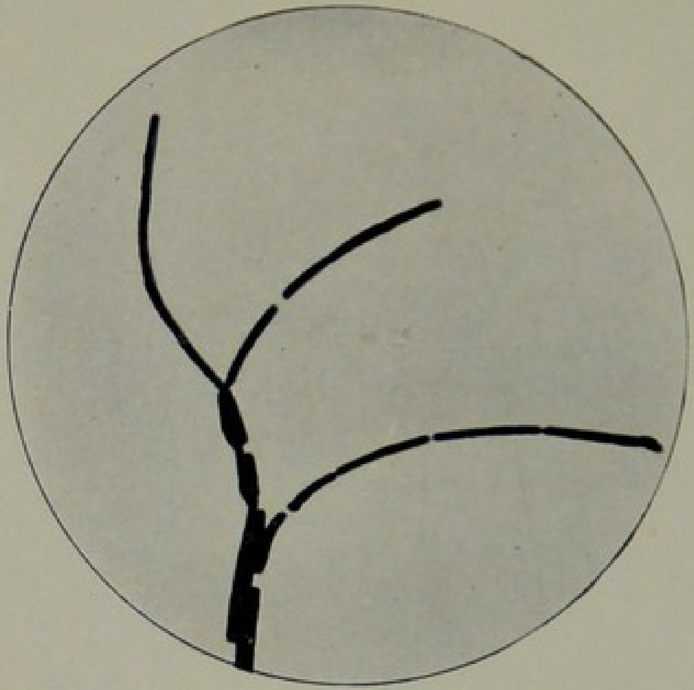


FIG. 62.—*B. capillareus.* Impression preparation from a gelatine plate culture, 20 hours' growth at 20° C. × 1,000.

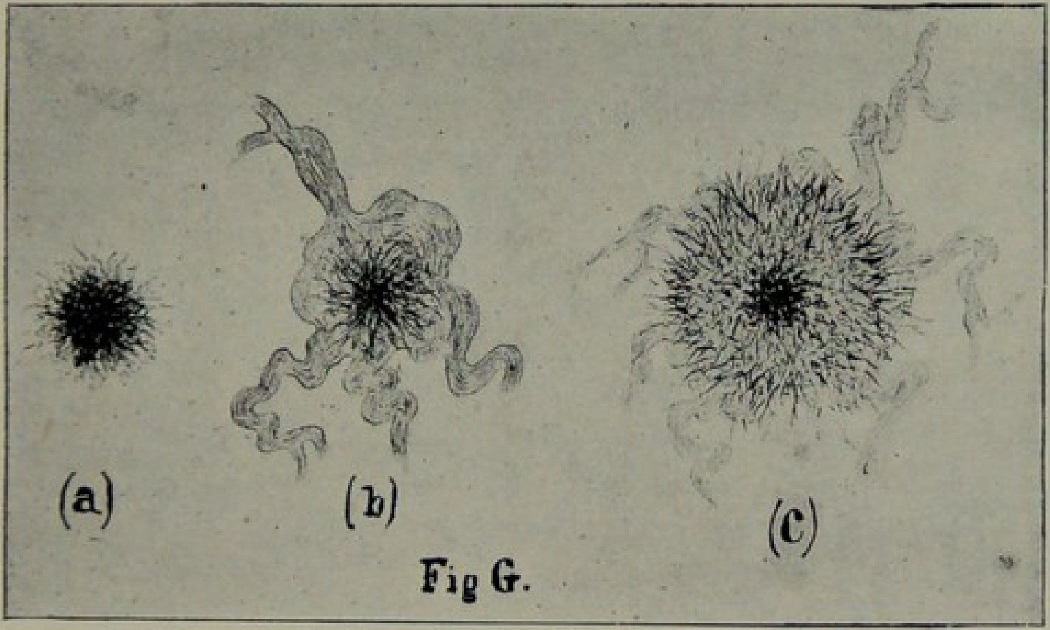


FIG. 63.—*B. capillareus.* Under a low power of the microscope.
(*a*) Deep-seated colony in gelatine. Twenty hours' growth at 20° C.
(*b*) Colony partly deep and partly superficial. Twenty hours' growth at 20° C.
(*c*) Colony at a later stage of growth and after liquefaction had set in.
(Diagrammatic.)

organisms than the sewage before treatment. Thus, while the chemical results were always satisfactory, the bacteriological results were usually quite the reverse, because the microbes producing the chemical changes passed through the coke-beds in practically unaltered numbers.

[The reasons for this state of things would seem to be that the process itself depends for its success on the vital activity of bacteria; that the fragments of coke are not fine enough to allow of the mechanical separation of the germs; that the products of the growth of the microbes, while they are self-injurious, are not sufficiently poisonous to destroy the life of the microbes, although they, doubtless, exercise a restraining influence on the extent of the multiplication: and finally, that purification is not carried sufficiently far to exhaust all the assimilable pabulum in the liquid.]

It has already been pointed out that *B. coli* is an aërobic (facultative anaërobic) microbe of intestinal origin which may be pathogenic, and that *B. enteritidis sporogenes* (Klein) is a pathogenic anaërobe typical of excremental matters and may be causally related to certain cases of acute diarrhœa in the human subject; cultures of this microbe are extremely virulent when injected subcutaneously into guinea-pigs.

Again, it has been stated that *B. coli* and the spores of *B. enteritidis sporogenes* are present in the effluents from the coke-beds in numbers usually exceeding 100,000 and 100 respectively per c.c. Further, it has been shown that a *proteus-like* germ ("*sewage proteus*") is present in abundance in the effluents—usually more than 100,000 per c.c. Some *strains* of this microbe are very virulent to guinea-pigs. Lastly, a highly virulent *strain* of *B. pyocyaneus* has been isolated from so minute an amount as $\frac{1}{1000}$ c.c. of a Barking coke-bed effluent. There is some evidence to show that this microbe possibly may be the cause of some epidemics of diarrhœa.

Moreover, the cultures made from the crude sewage and from the effluents were frequently compared side by side, yet no distinct differences could be made out between the two sets of cultures as regards the species of microbes.

[Of course this does not preclude the possibility of failure to detect points of difference not easily appreciable even to the trained observer. Still less does it mean that no selective process was in operation in the coke-beds. It is known that certain microbes, *e.g.*, the nitrifying germs, do not grow in the media ordinarily used by bacteriologists. The mere fact that the raw sewage contained little or no oxidised nitrogen, while the effluents contained nitrites and nitrates, implies that nitrification was in progress, and doubtless the nitrifying germs were not only stored in the coke-beds, but were present in the effluents in greater number than in the raw sewage. Indeed, certain tentative experiments which were carried out in this connection seemed to support this view.]

The records showing that *streptococci*, presumably of intestinal origin, pass through the coke-beds in practically unaltered numbers, and may be isolated from $\frac{1}{1000}$ c.c. or less of the effluents, are significant. It is to be anticipated that if *streptococci* can resist the biological processes at work in the coke-beds, there is small ground for the belief that other germs of a dangerous sort, *e.g.*, the typhoid bacillus, will be destroyed.

It has been shown that although the metabolic *products* alone of the bacteria in the effluents are not fatal even when large doses are injected subcutaneously into guinea-pigs, the effluents *plus* their contained bacteria are decidedly pathogenic, and do not indeed differ in this respect materially from the raw sewage.

[In rodents a local reaction is always observed, and abscess formation and ulceration frequently result from the injections, although they do not necessarily prove fatal.

When death rapidly results, the fatal result seems to be usually due to virulent *B. coli* or *B. proteus* or *B. enteritidis sporogenes*, or to microbes more or less closely allied to one of these species. Doubtless, however, other microbes are also concerned in producing a pathogenic effect. Sometimes the animal apparently recovers, but eventually may die from *pseudo-tuberculosis* (*B. pseudo tuberculosis*).

Lastly, it has been shown that the deposit accumulating on the coke in the bacteria-beds contained the spores of *B. enteritidis sporogenes* in great abundance, and also that two mice each inoculated subcutaneously with a small portion of the Barking coke-bed deposit died with all the characteristic symptoms of *tetanus* (lock-jaw). Further "*acid-fast*" *bacteria* were present in considerable numbers in the deposit, and they were also found in the crude sewage and effluents—particularly in the latter. The inference would seem to be that the "*acid-fast*" *bacteria* are stored in the coke-beds, and are continuously or occasionally washed away in the effluents.

[Although many of these "*acid-fast*" *bacteria* could not with certainty be morphologically distinguished from the *tubercle bacillus*, it was not claimed that they were *necessarily* the microbe of *tuberculosis*, alive or dead, virulent or non-virulent. But it was pointed out as a significant fact that in one instance a guinea-pig inoculated with the deposit from a bacteria-bed (not, however, one at Barking or Crossness), especially rich in these "*acid-fast*" *bacteria*, did die from actual *tubercular* infection, and that sections of its organs when appropriately stained showed the presence of *tubercle bacilli*.]

In view of these results, only one conclusion seems possible, namely, that until reliable evidence to the contrary is forthcoming, *the effluents from the bacteria-beds ought to be regarded as hardly, if at all, more safe in their possible relation to disease than the raw sewage before treatment.* This conclusion, however, must not be interpreted in a wrong sense. It does not mean (the contrary is my opinion) that the bacterial treatment of London crude sewage is a measure to be condemned from the chemical and practical point of view and under all the conditions obtaining in the present case.

3. *Final Conclusions.*

In framing final conclusions the following points have been carefully considered:—

The Thames in its lower reaches is not used for drinking purposes. It is, perhaps, hardly necessary to add that if this were not the case my recommendations would be totally different to those here presented. As regards the possibility of contamination of shell fish at the mouth of the Thames, I am unable to express a definite opinion as my investigations on behalf of the London County Council did not cover this field of enquiry. But as the effluent after chemical treatment is seemingly worse bacteriologically than the effluent from the bacteria-beds and much more impure chemically, the inference is that the bacteria-bed treatment is to be preferred.

The existing chemical treatment yields an effluent in most respects inferior to the effluents obtained from the experimental bacteria-beds.

The state of the lower river during hot weather when accompanied by periods of drought calls for prompt action. It is conceivable that to some extent the present unsatisfactory conditions are of a cumulative character; and that, unless remedial measures are soon adopted, there may arise in the future a condition of affairs which it may take a considerable time to modify or control.

The bacterial treatment of London crude sewage has received a trial extending over some years, and, although in certain directions the results are not altogether satisfactory, there can be no question that it is possible to obtain a better effluent by the use of contact beds than by the existing mode of chemical treatment.* During the progress of my observations, the unsatisfactory features of the experiments have been the bacteriological results and the initial if not progressive loss of capacity in the coke-beds. As regards the former, I have previously expressed the opinion that in the case of the lower Thames the bacteriological are of secondary importance when compared with the chemical results. As regards the latter, Dr. Clowes has furnished evidence that the choking of the coke-beds can be kept within bounds by a preliminary process of rapid sedimentation of the sewage.

An unbiassed consideration of the subject from the practical and economic point of view might not result in conclusions favourable to the biological as compared with the chemical treatment. But nicely balanced questions of alternative cost should not be allowed to dominate the serious question at stake, namely, the extent to which it is possible and practicable to improve the condition of the lower Thames. No doubt, special laws and privileges are attached to the discharge of London sewage into the river Thames; but to take undue advantage of this circumstance would be inconsistent with the liberal and progressive policy pursued by the Council in regard to other matters affecting public health.

Lastly, it may be pointed out that instances are not wanting of the successful bacterial treatment of sewage on a large scale. One example is to be found at Manchester, and there are no reasonable grounds for doubting that as good results could be obtained in the case of London crude sewage.

Taking into account all these considerations, I am of opinion that the gradual adoption of the bacterial treatment of sewage in place of the existing chemical treatment is a practicable measure to be recommended and would lead to a progressive improvement in the condition of the lower Thames.

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* It must be understood that neither in this book nor in any of my previous reports have I expressed any opinion as to the relative merits of the different bacteria-bed processes of sewage treatment. I have confined my remarks to the results obtained with contact beds at Barking and Crossness, and have contrasted these results, not with other bacterial processes, but with the results obtained from the existing chemical treatment at the Outfall Works.

DIVISION III.

PARTICULARS OF BACTERIAL WORK

AT

VARIOUS CENTRES.

CONTENTS.

DIVISION III.—BACTERIAL WORK AT VARIOUS CENTRES.

The list of the names of the towns in alphabetical order will be found in the second column of each table.

THE BACTERIAL TREATMENT OF SEWAGE.

DIVISION III.

BACTERIAL WORK AT VARIOUS CENTRES.

THE BACTERIAL TREATMENT OF SEWAGE AND OF SEWAGE EFFLUENT AT VARIOUS CENTRES THROUGHOUT THE COUNTRY.

While the Fourth Report to the Main Drainage Committee of the London County Council on the bacterial treatment of crude sewage was being prepared, information as to similar work was courteously supplied by many local authorities. The details were tabulated and published in the fourth report as an appendix. On account of the value attaching to this tabulated information it has been considered advisable to incorporate it in this book. Owing to the small size of the pages of the book as compared with those of the Fourth Report, it has been found necessary to slightly modify the tables in order that the general arrangement of them might be retained. The modification, however, has been of so slight a nature as not to detract from the value of the information.

The table comprises statements from 47 centres, and includes the whole of the information respecting the bacterial treatment of sewage or sewage effluent, obtained in answer to about 60 applications. In most of the other cases bacterial treatment was not in use.

Favourable results are reported as having been obtained from all except two of the 47 centres. The two centres referred to as exceptions are Glasgow and Huddersfield.

At Glasgow the results of the treatment of sewage in experimental bacteria-beds indicated a purification from putrescible matter of 95 per cent., while the open "septic" tank was the means of reducing the amount of sludge by 54 per cent. Similar results have been accepted as satisfactory at other centres. The objection to the use of bacteria-beds at this centre appears to be that the area required for their installation would be 164 acres, while the system of treatment by lime and sulphate of alumina could be satisfactorily carried out on a superficial area of 23 acres. By this latter method it is claimed that every trace of suspended matter is removed, and that 30 per cent. of purification from putrescible matter is effected.

At Huddersfield the sewage is of an exceptional character, since 30 per cent. of it is derived from manufacturing processes, almost wholly woollen, and it contains a quantity of soap, fat, and dyes, and a variety of chemicals used in the dyeing and finishing of woollen goods. The best results were obtained by the treatment of the sewage with a small quantity of lime and sulphate of iron, followed by double contact in bacteria-beds. The beds which were used for this purpose retained their capacity much better than those which dealt with either the crude sewage or with the septic tank effluent. Owing to the final effluent being frequently unsatisfactory, and also to the rapid decrease of the capacity of the coarse bed, the use of this system on a large scale is not contemplated.

A careful consideration of all the information obtained from the various centres where bacterial treatment has been tried convinces me that the process has been uniformly successful when the construction and use of the necessary plant has been reasonably and properly carried out. The only exception that appears possible to this general statement is interference which is caused by the sewage being of a very unusual character.

The information in these tables has been brought up to the 30th April, 1902.

The information set forth in the following tables has been courteously supplied by the various local authorities throughout the country, who have used bacteria-beds in connection with the treatment of sewage or sewage effluent, either in a permanent installation or in an experimental form.

In consequence of the necessarily complicated nature of any attempt to arrange in systematic order the results of such work carried out under very varying conditions, some explanation of the tables and of their arrangement is necessary.

The information has been placed in two main divisions, one dealing with the bacteria-beds and the other dealing with the "septic" tanks; there is also an additional column for remarks.

The division dealing with the bacteria-beds is divided into three tables, as follows:—

Table 1.—Particulars of the bacteria-beds.

Table 2.—Particulars as to the working of the bacteria-beds.

Table 3.—Particulars as to the capacity of the bacteria-beds, and as to the loss of capacity during working.

The division dealing with the "septic" tanks is divided into two tables as follows:—

Table 4.—Particulars of the "septic" tanks, of the settling tanks, and of the detritus tanks.

Table 5.—Particulars as to the working of the tanks.

Table 1 is a record of the details of the construction of the various beds used by the different local authorities. In some instances, more especially in centres where reports have been published of the work which has been carried out in the bacterial treatment of sewage, the details of the various beds are very full, and in these cases each bed is dealt with separately. In other instances, principally where the treatment is of a permanent character and the beds are consequently uniform in size and structure, the groups of beds only are described.

In column 8, "Material and size of the material of which the beds are composed," the size is determined by the mesh of the sieves used in screening the material, unless otherwise stated. Thus $\frac{1}{2}$ to $\frac{1}{16}$ inch means that the material is such as would pass through a screen of $\frac{1}{8}$ inch mesh and would not pass through a screen of $\frac{1}{16}$ inch mesh.

Table 2 is a record of the different experiments which have been carried out at the various centres, but in many instances the records are insufficient to justify the results being set out separately in the table. In such instances only the general details of the manner in which the beds have been worked are recorded. In the case of permanent installations, where the beds have been uniformly dealing with the same class of liquid for some years, only the more recent results are given in the table.

The figures in column 27 "Quantity of sewage treated in 24 hours per acre of bed one foot deep" have been calculated from data given, in order that the quantities dealt with by the various beds at a uniform depth, may be seen at a glance.

Table 3.—The importance of information bearing on the capacity of the beds and on the loss of capacity noticed in the working of the beds, rendered it necessary to devote a table to this subject. The records in this table are not intended to correspond with the experiments detailed in the previous table; they are merely such records as have been made of the variations in the capacity of beds. In some instances the records furnished were too extensive to insert in these tables; in such instanc extracts have been made from the data supplied.

The original water-capacity of the bed in the tank means the liquid capacity of the bed after the material of which it is formed has been thoroughly soaked. The original water-capacity therefore does not mean the quantity of liquid which could be poured into the bed in its dry condition, but rather the quantity which could be drained from the working bed during the specified time of emptying.

Since the capacity of a bed alters considerably during a lengthened period of rest, the terms have usually included measurements which have been made after such rest periods. Such measurements have not always been made from the first filling after a rest period, and in such instances a draining period is generally recorded as well as the number of fillings since the rest period.

Table 4 furnishes details concerning the "septic" tanks, the settling tanks, and the detritus tanks used at the various centres.

Table 5 is a record of the working of the various tanks.

TABLE I.—Particulars

No.	Name of town or district.	Nature of Installation. P.—Permanent. T.—Temporary.	Number or names of the beds. P.—Primary. S.—Secondary T.—Tertiary.	Average or working area of the beds. Square feet.	Measurement of the surface of the beds. Feet.	Depth of the beds. Feet.	Material and size of the material of which the beds are composed.
1	2	3	4	5	6	7	8
1	Accrington ...	P.	10 ... ... 4	3,019 1,944	62 in dia. each 49·75 in dia. each	8.5 and 9 8 and 9	Coke, 2 to 3-inch ... " " "
2	Aldershot ...	P.	Top or primary Bottom or secondary	2,146 5,800	58 × 37 58 × 100	4 1·5	Clinkers, ¾-inch ... " varying size " generally fine
3	Acton... ...	T.	...	594	...	6·5	Clinkers, 2-inch
4	Aylesbury ...	T.	4 ... ... 6	31,740 total area	Varies from 50 × 30 to 116 × 30	5·0 3·25	Coarse burnt ballast Coke breeze
5	Barnsley ...	T.	3	32,400	120 × 90	3	Broken clinker and ashes ¼-inch ... ½ " ... 1 " ... 1½ " ...
6	Birmingham...	T.	1 to 8 ... Percolating No. 1 Percolating No. 2	133,656 44,552 10,890 10,890	150 × 150 148½×148½ at bottom 62 diam. at top 70 diam. at bottom	3 3 5 4·5	Coke, 1 to 1¼ inch Destructor clinker, 1 to 1¼-inch Coke, 1 inch Coke, 1 inch
7	Blackburn ...	T.	1 ... ... 1	4,770 4,770	... ...	5·5 5·5	Coke ... ... Coke breeze
8	Bloxwich district of Walsall	T.	8 P ... 8 S ...	... ...	... ...	2·5 2·5	½ to $\frac{1}{16}$ inch ... ½ inch to dust
9	Bristol— At Knowle At St. John's-lane	 T. T.	 2 Knowle 1 St. John's	 132 each 396	 22 × 6 22½ diameter 30 at bottom	 6 3	Washed clinker from destructor which passed through a 2-inch ring

of the Bacteria-beds.

Thickness of each layer of material, arranged in their order in the beds, from the top downwards. 9	Method of under-draining the beds. 10	Actual or estimated cost of making the beds. 11	Actual or estimated cost per acre of making the beds. 12	Cost of treating sewage per million gallons. 13
		£	£	£ s. d.
...	Half 18-inch perforated earthenware pipes laid on concrete bottom	2·25 per sq. yard. Including excavation, concreting bottom, under-draining, brick-work in cement, and coke	10,890	4 6 0 (about)
15 inches ... 33 ,,	Only by the packing of large material. No pipes are used	250	5,000 (about)	
		250	1,700 (about)	
...	...	...	...	...
...	9-inch main drains (two mains to each large bed), with double junctions 2 feet apart, and 3-inch agricultural pipes arranged in herring-bone fashion	3,200 (by contract) for coke breeze beds	6,400	15 0 0
9 inches ... 9 ,, 9 ,, 9 ,,	By land tiles and square longitudinal drains 18 inches by 12 inches	1,343·5	1,400 (about) including the open "septic" tank	
Similar throughout	The whole bed is laid on a false bottom, in which there are channels 6 inches by 6 inches and 148 feet long	48,000 (about)	12,000 (about)	
Similar throughout	3-inch agricultural drain tiles laid herring-bone fashion in channels covered with 2-inch stone covers. There is a fall of 18 inches in each bed			
...	Land tiles	1,000	5,000	
...	No pipes, floor inclined from centre to border			

No.	Name of town or district.	Nature of Installation. P.—Permanent. T.—Temporary.	Number or names of the beds. P.—Primary. S.—Secondary T.—Tertiary.	Average or working area of the beds. Square feet.	Measurement of the surface of the beds. Feet.	Depth of the beds. Feet.	Material and size of the material of which the beds are composed.
1	2	3	4	5	6	7	8
10	Burnley—Duckpits (septic tanks) and Woodend works (beds)	P.	1 P ...	31,050	...	3	Hard furnace clinker ¾-inch and above
			2 P ...	28,998	...		
			3 P ...	27,873	...		
			4 P ...	27,153	...		
			5 P ...	28,890	...		
			6 P ...	54,882	...		
			12 P ...	50,094	...		
			18 P ...	22,473	...		
			14 S ...	25,893	...	3	Hard furnace clinker from ¼-inch to ¾-inch.
			15 S ...	26,568	...		
			16 S ...	27,441	...		
			17 S ...	27,873	...		
			19 S ...	24,192	...		
			22 S ...	17,424	...		
			23 S ...	15,885	...		
			26 S ...	59,238	...		
11	Burslem ...	T. P.	3 P ...	144,000 (total)	...	3	Pottery refuse, ½ to 1½-inch
			3 S ...	...	...	3	
			3 T ...	...	...	3	Pottery refuse, ½ to 1-inch
12	Bury	P.	6	8,100	45 × 30	3	Coke } ⅜ to 1½-inch
			6	8,100 (totals)	45 × 30	3	Cinders
13	Cambridge ...	...	2	9,800 (total)	(8,700 superficial feet)	10	Clinkers, 2 to ¾-inch " ⅜ to ⅛-inch " above 2 inches
14	Carlisle ...	P.	4	5,400 (each)	120 × 45	4	Sandstone, 5 to 1-inch
15	Croydon ...	P.	6	5,140	Irregular	3·75	Coarse burnt clay ballast, 1 to 3-inch
16	Darwen ...	P.	5	...	49 × 24	3·5	Sand, $\frac{1}{24}$ to $\frac{1}{16}$-inch Hard vitrified clinker
17	Epsom ...	...	6 P ... 6 S ...	...	...	3	1½-inch ½-inch
18	Evesham ...	P.	1 to 4 ...	20,000	91 × 55	3·5	Slag ¼ to 1¼-inch
19	Glasgow ...	...	4 first contact beds	3,594 (total)	...	3·25	Engine ashes, ¼-inch " ⅛ " " ⅜ "
			4 second contact beds	3,582 (total)	...	3·25	" ⅛ " " ¼ " " ⅛ "

continued.

Thickness of each layer of material, arranged in their order in the beds, from the top downwards. 9	Method of under-draining the beds. 10	Actual or estimated cost of making the beds. 11	Actual or estimated cost per acre of making the beds. 12	Cost of treating sewage per million gallons. 13
		£	£	£ s. d.
...	Main drain of salt glazed socketted earthenware pipes varying from 12 inches to 15 inches in diameter according to size of bed. Side drains of 4-inch salt glazed earthenware socketted pipes, perforated round ¾ of pipe. Holes ½-inch in diameter. Arranged 7½ feet apart. In the secondary beds the side drains are 4-inch field tiles. The underdrains are in all cases covered with coarse hand-picked clinker to a depth of 9 inches.	...	Total average cost of bed per acre £1,300. The cost varies from £1,200 to £1,400 according to the amount of excavation and banking necessary.	
...	Covered channels in concrete bottoms packed round with coarser material	... (Estimated cost of extensions now being made, exclusive of filling)	2,740	
6 feet 2 feet 2 feet				
Not in layers	Not underdrained	2,500	5,100	
All the same size	3-inch agricultural drain pipes, 5 feet apart, leading to central drain	2,600 (about)	3,660	
6 inches 3 feet	Channels in the concrete floors of the beds, covered with stone flags			
Mixed ...	Perforated pipes	1,000 (filling only)	4,600	
9 inches 1 feet 9 inches 9 inches 2 feet ... 7 inches 8 inches	Dry built brick drains, 9 inches by 9 inches, in the centre of the bed and 4-inch field drain pipes laid diagonally from the centre to the sides	The installation, which is merely experimental and on a very small scale, cost £980. The original cost of the precipitation tanks which contain the beds is not taken into account		

No	Name of town or district.	Nature of Installation. P.—Permanent. T.—Temporary.	Number or names of the beds. P.—Primary. S.—Secondary T.—Tertiary.	Average or working area of the beds. Square feet.	Measurement of the surface of the beds. Feet.	Depth of the beds. Feet.	Material and size of the material of which the beds are composed.
1	2	3	4	5	6	7	8
20	Haslingden, Rawtenstall and Bacup	P.T.	16	...	45×30	3	Fine clinker ... Coarse and fine coke Burnt ballast and aërating pipes Coarse coke ... Burnt ballast and 4-inch drain pipes Afterwards the 6 inches of fine clinker were replaced by 1 foot of coarse clinker
21	Heywood ...	T.	First contact coarse beds	...	...	3	Material 1 to 3 inch
			Second contact fine beds	...	...	3	„ ¼ to 1 inch
			Single fine beds	...	...	4·25	Sand and coke
22	Huddersfield...	T.	Coarse ...	1,600	40 × 40	3·5	Clinker, ⅝ to 5-inch
			Fine ...	1,800	48 × 38	3·25	Clinker, ¼ to ⅝-inch Clinker, ¼ to 1½-inch Clinker, rough ...
			No. 7 ...	1,800	48 × 38	3·25	Clinker, ⅛ to ¼-inch Clinker, ¼ to 1-inch Clinker, rough ...
		(One bed given as a type of 24 similar beds)					
			Coarse ...	288	16·5 × 18·5, 15·5×17·5 at bottom	3·75	Clinker, $\frac{3}{16}$ to ½-inch Clinker, 1 to 3-inch
			Fine ...	288	16·5 × 18·5, 15·5×17·5 at bottom	3·75	Clinker, $\frac{3}{16}$ to ¼-inch Clinker, $\frac{3}{16}$ to 1-inch
			"Trickling bed"	1,071	Hexagonal. Average diameter 37 ft	7	Clinker over 1½-inch Clinker over 2-inch
23	Hyde	...	1	45 diameter	...	9	Coke rejected by 3-inch mesh
24	Keighley ...	T.	Rough bed	100	10 × 10	3·25	Coke, 1 to 3-inch ...
			Fine bed ...	...	...	...	„ ¼ to 1-inch ...
25	Kettering ...	T.	1	210	21 × 10	3	Gravel Pebbles ... Coke, ¼ to 1-inch ...
		P.	2	16,268	170 × 102, 162 × 94 at bottom	4	Coke breeze, $\frac{3}{16}$ to 1¼-inch
			1	16,268		4	Coke breeze, $\frac{3}{16}$ to 1¼-inch
			1	12,782	170 × 81, 162 × 73 at bottom	4	Burnt ballast, ½ to 2-inch
	A layer of iron furnace slag, 2 inches in thickness, was placed on the top of each bed						

continued.

Thickness of each layer of material, arranged in their order in the beds, from the top downwards. 9	Method of under-draining the beds. 10	Actual or estimated cost of making the beds. 11	Actual or estimated cost per acre of making the beds. 12	Cost of treating sewage per million gallons. 13
		£	£	£ s. d.
6 inches ... 14 inches 4 inches 8 inches 4 inches	4-inch drain tiles surrounded with burnt ballast	5,800		
3 feet 3 inches	Land tiles			
9 inches ...	" "			
1 foot 11 inches 7 inches				
6 inches ...	" "			
2 feet 3 inches 6 inches				
3 inches ... (over part only) 3 feet 6 inches (in parts)	Half tiles on concrete floor			
6 inches ...	" "			
3 feet 3 inches				
4 feet 3 feet	Perforated half tiles on brick floor.			
9 feet ...	Half tiles on bricks, concrete floors	150	180	
...	Land tiles	...	4,500	
3 inches ... 2 feet 9 inches	Land drain tiles, 2 inches in diameter laid herring-bone fashion to 3-inch central drain			
4 feet 2 feet 2 feet	Main drain with cemented joints up centre of each bed, 12 inches in diameter for one-half the length, 9 inches for the other. Side drains, land tiles 2 inches in diameter, butt jointed, 5 feet apart, laid herring-bone fashion	5,000 (about)	3,540	

TABLE I.—

No.	Name of town or district.	Nature of Installation. P.—Permanent. T.—Temporary.	Number or names of the beds. P.—Primary. S.—Secondary T.—Tertiary.	Average or working area of the beds. Square feet.	Measurement of the surface of the beds. Feet.	Depth of the beds. Feet.	Material and size of the material of which the beds are composed.
1	2	3	4	5	6	7	8
26	Leeds ...	...	No. 1 coarse bed	5,580	90 × 65, 88 × 63 at bottom	5	Coke, 3-inch and larger
			No. 2 fine bed	5,580	100 × 61, 99 × 51 at bottom	6	Coke, 3/16 to 1½-inch
			No. 3 coarse bed	5,445	...	3	Clinker, ½ to 1-inch
			No. 4 fine bed	5,445	...	3	Clinker, 3/16 to ½-inch
			No. 5 coarse bed	5,445	...	3	Clinker, 1 to 2-inch
			No. 6 fine bed	5,445	...	3	Clinker, 3/16 to ½-inch
			No. 7 fine bed	8,100	...	3·5	Clinker, ⅝ to 1-inch
			No. 8 fine bed	4,320	...	3·5	Clinker, ⅝ to 1-inch
			Whittaker No. 1	...	...	10	Clinker, 1 to 3-inch
			Whittaker No. 2	...	...	9·5	Coke, above 1½-inch " 2 "
			1 continuous	153	12 × 12 (about)	3·5	Coke, coarsest available
			2 "	153	...	2·5	Coke, 1 to 1½-inch
			3 "	153	...	2·5	Coke, about ⅝-inch
			Ducat ...	435·6	...	10	Clinker, [illegible] to ⅝-inch
27	Leicester ...	P. T.	1 P ...	1,110	37 × 30 (mean)	4½	Clinker, 1¼ to 2¼-in.
			2 P ...	1,110			Clinker, 1¼ to 2¼-in.
			3 P ...	1,110			Clinker, ¾ to 1¼-in.
			4 P ...	1,110			Clinker, ¾ to 1¼-in.
			1 S ...	675	...	3	Clinker, ⅛ to ½-inch
			2 S ...	675	...	3	Clinker, 1/16 to ½-inch Clinker, 1/16 to ⅛-inch Clay ballast, ½ to 1-inch Burnt ballast, 1/16 to ⅛-inch
28	Lincoln ...	P.	1 P ...	3,255	71 × 50	4 10/12	Broken coke and clinker Primary beds, 1½-inch Secondary beds, ¾-inch
			2 S ...	8,586	159 × 54	4 10/12	
			3 P ...	3,600	72 × 50	4 10/12	
			4 S ...	18,198	182 × 100	5¼	
			5 P ...	3,303	82·5 × 40	4 10/12	
			6 S ...	17,280	160 × 108	5	
			7 P ...	2,970	90 × 33	4 10/12	
			9 P ...	3,249	79·75 × 40·75	4½	
			11 P ...	3,258	78·5 × 41·5	4½	
			13 P ...	18,954	189·5 × 100	5	
			15 P ...	14,301	162·5 × 88	5¼	

continued.

Thickness of each layer of material, arranged in their order in the beds, from the top downwards. 9	Method of under-draining the beds. 10	Actual or estimated cost of making the beds. 11	Actual or estimated cost per acre of making the beds. 12	Cost of treating sewage per million gallons. 13
		£	£	£ s. d.
...	3-inch agricultural drain pipes, surrounded by large coke			
...	" "			
...	Partly drained by 3-inch pipes and coarse clinker			
...	" "			
...	" "			
...	" "			
...	Not drained			
...	3-inch agricultural drain pipes			
...	9-inch drain pipe in concrete			
... 1 foot	18-inch half-round drain pipes on cement			
Afterwards 1½ inch and upwards	9-inch drain pipes			
...	6-inch and 4-inch land tile drains. Two 6-inch layers of old flattened tins, 1 foot apart, were laid in the body of the beds.			
...	3-inch land tile drains			
6 inches ...	3-inch land tile drains			
19 inches mixed				
11 inches				
Same throughout	2 and 3-inch pipes leading to each valve. In the large beds there are 4 to 6 valves. The main pipes are provided with branches	..	5,000	0 14 0 (labour on beds) 0 12 3 (precipitant)

No.	Name of town or district.	Nature of Installation. P.—Permanent. T.—Temporary.	Number or names of the beds. P.—Primary. S.—Secondary T.—Tertiary.	Average or working area of the beds. Square feet.	Measurement of the surface of the beds. Feet.	Depth of the beds. Feet.	Material and size of the material of which the beds are composed.
1	2	3	4	5	6	7	8
29	Liverpool (West Derby sewage farm)	P.	1 P ...	...	70·5 × 29·3	28	Burnt clay, 3-inch
			1A. S ...	...	80·6 × 28·3	2·6	Coke, 3-inch ... Ballast ... ...
			2 P ...	...	70·5 × 29·3	3	Red sandstone, 3-in
			2A. S ...	...	80·6 × 28·3	3	Coke breeze, small size
			3 P ...	...	70·5 × 29·3	3	Ordinary gas coke, 2-inch
			3A. S ...	...	80·6 × 28·3	3	Sand and gravel ...
30	Manchester ...	P.T.	Roscoe coke	225	12·5 × 18	3	Clean washed gravel Coke or cinder, ⅛ to ⅜-inch Coke or cinder under ¾-inch Coke or cinder under 1¼-inch Rough clinker ...
			Roscoe cinder	225	12·5 × 18	3	
			Carbonaceous ironsand	225	12·5 × 18	2·5	Ironsand ... ... Rubble ... ...
			Spent pyrites	225	12·5 × 18	3	Burnt pyrites, ⅛-in. Burnt pyrites, 1-in. Burnt pyrites, large
			Fine cinder	225	12·5 × 18	2·5	Clinkers, ⅛-inch ... Rubble ... ...
			Rough cinder	6048	...	1¼	Boiler clinkers ...
			A	571·6	each 33·5 × 33·5, 17·5 × 17·5 at bottom	3	Clinker, 1 to 3-inch. Afterwards ¾ to ⅛-inch
			B	571·6		3	Clinker, ½ to 1-inch
			C	571·6		3	Clinker, ¼ to ¾-inch
			D	571·6		3	Clinker, ⅛ to ½-inch
			E	56·3	12 × 12, 3 × 3 at bottom	3	Clinker, ⅛ to ¼-inch
			Stoddart's	144	...	6	Coke, 3 × 2-inch... Clinkers, 3 × 2-inch
			1A 2A	... ...	165 × 134·25	3½	Clinkers, 3/16-inch Clinkers, large
			Septic system (6 beds)	294 each	...	4	...
			½ acre beds 1 to 10 13 to 18 22 to 27 33 to 38 44 to 48	21,780 each	...	3½	Clinkers, 3/16-in., large clinkers over drains
			Storm-beds 1 to 15	37,026 each	...	2·5	Unscreened clinkers, large clinkers over drains

continued.

Thickness of each layer of material, arranged in their order in the beds, from the top downwards. 9	Method of under-draining the beds. 10	Actual or estimated cost of making the beds. 11	Actual or estimated cost per acre of making the beds. 12	Cost of treating sewage per million gallons. 13
		£	£	£ s. d.
Not graded ...	6-inch main with 3-inch collecting drains			
14 inches				
18 inches				
Not graded				
”				
”				
”				
3 inches ...	Open drain pipes and land drain tiles			
6 inches ...				
6 inches				
9 inches				
12 inches				
24 inches				
6 inches				
6 inches	This bed was reduced to 2·75 feet in depth on 7 Dec., 1900			
24 inches				
6 inches				
24 inches				
6 inches				
...	Grips in land filled with bricks			
	The material of this bed was taken out, broken and re-screened in June, 1899			
...	6-inch and 2-inch pipes in channels in bottom of tanks. Pipes surrounded by coarse material.	...	...	2 0 0 estimated
	Bed D was reduced to 2 feet in depth on 21 March, 1900			
12 inches ...	... ...	17·56	(labour and material)	
5 feet ...	... ...	32·16		
28 inches ...	12-inch pipes in grooves in bottom of tanks			
12 inches ...				
...	... ...	...	3,350 (actual)	
...	Radial channels covered with perforated fire-clay slabs	...	2,550 (actual)	
	Brick under-drains on concrete foundation, covered with open-jointed fire-clay slabs	...	1,655 (actual)	

TABLE I.—

No	Name of town or district.	Nature of Installation. P.—Permanent. T.—Temporary.	Number or names of the beds. P.—Primary. S.—Secondary T.—Tertiary.	Average or working area of the beds. Square feet.	Measurement of the surface of the beds. Feet.	Depth of the beds. Feet.	Material and size of the material of which the beds are composed.
1	2	3	4	5	6	7	8
31	Middleton ...	P.	1 and 2 ...	22,230	62·5, 59·5 at bottom	3	Clean riddled mill cinders 1-in. 3-in.
32	Nelson ...	P.	1 P ...	49,500	116 × 80	3	Coarse clinkers
			2 P ...	(total)	93 × 80	3	
			3 P ...		116 × 80	3	
			4 P ...		93 × 80	3	
			5 P ...		116 × 85	3	
			6 P ...		86 × 85	3	
33	Oldham ...	P.	1	...	118 × 89	2¾	Screened furnace ashes about ¼-in.
			2	...	139 × 89	2¾	
			3	...	139 × 89	2¼	
			4	...	139 × 89	2½	
			5	...	157½ × 93¼	2¼	
			6	...	155½ × 89½	2¼	
			7	...	155½ × 89½	2¼	
			8	...	132 × 101¾	2	
			9	...	132 × 100½	1¾	
			10... ...	...	161 × 17	2¼	
			11... ...	...	161 × 68	2	
			12... ...	13,338	...	2½	
			13... ...	...	145 × 95	3	
			14... ...	...	136 × 95½	3	
			15... ...	...	...	3	Crushed and screened clinker from refuse destructor
			16... ...	...	...	3	
			18... ...	...	...	3	
			17...	(added	since April,	'02)	
			19 to 22 ...	"	" "		
34	Ormskirk ...	P.	3	2,400 (each)	...	3·5	Coke breeze ...
35	Oswestry ...	P.	9 P ...	...	60 × 60, 51 × 51 (at	4½ botto	Cinders, ⅜ to 1½-inch m)
			9 S ...	...	60 × 50, 51 × 41 (at	4½ botto	Cinders, ⅜ to 1-inch m)
36	Oldbury ...	...	4 P ...	50,535	(total)	3·25	1¾ to ⅜-inch
			18 S ...	29,943	(total)	3·25	1½ to ⅜-inch
37	Reigate ...	T.	Primary coarse	450	21·25 square	3·5	Broken bricks, coke and cinder, 3 to 1½-inch 1½ to ¾-inch ... ¼ to 1/12-inch ...
			Secondary fine	450	24 diameter (circular)	3·5	Broken bricks and coke, ½ to 1/12-inch ½ to 3/16-inch ... Polarited clinkers ½ to 3/16-inch
38	Rochdale ..	T.	2	1,800 (each)	48 diameter	9	Gas coke, above 1½-inch

continued.

Thickness of each layer of material, arranged in their order in the beds, from the top downwards. 9	Method of under-draining the beds. 10	Actual or estimated cost of making the beds. 11	Actual or estimated cost per acre of making the beds. 12	Cost of treating sewage per million gallons. 13
		£	£	£ s. d.
2 feet 6 inches 6 inches	9-inch central drain and 4-inch unsocketed perforated drain pipes arranged herring bone fashion	1,145	2,290	2 10 2¼
One grade only	Earthenware pipes	...	3,000	
Material is not graded in the beds, but larger pieces have been arranged round under-drains	Two rows of unsocketed earthenware pipes	...	...	1 16 11
...	Mains E.S.P.... ... ... Wing drains 4-inch land tiles	60	1,089	
Not graded ...	3-inch agricultural drain pipes which lead into brick channels	2,100 Cost of permanent works,	1,615	1 12 6 (including sludge disposal)
1 foot 6 inches 1 foot 6 inches 6 inches	Agricultural tiles			
9 inches 9 inches 1 foot 6 inches	Bricks laid as stretchers with headers above ½-inch open joints			
Uniform throughout	Perforated semi-circular 18-inch pipes laid on bricks on a concrete floor	...	(about) 5,000 for construction of beds and coke only	4 0 0 (estimated)

TABLE I.—

No	Name of town or district.	Nature of Installation. P.—Permanent. T.—Temporary.	Number or names of the beds. P.—Primary. S.—Secondary T.—Tertiary.	Average or working area of the beds. Square feet.	Measurement of the surface of the beds. Feet.	Depth of the beds. Feet.	Material and size of the material of which the beds are composed.
1	2	3	4	5	6	7	8
39	Salford ...	P.	Roughing beds	...	...	3	Gravel, fine ...
		T.	1 to 14 ...	126	...	5 & 8	Cinder 6 to 2-inch
40	Sheffield ...	T.	3 P ...	45,000	(total of 3)	5	Coke
			3 S ...	40,500	(total of 3)	3½	Coke
41	Southport ...	T.	2 coarse ...	900 (each)	30 × 30, 24 × 24 at bottom	3	Coke, ½-inch ..
			1 fine ...	900		3	Coke, ⅜-inch
42	Swinton and Pentlebury	P.	10 P. ...	...	75 × 75	3·25	Rough clinkers ... Cinders above ½-in.
			10 S. ...	...	75 × 75	...	Cinders above ¾-in. Cinders, ⅛ to ⅜-inch
43	Wolverhampton	T.P.	1	810	...	4·25	Slack ... ...
			2	4,500	...	4·25	Furnace ashes, 3/16 to 1¼-inch
44	Wednesbury ...	T.	P. ...	...	...	3	Furnace clinkers, 2 to 1-inch ¾ to ½-inch ½ to ¼-inch
			S.	...	...	5	Coal, ¾-inch ... Coal, ½-inch ... Coal, ⅜ to ¼-inch ... Coal, 3/16 to 1/16-inch Fine dust ...
			S.	...	...	5	Granite, same size as coal bed
45	West Bromwich	P.	Single contact	2,520	60 × 42	3	Engine ashes, ½ to 2-inch
			P. ...	7,200	120 × 60	3·5	„ ¼ to 2-inch
			S.	7,200	120 × 60	3	„ ⅛ to ¼-inch
46	Worcester ...	...	3	...	80 × 3	2	Furnace ashes, 1 to 1/20-inch
47	York	T	1	800	40 × 20	3	Clinker, cinder and coke, ¾ to 1¼-inch
			2	800	40 × 20	3	
			3	800	40 × 20	3	
			4	800	40 × 20	3	
		T	1A... ...	...	90 × 30	2·75	Clinker, cinder and coke, 1¼ to 3-inch
			2A... ...	...	90 × 30	2·75	„ ⅜ to ¾-inch
		T	Ladder filter composed of 10 chambers		4 × 3 5/12	2	Clinker
		T	York filter (circular)		67·5 dia.	6·5	„ ½ to 2½-inch
		T	Gravel ...	...	19½ × 11¼	3	Clean gravel, coarse „ ⅜-inch „ ½-inch „ ¾-inch „ 1¼-inch

continued.

Thickness of each layer of material, arranged in their order in the beds, from the top downwards. 9	Method of under-draining the beds. 10	Actual or estimated cost of making the beds. 11	Actual or estimated cost per acre of making the beds. 12	Cost of treating sewage per million gallons. 13
...	... ...	£ ... of chemical	£ 7,000 precipitation &	£ s. d. 0 16 0 (exclusive pumping)
Uniform ...	By 6-inch open-jointed earthenware pipes	250 (approximately)		
12 inches 9 inches 6 inches 12 inches				
Uniform ... "	6 inch channels covered with perforated inverts	...	7,000 3,000	
24 inches 6 inches 6 inches 3 inches 3 inches 24 inches 24 inches 6 inches				
Not graded ...	No under drains in any of the beds. Valves fixed at the side for emptying	400 600 600		
...	No under drains			
3 layers, the largest material at the bottom. Layers of coarser material at the top				
4½ inches 4½ inches 9 inches 9 inches 9 inches				

TABLE II.—Particulars as to the

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
1	Accrington ...	Aug., '99, to date	...	Screened sewage which has passed through a detritus chamber and which has afterwards passed through septic tanks	...	...
2	Aldershot ...	...	...	Crude sewage after having passed through a small detritus chamber. No screening. Storm water is separate from sewage	...	...
3	Acton... ...	...	...	...	...	...
4	Aylesbury ...	...	...	Sewage which has previously passed through a settling tank	...	...
5	Barnsley ...	During the last 12 months	1, 2 and 3	Only night water which has previously passed through a septic tank is treated, not sewage. Road detritus and sand are separated from the liquid	Lime and alumino-ferric	...
6	Birmingham...	Less than six months (April, '02)	1 to 8	Storm water and excess sewage from Rea main sewer	None ...	...
		Over six months (March, '03)	1 and 2 Percolating	Septic water from septic tanks	...	...
7	Blackburn ...	Two years	...	Screened sewage which has been from 12 to 16 hours in the septic tank	...	...
8	Bloxwich district of Walsall	...	...	Sewage which has passed through a septic tank	...	...
9	Bristol—					
	At Knowle...	Three years	...	Sewage which has passed through a septic tank	...	...
	At St. John's-lane	Three years	...	Sewage which has passed through a septic tank	...	...

Working of the Bacteria-beds.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds.	during which the beds remained full (contact period).	occupied in emptying the beds.	during which the beds remained empty (aëration period).			Gallons.	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated.	of albuminoid ammonia.
21	22	23	24	25	26	27	28	29
Continuously worked Spinklers are used				...	1	215,111	90·0 (at70°F)	91·3
...	...	...	...	2½	2	Primary beds deal with about 500,000 gallons per day	75·3	71·0
Secondary beds worked on continuous flow principle				...	...	Secondary beds deal with about 130,000 gallons per day	91·1	89·3
Continuous method Whittaker and Bryants sprinklers are used			...	...	...	About 372,300	69·1	77·3
Varies according to flow from the town	2	½ and 1	2	...	...	A minimum quantity of 250,000 gallons to the six coke-breeze beds (about ½ acre) per day	(60 to 80 per cent. purification is effected)	
Depends upon the night flow and weather	...	...	...	1	1			
2	7	3	12	1	1	Varies	53·5	
...	...	...	...	...	...	...	86·9 74·2	88·9 76.9
Varied during the experiments				2 & 3	2	...	75 to 80	97·1
1	2	1	3	2½	2	...	96·3	97·7
Continuous process			...	...	1	1,048,666 Stoddart distributor used		
Continuous process			...	...	1	204,893 Candy Caink distributor used		

TABLE II.—

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
10	Burnley— Duck pits (septictanks) and Woodend works (beds)	months. 40	1 P	Septic tank effluent	Lime	0·21
		42	2 P			
		21	3 P			
		26	4 P			
		33	5 P			
		13	6 P			
		6	12 P			
		62	18 P			
		32	14 S	First contact bed effluent		
		12	15 S			
		26	16 S			
		20	17 S			
		38	19 S			
		47	22 S			
		46	23 S			
		3	26 S			
11	Burslem ...	...	...	Sewage which has been screened and passed through a septic tank	...	...
12	Bury	Since Mar., 1900	...	Sewage which has passed through a screening tank and been chemically treated and sedimented	Ferrozone or aluminoferric	6 to 7
13	Cambridge ...	...	...	Storm flow more especially	...	...
14	Carlisle ...	2 years ...	...	Sewage which has been screened	...	...
15	Croydon ...	2 years ...	...	Sewage which has been screened and settled	...	...
16	Darwen ...	About 3 years	1 to 5	Sewage which has passed through a precipitation tank to remove as much solid matter as possible	Aluminoferric	7
17	Epsom ...	...	...	In one case sewage from a septic tank, and in the other case sewage from land	...	...

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds.	during which the beds remained full (contact period).	occupied in emptying the beds.	during which the beds remained empty (aëration period).			Gallons.	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated.	of albuminoid ammonia.
21	22	23	24	25	26	27	28	29
3 (per acre)	2	2¼ (½ acre beds) 3½ (1 acre beds)	3 (minimum)	2	1	96,800	63·7	67·9
							63·1	63·7
							59·1	55·9
							64·3	65·5
							57·7	58·9
							57·1	61·9
							58·5	61·5
							63·7	54·0
					2	...	83·4	84·0
							83·8	83·9
							83·8	86·8
							90·0	83·3
							85·9	87·4
							86·6	88·5
							83·8	88·6
							87·2	73·3
1	2	1	4	3	3	242,000		
1½	1½	1½	1½	4	...	333,333		
Streaming method of supply to beds								
1½	2	1½	2	3	2	223,926	39·8 (by coarse bed)	42
Night sewage is treated continuously in these beds						(by coarse bed and land)	47·5	49
						(by experimental bed, ⅛-in. mesh)	58	55
						(by experimental bed, $\frac{1}{32}$-in mesh)	79	76·5
1½	2	1½	2½	2	1	169,500	54·5	53·3
8 hours			4	2	1	333,333		
...	2	...	...	3				

TABLE II.—

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
18	Evesham ...	6 months (Feb., '03)	...	...	None	used
19	Glasgow ...	...	...	Open septic tank effluent derived from crude sewage containing a large quantity of trades effluent of a variable nature	None ...	...
20	Haslingden, Rawtenstall and Bacup	...	...	Sewage which had been screened and which had passed through a septic tank	...	...
21	Heywood ...	...	...	Sewage from septic tank ... Sewage which had been chemically precipitated ...	...	...
22	Huddersfield...	10 Aug.,'98, to 23 Jan., '00	Coarse ...	Sewage which had passed through a zinc plate with $\frac{1}{16}$-inch perforations	...	...
			Fine ...	Effluent from coarse bed ...	...	...
		14 months (1903) (Some of the beds 4½ years)	7	Sewage which had been chemically treated and sedimented	Lime ... Sulphate of iron	3·5 2·9
		2½ years ...	Coarse ...	Sewage which had passed successively through a screen of 1-inch mesh, a small detritus tank, and a septic tank	...	...
			Fine ...	Effluent from coarse bed ...	...	...
		9 months...	Trickling	Sewage which had passed successively through a 1-inch screen, a small detritus tank and a septic tank	...	...
23	Hyde	3 years ...	...	Crude sewage which had passed through the septic tank	None ...	...
24	Keighley ...	18 months.	...	Sewage which had passed through detritus and sedimentation tanks	None ...	...

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds.	during which the beds remained full (contact period).	occupied in emptying the beds.	during which the beds remained empty (aëration period).			Gallons.	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated.	of albuminoid ammonia.
21	22	23	24	25	26	27	28	29
4	3	3	3	1	1	86,000		
½	2	1	2 to 3	1 to 3	2	36,814 One filling daily	95	90·6
3	1	1	14	2	...	...	86	90
Partly on the continuous method				...	...	...	79·6	87·1
							(Purification is calculated on the septic tank effluent)	
...	...	...	...	...	1	...	60	
1	2	1	...	2	2	83,733 (1st contact)		
1	2	1	...	2	2	...	79	80
							(2nd contact)	
1	1 or 2	1	...	3	2	268,000 (1st contact)	88	88
1	1 or 2	1	...	3	2	230,000 (1st contact)		
1	1 or 2	1	...	3	2	351,000 (2nd contact)	85	84
The septic sewage is sprinkled on to the bed 16 hours out of the 24						200,000	84	85
							(estimated on dissolved matter only)	
Continuous		...	...	...	...	2,178,000	85·7	90
Varied		...	...	...	2	126,000		

TABLE II.—

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
25	Kettering ...	About 4 years	...	Sewage which has passed through precipitation tanks	None ...	...
26	Leeds... ...	2 Oct., '97 to 2 Feb., '98	No. 1 coarse	Sewage screened by vertical bars 1 inch apart	None ...	...
			No. 2 fine	...	...	...
		18 Feb., '98 to 3 Mar., '98	"	Sewage which had been chemically treated and sedimented	Lime ...	
		4 Mar., '98 to 8 Sept., '98	"	Sewage which had passed through a fine screen with holes ½ inch diameter	None ...	... *Incre †Redu
		9 Sept., '98 to 18 Nov., '98	"	Sewage which had been settled	None ...	...
		2 Dec., '98 to 6 Jan., '99	1, 2, 3, 4	Sewage which had been settled	Lime ...	2·8
		7 Jan., '99 to 1 June, '00	1, 2. 3, 4, 5, 6	Sewage from which the grit had been settled	None ...	...
		8 Mar., '99	7	Sewage which had been chemically treated and sedimented	Lime ...	...
		20 Mar., '99	8	Sewage which had passed through a septic tank	...	...
		22 Sept., '99 to 16 June, '00	1, 2, 3, 4, 5, 6	Sewage which had passed through the closed septic tanks	None ...	...
		9 Mar., '99 to 12 May, '00	Whittaker No. 1	Sewage which had passed through No. 1 open septic tank	...	...
		2 Sept., '99 to 30 June, '00	Whittaker No. 2	Sewage which had passed through No. 1 open septic tank	...	...
			1, 2 & 3 continuous	Sewage which had been screened (mesh, 37 per inch)	...	...
		29 Mar., '00 to 7 July, '00	Ducat	Sewage which had been screened ($\frac{3}{16}$ inch screen) and which had passed through a small grit chamber	...	...

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison. Gallons.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds. 21	during which the beds remained full (contact period). 22	occupied in emptying the beds. 23	during which the beds remained empty (aëration period). 24	25	26	27	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated. 28	of albuminoid ammonia. 29
3 (varies)	1	2 to 3	1 (varies)	2 or 3	1	31,250	50 (Purification of tank effluent)	35
1	2	1	4	3	2	(No. 12 precipitation tank used)		
1	2	1	4	3	2	(No. 11 precipitation tank used)	82·3	73·6
1	2	1	4*	3†	2			
ased to average of 8 hours during the experimental period								
1	2	1	4*	3†	2		84	86
ced to 2 fillings per day during the experimental period								
1	2	1	8 average	2	2	...	86·6	86·6
...	...	...	...	3	2			
...	...	...	...	...	...	...	92	87
...	2	...	...	3	...	...	77	62
...	2	...	...	3	1	...	74	63
...	...	...	...	1½	...	...	90	86
Continuous method				...	...	...	83 (Purification of septic effluent)	73
Continuous method				...	...	...	85 (Purification of septic effluent)	82
Continuous method				...	...	...	78	71
Working alternate hours for 10 hours, rest 14 hours				...	...	...	91 to 97	88 to 96

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
27	Leicester ...	24 Oct. to 10 Nov., '98	1 P	Sewage which had passed through an open detritus tank	...	...
		11 Nov. to 26 Nov., '98	1 P	Sewage which had passed through a closed detritus tank	...	...
		1 Sept. to 10 Nov., '98	...	Sewage which had passed through an open detritus tank and an open settling tank	...	...
		11 Nov. to 6 Dec., '98	...	Sewage which had passed through a closed detritus tank and an open settling tank	...	...
		7 Dec., '98 to 22 July, '99	...	Sewage which had passed through a closed detritus tank	...	...
		24 July to 15 Sept., '99	...	Sewage which had passed through a closed detritus tank and a closed septic tank	...	...
		19 Sept. to 13 Oct., '99	...	Sewage which had passed through a closed detritus tank	...	...
		28 Nov., '98 to 19 July '99	1 P	Sewage which had passed through a closed detritus tank	...	...
		20 July to 2 Sept., '99	...	Sewage which had passed through a closed detritus tank and closed septic tank	...	...
		4 Sept. to 15 Sept., '99	1 P, 1 and 2 S	Sewage which had passed through a closed detritus tank and closed septic tank	...	...
		19 Sept. to 13 Oct., '99	...	Sewage which had passed through a closed detritus tank	...	...
28	Lincoln ...	...	...	Sewage which had been chemically treated and sedimented (12 hours' settlement)	Alumino-ferric	3·5
29	Liverpool ... (West Derby Sewage Farm)	June, 1899 to date	All ...	Crude sewage	None	

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds.	during which the beds remained full (contact period).	occupied in emptying the beds.	during which the beds remained empty (aëration period).			Gallons.	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated.	of albuminoid ammonia.
21	22	23	24	25	26	27	28	29
1	2	2	3	3	1	...		
1	2	2	3	3	1	...		
1	2	2	3	1 & 3	1	...		
		(1 filling daily for first 12 days only)						
1	2	2	3	3	1	...		
1	2	2	3	3	1	...		
1	2	2	3	3	1	...		
1	2	1	2	4	1	...		
1	2	2	3	3	2	...	90·2	83·1
1	2	2	3	3	2	...	89·7	79·9
1	2	2	3	3	3	...	89·6	83·7
1	2	1	2	4	3	...	91·3	86·7
2	2	2	2	3	2	209,234		
½	2	1	Varies from 2 to 8	1 to 3	2	66,000 (average)		

TABLE II.—

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
30	Manchester ...	Dec., 1895 to Dec., 1900	Roscoe	"Chemical" effluent ...		...
		Dec., 1900 to Dec., 1902	"	" " ...		...
		11 Jan., '00 to 11 July '01	Iron sand bed	" " ...		...
		22 Mar.'00 to 27 Mar. '01	Fine Cinder	" " ...		...
		27 Mar.'01 to 24 Dec., '02	"	" " ...	Lime Sulphate of iron	2·17 1·17
		29 June, '99	Rough Cinder	" " ...		
		29 Mar. to 30 May, '00	"	" " and storm water		...
		13 June, '00 to 27 Mar '01	"	"Chemical" effluent and storm water		...
		27 Mar.'01 to 24 Dec., '02	"	" " ...		...
		25 Aug., '00 to 17 Jan.'01	Burnt pyrites	"Chemical" effluent ...		...
		27 Mar.'01 to 24 Dec., '02	"	" " ...		...
		20 Nov., '98 to 29 Apr '99	6 septic beds	Septic sewage	...	...
		17 to 21 Sep. '98	A and B	Settled sewage	...	...
		30 Sep., to 26 Oct., '98	"	" "	...	...
		28 Oct. to 16 Nov., '98	"	" "	...	...
		17 Nov. to 3 Dec., '98	"	" " (two fillings) and raw sewage (one filling)	...	...
		3 Dec. to 14 Dec., '98	A, B and E	Settled sewage (two fillings) and raw sewage (one filling)	...	...
		16 Dec., '98 to 7 Feb., '99	"	Raw sewage	...	...
		9 Feb. to 1 May, '99	"	" "	...	...
		13 April to 31 May, '99	C and D	Settled sewage and occasional fillings of storm water	...	...
		1 June to 7 June, '99	"	Open septic tank sewage ...	...	...
		8 June to 5 July, '99	"	" " ...	...	...
		6 July to 17 Aug., '99	"	" " ...	...	...

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds.	during which the beds remained full (contact period).	occupied in emptying the beds.	during which the beds remained empty (aëration period).			Gallons.	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated.	of albuminoid ammonia.
21	22	23	24	25	26	27	28	29
½	2	½	...	3 or 4	1	205,840 (coke	bed) 80	76
				2 or 3	1	208,120 (cinde	r bed) 84	80
...	...	...	...	...	...	142,683		
						152,879		
...	...	...	...	3	1	154,900	90·1*	84·5*
...	...	...	...	3	1	166,496	85·3*	82·6*
...	...	...	...	...	...	89,443		
...	...	...	...	3	1	...		
...	...	...	...	4	1	...	59·1*	53·5*
...	...	...	...	2	1	121,302		
...	...	...	...	...	...	...		
...	...	...	...	2	1	112,933		
...	...	...	...	...	...	185,393		
...	...	...	...	1 & 2	1			
...	...	...	...	1	2			
...	...	...	...	2	2			
...	...	...	...	3	2			
...	...	...	...	3	2			
...	...	...	...	3	3			
...	...	...	...	3	3			
...	...	...	...	4	3			
...	...	...	...	2	2			
...	...	...	...	2	2	(* Percentages calculated on the tank effluent. Oxygen absorption took place at room temperature.)		
...	...	...	...	3	2			
...	...	...	...	4	2			

TABLE II.—

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
30	Manchester ... (*continued*)	18 Aug. to	C	Open septic tank sewage ..	...	...
		14 Sep., '99	B and D	Effluent from primary bed C divided between these beds	...	...
		4 Oct. to	A and C	Open septic tank sewage ...	...	...
		7 Dec., '99	D	Effluent from primary beds A and C run on to bed D	...	...
		22 Aug. to 31 Aug., '99	A	Open septic tank sewage ...	...	...
		1 Sep. to 15 Sep., '99	"	" " ...	...	...
		16 Sep., '99	"	" " ..	...	...
		7 Dec., '99 to	A and C	" " ...	...	...
		11 Apr., '00	D	Effluent from primary beds A and C	...	...
		3-30 May '00	A and C	Settled sewage	...	...
			D	Effluent from primary beds A and C	...	...
		31 May'00 to	A and C	Open septic tank sewage ...	...	...
		27 Mar., '01	D	Effluent from primary beds A and C	...	...
		27 Mar.'01 to 24 Dec.,'02	"	" "	...	...
		7 Dec., '99 to 22 Feb. '00	B	Open septic tank sewage ...	...	...
		2 Mar. to 25 April, '00	"	" " ...	...	...
		8 May to 7 June, '00	"	" " ...	...	...
		15 June, '00 to 26 Mar '01	"	" " ...	...	...
		27 Mar.'01 to 24 Dec. '02	"	" " ...	...	...
		8 Aug., '00	Stoddart's	Open septic tank effluent ...	...	...
		28 Jan. to 17 April, '01	1A, 2A	" " ...	...	...
		Jan. to Dec., '02	1A	" " ..	...	...
31	Middleton ...	Commenced 29 Nov., '99	1	Tank effluent from sewage which has passed through a grit chamber, and then been treated with chemicals and sedimented	Ferozone	6
		26 Jan., '00	2			
32	Nelson ...	11 months	1	Tank effluent	Alumino-ferric	9
		3 years ...	2			
		2½ years ...	3			
		10 months	4			
		16 months	5			
		2½ weeks	6			

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds.	during which the beds remained full (contact period).	occupied in emptying the beds.	during which the beds remained empty (aëration period).			Gallons.	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated.	of albuminoid ammonia.
21	22	23	24	25	26	27	28	29
...	...	...	...	8	2			
...	...	...	...	4	2			
...	...	...	...	8	2	(* Percentages calculated on the tank effluent. Oxygen absorption took place at room temperature.)		
...	...	...	...	4	2			
...	...	...	...	2	1			
...	...	...	...	3	1			
...	...	...	...	4	1			
...	continuous on bed D			...	1			
...	continuous on bed D			...	2			
...	...	...	...	2	2			
...	...	...	...	4	2			
...	...	...	...	3	2			
...	...	...	...	6	2			
...	...	...	...	3	2	105,800	Beds A, 74·0*	B, & C. 61*
...	...	...	...	4	1		Bed 90·0*	D. 84*
continuous equal to				6	1			
...	...	...	...	2	1			
...	...	...	...	3	1			
...	...	...	...	3	1	125,132		
...	continuous		...	...	..	...		
...	...	...	...	1	1	...		
...	...	...	...	1 to 2	1	130,671	Bed 69·5*	1a. 68·7*
...	3	...	3	...	...	...	90·0	
½ (about)	...	...	...	6	...	...	...	71·4

TABLE II.--

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
33	Oldham ...	1897 to end of 1898	...	Effluent from chemically treated and sedimented sewage	Sulphate of iron Lime	1 4
		1899 to date	...	Effluent from sewage after subsidence	...	...
			12 and 13	Settling tank liquid drawn off by floating arms previous to cleaning tank	...	...
34	Ormskirk ...	...	...	Sewage after having gone through process of land filtration		
35	Oswestry ...	...	Primary Secondary	Settling tank liquid ... Effluent from primary bed	...	...
36	Oldbury ...	...	Primary Secondary	"Chemical" effluent ... Effluent from primary bed...	... ...	... ...
37	Reigate ...	3 years ...	1 and 2	Sewage containing large quantities of brewery and tannery refuse	None used	...
38	Rochdale ...	2½ years ...	1 and 2	Sewage after passing through open septic tank	None	...
39	Salford ...	...	...	Sewage from which road detritus, etc., has been removed in "silt pits," and which has passed through precipitation tanks	Lime	13
40	Sheffield ...	3 years ...	...	Sewage which has rapidly passed over two catch pits (the heavier detritus separates fairly readily, but finely divided mineral matter remains mixed with putrescible solids)	...	...
41	Southport ...	...	...	Screened sewage	...	...
42	Swinton and Pentlebury	...	...	Screened and chemically treated and precipitated sewage	Lime Sulphate of iron	...

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds. 21	during which the beds remained full (contact period). 22	occupied in emptying the beds. 23	during which the beds remained empty (aëration period). 24	25	26	Gallons. 27	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated. 28	of albuminoid ammonia. 29
½ to ⅔	2 to 3	2	2 (at least)	2 (Sundays included)	...	161,000 (about)	79·1	82·1
...	...	...	...	...	...	...	84·1	84·3
...	4 to 24							
...	...	...	...	...	...	110.083 110,195	88·2	89·7
½ to 1¼ 1 to 1½	1 to 2¼ 3 to 4	¾ 1	2 to 5 3 to 4½	2 to 5 2	... 2	100,000 ...	88·2 (20 mins. at 140° F)	89·7
... ...	2 2	... ...	... ...	... ...	1 2	...	94·6	91·2
...	...	...	...	...	2	...	81 at 55° F.	87
continuous process			...	...	...	215,111	84·0 at 57 to 63 F°.	84·2
continuous method by spray jets					2	2,500,000 to 7,000,000 5 to 8 feet deep		
1	1	2	4	3	2	200,000 (in first contact beds) 195,000 (in second contact beds)	87 to 90 at laboratory temperature	92·0 (about)
1	2	1	2	4	2	295,000	79·8 Average of 3 samples June & July, 1900	
...	1½	...	...	3	2	...		

TABLE II.—

No.	Name of town or district.	Time during which the beds were in use.	Name or number of the bed used.	Character of the liquid supplied by the beds.	Chemicals used for treating the sewage previous to bacterial treatment.	
					Name of chemical.	Grains per gallon of sewage.
14	15	16	17	18	19	20
43	Wolverhampton	...	1 2	Tank effluent after lime treatment. It was possible to only partially separate out road detritus	Lime	...
44	Wednesbury...	...	Primary	Septic tank effluent ..	...	...
			Secondary	... ...	...	...
			Secondary	... ...	...	...
45	West Bromwich	12 Sept., '99 to 1 Nov., '00	Single contract	Effluent from septic tank...	...	...
		3 Oct., '99 to 1 Nov., '00	Primary Secondary	Crude sewage	None	...
46	Worcester ...	...	...	Domestic sewage from isolation hospital	None	...
47	York	21 Apr., '99 to 31 Aug., '01	1, 2, 3, 4	Closed septic tank effluent	...	...
		13 June, '99 to 13 Oct., '00	1A, 2A	Crude sewage which had screened	...	...
		8 June, '99 to 15 Sept., '00	Ladder filter (10 chambers in series, later 2 sets of 5 chambers in series)	Raw sewage...	...	...
		5 July, '00 to 31 Aug., '01	York filter	Open septic tank effluent...	...	...
		23 Nov., '00 to 1 July, '01	1A, 2A	Open septic tank effluent...	...	...
		14 June, '99	1, 2, 3, 4	Closed septic tank effluent (finally treated on land filters)		
			Gravel	Open septic tank effluent (not satisfactory)	...	...

continued.

Number of hours				Number of fillings per 24 hours.	Number of contacts in successive beds.	Quantity of sewage treated in 24 hours, per acre of bed, one foot deep. Calculated for the purpose of comparison.	Average percentage purification effected on the crude sewage, as measured by the relative results of the estimations in raw sewage and in the final effluent	
occupied in filling the beds.	during which the beds remained full (contact period).	occupied in emptying the beds.	during which the beds remained empty (aëration period).			Gallons.	of oxygen absorbed in 4 hours at 80° F., unless otherwise stated.	of albuminoid ammonia.
21	22	23	24	25	26	27	28	29
1½	2	1½	7	1 & 2	...	650,000 (Two fillings) 400,000 (Two fillings) (Both on tank effluent)	83·5 80·5	
...	2	...	...	3	2			
continuous process			...	...	...		86·0	
...	...	...	...	...	...		87·7	
1½	2	1½	3	3	1	...	57	54·7
1½	2	1½	3	3	2	...	85·9	78·6
...	...	...	...	...	...	...	97·7	95·2
1½ to 2 variable	2	4 to 4½		2 & 3	1	69,193 and 196,085	65·47	61·97
varied		...	...	3	2	55,569	80·0	72·0
...	...	...	...	...	...	175,368	44·3	36·6
continuous process				...	...	327,631	84·5	90·0
1½	1½	2	3	3	1	65,200	78·6	87·6

TABLE III.—*Particulars as to the Capacity of the Bacteria*

No.	Name of town or district.	Name or number of bed.	Original water capacity of the bed in the tank.			Water capacity
			Date.	Gallons.	Percentage of the empty tank.	Date.
30	31	32	33	34	35	36
10	Burnley ... Duckpits septic tanks and Woodend works (beds)	1	8 Nov., '99	...	...	5 Oct., '00 5 Mar., '03
		2	28 Sept., '99	...	...	3 Oct., '00 5 Mar., '03
		3	3 June, '01	...	...	8 Oct., '02 4 Mar., '03
		4	8 Jan., '01	...	...	7 Feb., '01 4 Mar., '03
		5	5 June, '00	...	...	6 Oct., '00 4 Mar., '03
		6	10 Feb., '02	...	...	8 Oct., '02 5 Mar., '03
		12	15 Sept., '02	...	...	9 Oct., '02
		18	25 Jan., '98	...	...	5 June, '99 5 Mar., '03
12	Bury	...	A slight decrease in capacity has been noticed;			
14	Carlisle ...	4	Sept. 1900...	54,319	40	Sept. 1901...
16	Darwen ...	...	The capacity of the bacteria-beds was reduced by			
18	Evesham ...	1	30 June, 02	48,000	43	2 Jan., '03
19	Glasgow ...	4, 1st contact beds	17 Sept., '00	36,498 32,617	50 (estimated) 44·6 (actual)	Dec., '00 ... Mar., '01 ... May, '01 ... Aug., '01 ... Nov., '01 ... Dec., '01 ... Jan., '02 ... Mar., '02 ...
22	Huddersfield ...	Coarse bed	9 Aug., '98	19,000	54·4	3 Mar., '99 31 May, '99 11 July, '99 17 Oct., '99 24 Jan., '00
		No. 7	23 Jan., '02	16,200	44·5	12 Jan., '03
		Coarse bed (septic series)	22 Aug., '00	3,990	59·2	4 Mar., '03
		Fine bed (septic series)	22 Aug., '00	3,900	57·9	4 Mar., '03
		Trickling. Capacity cannot be determined. It is dealing with				
23	Hyde	No loss of capacity so far as determined Now working at				
24	Keighley ...	...	...	...	...	8 Mar., '02
25	Kettering ...	Fine sludge from the precipitation tanks clogs the surface of the beds, but in favourable weather the surface of the beds is loosened with a fork. This greatly improves the working of the beds. Road detritus appears to be retained in the Dortmund tanks, through which the sewage first flows				... Each bed Figures
		3 beds	1898 June to Aug.	170,000	41·8	

beds and as to the Loss of Capacity during working.

of the bed after use.		Number of hours occupied in draining the bed.	Number of days during which the bed had been resting previous to the measurement being made.	Loss of capacity. (+ indicates an increase in capacity.)		Length of time during which the bed was in use since last recorded measurement.	Number of fillings during the time.
Gallons.	Percentage of the empty tank.			Gallons.	Percentage of original water capacity of the bed.		
37	38	39	40	41	42	43	44
102,900	17·7	3	0	...	...	...	Beds filled twice daily with average rest amounting to 14 days per year
75,233	12·9						
111,300	20·5						
94,774	17·4						
70,449	13·5						
72,713	13·9						
166,949	32·8						
59,382	11·7						
157,800	29·1						
69,253	12·8						
200,600	19·5						
201,627	19·6						
286,800	30·5						
108,255	25·7						
61,564	14·6						
probably due to overwork							
44,642	33	...	7	9,677	17	...	...
one-third	...	...	...	...	...	...	...
33 000	30	3	...	15,000	31	6 months	...
19,700	26·9	...	...	12,917	39·6	101 days	167
17,492	23·9	...	...	2,208	6·8	83 "	213
21,412	29·3	...	19	3,920 +	12·0	44 "	88
20,321	27·8	...	...	1,091	3·3	87 "	174
21,839	29·9	...	25	1,518 +	4·7	76 "	152
18,981	26·0	...	...	2,858	8·8	22 "	22
19,046	26·0	...	...	65 +	0·2	42 "	42
17,997	24·6	...	...	1,049	3·2	58 "	88
9,000	25·8	...	...	10,000	52·6	29 weeks	317
7,300	20·9	...	...	1,700	8·9	13 "	148
6,100	17·5	...	...	1,200	6·3	6 "	70
5,600	16·0	...	...	500	2·6	14 "	156
4,800	13·7	...	...	800	4·2	14 "	164
12,150	33·4	3	...	4,050	25·0	51 "	672
1,680	24·9	3	...	2,310	58·0	132 "	
2,200	32·7	3	...	1,700	44·0	"	
more than twice the quantity it dealt with at first and shows no signs of clogging							
higher speed than before							
660	33	...	None				
rests one week and works three weeks when practicable							
relating to capacity are working averages							
130,000 (average)	32·0	2 to 3	...	40,000	23·4	Since 1898	

TABLE III.—

No.	Name of town or district.	Name or number of bed.	Original water capacity of the bed in the tank.			Water capacity
			Date.	Gallons.	Percentage of the empty tank.	Date.
30	31	32	33	34	35	36
26	Leeds	No. 1 Coarse bed	...	83,300	47·7	2 Dec., '97
						16 „ '97
						30 „ '97
						13 Jan., '98
						27 „ '98
						2 Mar., '98
						14 „ '98
						26 „ '98
						9 Apr., '98
						23 „ '98
						5 May, '98
						20 „ '98
						2 June. '98
						16 „ '98
						28 July, '98
						11 Aug., '98
						25 „ '98
						8 Sept., '98
						18 Nov., '98
						7 Oct., '99
		No. 3	...	51,800	50·7	1 July, '00
		„ 5	...	53,100	52·0	20 „ '00
		„ 7	...	55,700	31·4	5 „ '00
		„ 8	...	29,500	31·2	1 „ '00
27	Leicester ...	1, 2, 3, 4 P	24 Sept., '98	61,865	49·5	15 Oct., '98
						21 Dec., '98
						16 Feb., '99
						3 Mar., '99
						29 Mar., '99
						10 April, '99
						17 May, '99
						30 May, '99
						4 Oct., '99
						6 Nov., '99
						6 Nov., '99
28	Lincoln... ...	13	14 Feb., '01	...	...	12 May, '01
		...	...	...	...	5 Oct., '01
		...	...	...	...	12 Oct., '01
		...	...	...	...	24 Feb., '03
		1, 3, 5, 7	...	...	...	12 May, '01
		...	...	...	...	16 Sept., '01
		...	...	...	...	1 Oct., '01
		...	...	...	...	5 Oct., '01
		...	...	...	...	24 Feb., '03
		15	27 Nov., '01	193,750	41	3 Mar., '02
		...				5 May, '02
		...				17 Jan., '03
		9 and 11				19 Aug., '01
						21 Nov., '01
						7 Feb., '02
						12 April, '02
						5 May, '02
						22 Dec., '02

continued.

of the bed after use.		Number of hours occupied in draining the bed.	Number of days during which the bed had been resting previous to the measurement being made.	Loss of capacity. (+ indicates an increase in capacity.)		Length of time during which the bed was in use since last recorded measurement.	Number of fillings during the time.
Gallons.	Percentage of the empty tank.			Gallons.	Percentage of original water capacity of the bed.		
37	38	39	40	41	42	43	44
63,400	36·3	...	...	19,900	23·9	9 weeks	
58,800	33·6	...	...	4,600	5·5	2 ,,	
57,100	32·7	...	...	1,700	2·0	2 ,,	284
51,100	29·2	...	...	6,000	7·2	2 ,,	
45,400	26·0	...	...	5,700	6·8	2 ,,	
52,100	29·8	...	...	6,700+	8·0	...	
52,300	29·9	...	...	200+	0·2	...	
46,100	26·4	...	...	6,200	7·4	...	
42,900	24·5	...	...	3,200	3·8	...	
40,100	22·9	...	...	2,800	3·4	...	
45,800	26·2	...	7	5,700+	6·8	...	
44,300	25·3	...	...	1,500	1·8	...	315
44,600	25·5	...	...	300+	0·4	...	
43,200	24·7	...	...	1,400	1·7	...	
56,500	32·3	...	38	13,300+	16·0	...	
45,800	26·2	...	...	10,700	12·8	...	
42,400	24·3	...	...	3,400	4·1	...	
41,000	23·5	...	...	1,400	1·7	...	
42,200	24·1	...	...	1,200+	1·4	...	135
26,900	15·4	...	...	15,300	18·4		
18,200	17·8	...	...	33,600	64·9		
16,600	16·3	...	...	37,500	70·6		
25,600	14·5	...	...	30,100	54·0		
11,000	11·6	...	...	18,500	62·7		
59,066	47·3	...	...	2,799	4·5	21 days	
49,795	39·9	...	...	9,271	15·0	67 ,,	
43,211	34·6	...	...	6.584	10·6	57 ,,	7th filling after rest
45,432	36·4	...	3½	2,221+	3·6	15 ,,	
43,051	34·5	...	...	2,381	3·8	26 ,,	
48,238	38·6	...	10	5,187+	8·4	12 ,,	
41,859	33·5	...	...	6,379	10·3	37 ,,	
48,572	38·9	...	12	6,713+	10·9	13 ,,	
35,107	28·1	...	...	13,465	21·8	128 ,,	
44,232	35·4	...	24	9,125+	14·7	33 ,,	2nd filling after rest
40,504	32·4	...	...	3,728	6·0	0 ,,	
217,500	36·8	...	11	...	...	13 weeks	
150,000	25·4	...	7	67,500	...	21 ,,	
168,750	28·5	...	7	18,750+	...	1 ,,	
140,000	23·7	...	0	28,750	...	16 months	
127,500	31·5	...	11				
101,250	25·0	...	0	26,250	...	18 weeks	
120,000	29·7	...	7	18,750+	...	2 ,,	
101,250	25·0	...	0	18,750	...	4 days	
101,500	25·1	...	0	250+	...	16 months	
160,000	34·2	...	0	33.750	17·4	14 weeks	
150,000	32·1	...	0	10,000	5·2	9 ,,	
152,500	32·6	...	10	2,500+	...	8 months	
70,000	39·7	...	0				
55,000	31·2	...	0	15,000	...	13 weeks	
60,000	34·0	...	9	5,000+	...	11 ,,	
60,000	34·0	...	5	...	...	9 ,,	
54,750	31·1	...	0	5,250	...	3 ,,	
57,500	32·6	...	0	2,750	...	7 months	

TABLE III.—

No.	Name of town or district.	Name or number of bed.	Original water capacity of the bed in the tank.			Water capacity
			Date.	Gallons.	Percentage of the empty tank.	Date.
30	31	32	33	34	35	36
29	Liverpool ... (West Derby Sewage Farm.)	1	28 June, '99	15,575	45	23 April, '02
30	Manchester ...	Roscoe coke	15 Dec., '95 (Bed had been washed)	1,750	...	5 Jan., '98 7 Jan., '01 17 Jan., '01 26 Mar., '02 31 July, '02
		,, cinder	15 Dec., '95 (Bed had been washed)	1,750	...	5 Jan., '98 7 Jan., '01 25 Jan., '01 26 Mar., '02 31 July, '02
		A	27 Oct., '98	4,800	45	15 Nov., '98 20 April, '99 20 Sept., '99 21 Sept., '99 22 Dec., '99 5 July, '00 6 July, '00 25 Feb., '01 20 Mar., '02 5 Feb., '03
		B	10 Sept., '98	5,004	47	16 Nov., '98 20 April, '99 22 Sept., '99 2 Aug., '00 24 Jan., '01 22 Mar., '01 8 April, '02 4 Feb., '03
		C	11 April, '99	5,000	47	5 July, '99 14 Sept., '99 15 Sept., '99 26 Sept., '99 1 June, '00 23 Aug., '00 14 Mar., '01 15 Mar., '01 3 April, '02 4 Feb., '03
		½ acre bed 1A	...	...	...	5 Dec., '01 5 Jan., '03 2 Mar., '03
31	Middleton ...	1 and 2	...	...	...	...
32	Nelson	1				10 Feb., '02
		2				11 ,,
		3				12 ,,
		4				13 ,,
		5				25 ,,
		6				26 ,,

continued.

of the bed after use.		Number of hours occupied in draining the bed.	Number of days during which the bed had been resting previous to the measurement being made.	Loss of capacity. (+ indicates an increase in capacity.)		Length of time during which the bed was in use since last recorded measurement.	Number of fillings during the time.
Gallons.	Percentage of the empty tank.			Gallons.	Percentage of original water capacity of the bed.		
37	38	39	40	41	42	43	44
9,375	27·1	...	0	6,200	39 8	10 months	
1,260	...	2	...	490	28	2 years	
1,008	...	...	1	258	15	3 ,,	
1,166	...	2½	...	158+	9	10 days	
1,008	...	10½	...	258	15	15 months	
1,008	...	4	...	Nil.	...	4 months	
1,330	...	2	...	420	24	2 years	
1,080	...	...	1	250	14	3 ,,	
1,224	...	2½	...	164+	9	18 days	
1,044	...	10½	...	180	10	14 months	
1,080	...	4	...	36+	...	4 months	
4,530	43	3	...	270	6	19 days	
3,350	32	2½	7	1,180	25	22 weeks	
3,930	37	4¼	...	580+	12	22 ,,	
3,520	33	1¼	...	410	9	1 day	
2,860	27	3	...	660	14	13 weeks	
2,660	25	...	7	200	4	28 ,,	
2,280	22	7½	...	380	8	1 day	
2,440	23	...	2	160+	3	33 weeks	
2,210	21	10½	...	230	5	51 ,,	
2,150	20·3	6½	...	60	1	1 year	
4,530	43	3	...	474	9	10 weeks	
4,350	41	2½	7	180	4	22 ,,	
4,470	42	3½	...	120+	2	22 ,,	
2,980	28	1¼	...	1,490	30	45 ,,	
3,110	29	...	7	130+	3	25 ,,	
2,600	25	1¼	...	510	10	8 ,,	
2,730	26	11	...	130+	3	17 days	
2,570	24·3	6½	...	160	3	10 months	
3,690	35	4	...	1,310	26	12 weeks	
1,965	19	1½	...	1,725	34	10 ,,	
2,220	21	3½	...	255+	5	1 day	
3,520	33	...	11	1,300+	26	11 days	
2,580	24	6	...	940	19	35 weeks	
3,100	29	...	7	520+	10	12 ,,	
2,580	24	...	7	520	10	29 ,,	
2,230	21	7	...	350	7	1 day	
2,250	21	10½	...	20+	4	1 year	
2,000	18·9	6½	...	250	5	10 months	
175,142	39	...	...	...	...	...	135
143,894	32	...	...	...	...	...	658
143,054	31·5	...	...	...	...	...	727
1,700,000 One bed only							
33,870	20·1	...	½	...	...	11 months	
21,540	15 6					3 years	
22,170	12·9					2½ ,,	
35,920	26·0					10 months	
37,330	20·6					16 ,,	
59,170	44·7					2½ weeks	

TABLE III.—

No.	Name of town or district.	Name or number of bed.	Original water capacity of the bed in the tank.			Water capacity
			Date.	Gallons.	Percentage of the empty tank.	Date.
30	31	32	33	34	35	36
33	Oldham... ...	1	...	...	40	1900
		2				"
		3				"
		4				"
		5				"
		6				"
		7				"
		8				"
		9				"
		10				"
		11				"
		13				"
		14				"
35	Oswestry ...	Primary	...	...	...	...
38	Rochdale ...		No loss of capacity detected			
41	Southport ...	Coarse and fine	...	7,500 (each)	44·4	
43	Wolverhampton	1	Nov., '02	10 660	45·0	
		2	Sept., '02	50,660	42·0	
44	Wednesbury ...	Primary	...	15,000		
		Secondary		35		
45	West Bromwich.	Single contact	...	16,666	35·3	...
		Primary		45,000	28·6	...
		Secondary		45,000	33·3	...
47	York	1A	13 June, '99	18,550	40	11 Sept., '99 25 Sept., '99 6 Nov., '99
		2A	No appreciable reduction of this bed was			

continued.

of the bed after use.		Number of hours occupied in draining the bed.	Number of days during which the bed had been resting previous to the measurement being made.	Loss of capacity. (+ indicates an increase in capacity.)		Length of time during which the bed was in use since last recorded measurement.	Number of fillings during the time.
Gallons.	Percentage of the empty tank.			Gallons.	Percentage of original water capacity of the bed.		
37	38	39	40	41	42	43	44
60,121							
70,138							
57,382							
63,762							
73,361							
69,520							
69,520							
58,183							
58,038							
53,000							
54,740							
71,150							
70,550							
...	...	...	...	...	30 to 40	3 to 4 years	
9,950	21·1	...	...	6,716	40·2	...	816
29,455	18·7	...	...	15,545	34·5	12 months	...
33,337	24·6	...	...	11,663	25·9	12 ,,	...
9,300	20·2	...	...	9,250	50	90 days	200
13,650	29·7	...	14	4,350+	23	14 ,,	
9,600	20·9	...	...	4,050	22	43 ,,	
d.							

TABLE IV.—*Particulars of the "Septic" Tanks, of the Settling Tanks, and of the Detritus Tanks.*

No.	Name of town or district.	Number or names of the tanks.	Whether the tanks are open or closed.	Dimensions of the tanks.		Capacity of the tanks.
				Area. Feet.	Depth. Feet.	Gallons.
45	46	47	48	49	50	51
1	Accrington	1 Detritus 6 Septic	... Open	... ...	... ...	... 1,900,000
2	Aldershot	No septic tanks used				
3	Acton	Septic	Open	...	...	146,000
4	Aylesbury	Settling	...	50 × 30	...	40,000
5	Barnsley	Settling Septic	... Open	90 × 120 10,800	... 3	200,000 202,500
6	Birmingham ...	Settling	...	315 (average length)	...	5,441,875
		Septic 1 to 20	Open	189,000 (sq. ft.)	6·05	7,143,500
7	Blackburn	2 Settling	Open	...	...	750,000
8	Bloxwich district of Walsall	Septic	Open	Tank holds about 6 hours flow of sewage		
9	Bristol—					
	At Knowle ...	2 Knowle	Closed	275 and 360	6	26,000 (total)
	At St. John's-lane	1 St. John's	"	200	6	8,125
10	Burnley—					
	Duck pits (septic tanks) and Wood-end works (beds)	1 Detritus	...	49 × 39·5	Varies from 6·75 to 7·75	99,000
		2 "	...	49 × 39·5		"
		3 Septic	Closed	49 × 39·5		"
		4 "	Open	49 × 39·5		"
		5 "	"	49·5 × 39·5		"
		6 "	"	49·5 × 39·5		"
		7 "	"	52 × 39·5		"
		8 "	"	52 × 39·5		"
		9 "	"	73 × 39·5		120,250
		10 "	"	73 × 39·5		"
		11 "	"	76 × 39·5		"
		12 "	"	76 × 39·5		"
11	Burslem	Septic	Open			
12	Bury	6 circular settling tanks.		...	(each)	50,000
15	Croydon	Settling	...	1,500 long	...	41,000
16	Darwen	Settling	...	...	...	About one day's dry weather flow
		The septic experiments were not very successful				
17	Epsom	Septic	...	...	11,000	
18	Evesham	3 Septic Settling	Open ...	1,780 21 long	4·5 ...	150,000 $\frac{1}{10}$ of daily flow

TABLE IV.—*continued.*

No.	Name of town or district.	Number or names of the tanks.	Whether the tanks are open or closed.	Dimensions of the tanks.		Capacity of the tanks. Gallons.
				Area. Feet.	Depth. Feet.	
45	46	47	48	49	50	51
19	Glasgow	1 Septic	Open	3,881	8·25	200,000
20	Haslingden, Rawtenstall and Bacup	4 Septic	Open	60 × 180 (each)	7·5 (average)	456,250 (each)
22	Huddersfield ...	1 Detritus				
		24 Settling	...	40 long	(total)	1,250,000
		1 Septic	Open	1,590	5·5	55,000
23	Hyde	1 Septic	Open	90 long	...	75,000
24	Keighley	Settling	...	10 long	...	687
		Septic	Open	540	3·7	8,750
25	Kettering	2 Precipitation (Dortmund)	...	25 in diam.	40 to bottom of cone	80,000 (each)
		8 Precipitation	...	60 long	...	35,970
				60 ”	...	35,700
				60 ”	...	35,700
				60 ”	...	34,860
				60 ”	...	34,270
				84 ”	...	49,590
				84 ”	...	49,590
				84 ”	...	49,120
		Septic action apparently occurs in the precipitation tanks				
26	Leeds	1 Septic	Open	6,000	$7\frac{7}{12}$	250,000
		2 ”	”	6,000	$7\frac{7}{12}$	250,000
		3 ”	”	6,000	$7\frac{7}{12}$	250,000
		4, 5, 6, 7 Septic	”	...	...	2,000,000 (total)
		2 Cameron or Exeter	Closed	54 × 10	9	40,000
27	Leicester	Detritus	Open	30 long	...	18,681
		”	Closed	15 wide	7	...
		Septic	”	130 × 30	6 to 4¼	125,962
28	Lincoln	Septic				
		C.D.E.F.	Open	54 × 89	6	180,672 each
		A.B.	”	52 × 23	6·75	54,203 ”
		G.	”	78 × 89	7	303,712
		I.	”	139 × 46	7·25	313,048
		II.	”	168 × 39	6·5	281,024
30	Manchester	2 Septic	Open	300 × 100	6	1,125,000
		The open septic tanks have been recently enlarged as follows—		300 × 100	7	1,300,000
31	Middleton	Settling	..	24 in diam.	...	120,000
32	Nelson	10 Settling	...	100 × 30 (each)	...	1,050,000
		Septic tank only just started				

TABLE IV.—*continued.*

No. 45	Name of town or district. 46	Number or names of the tanks. 47	Whether the tanks are open or closed. 48	Dimensions of the tanks.		Capacity of the tanks. Gallons. 51
				Area. Feet. 49	Depth. Feet. 50	
33	Oldham	2 Detritus	...	45 long		
		11 Settling	...	128 „	...	1,940,400 (total)
		Septic	Open	...	7·5	175,400
		Septic	Covered	128 long	...	175,400
		(Old Settling tank converted since April, 1902.)				
34	Ormskirk	8 Settling	...	...	...	83,000 (total)
35	Owestry	Settling	...	70 long	...	56,000 (total)
37	Reigate	2 Settling	...	4 × 8	3·5	
38	Rochdale	Septic	Open	6,400	5	200,000
39	Salford	12 Settling	...	110 long each	...	5,250,000 (total)
43	Wolverhampton ...	Septic	Open	7,500	5·3 (mean)	249,000
44	Wednesbury ...	1 Septic	Covered			
		2 „	Open			
45	West Bromwich ...	2 Septic	Open	800	5	25,000 (each)
47	York...	Septic	Closed	800	8	40,000
		„	Open	6,400	6·25	250,000

TABLE V.—*Particulars as to the Working of the Tanks.*

No. 52	Name of town or district. 53	Name or number of tank used. 54	Dates between which the tanks were in use. 55	Length of time during which the tanks were used. Weeks. 56	Rate of flow of sewage through the tanks. Gallons per day. 57	Quantity of sewage passed into the tanks. Gallons. 58	Quantity of sludge left in the tanks. Tons. 59	Percentage reduction in the amount of sludge effected by "septic" action. 60
1	Accrington ...	6 Open	15 months' continuous use	...	1,250,000 (dry weather flow)			
4	Aylesbury ...	Settling	...	...	250,000			
5	Barnsley ...	Settling	...	...	200,000 (about)			
6	Birmingham ...	Settling Septic 1 to 20	... In use constantly	... 104	22,000,000 22,000,000	...	None	*
7	Blackburn ...	Septic 1 „ 2	...	104	240,000	...	...	72 of the suspended solid matter
9	Bristol— At Knowle... At St. John's-lane	Septic „	Jan., '00 to Mar., '02	... ...	39,000 1,600			
10	Burnley ...	The detritus tanks are emptied every 3 weeks and contain about 80 tons when pressed into cake. The whole 12 tanks were sludged every 4 months up to 1 Oct., 1902, since when no sludging has been done.						
12	Bury	Settling	...	...	2,000,000			
15	Croydon ...	Settling	...	...	450,000			
18	Evesham ...	Septic	2 years to Jan., '03.	25	150,000	No increase in sludge during 12 months		
19	Glasgow ...	Septic	15 Sept., '00, and 2 May, '01	33	...	44,525,128	818·5	54·25
20	Haslingden, Rawtenstall and Bacup	Septic	Dec., '99 to Dec., '01	104	456,250	47,000,000	Average depth of 3 feet in tank	
22	Huddersfield ...	Settling	...	...	6,000 000 (total)			
		Septic	23 July, 1900, to 29 May, 1901	44	50,000 (about)	15,232,000	107·88	38

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* The sludge which had to be disposed of before septic tanks were used amounted to double that which is now to be removed from the sedimentation tanks.

Table V.—*continued.*

No. 52	Name of town or district. 53	Name or number of tank used. 54	Dates between which the tanks were in use. 55	Length of time during which the tanks were used. Weeks. 56	Rate of flow of sewage through the tanks. Gallons per day. 57	Quantity of sewage passed into the tanks. Gallons. 58	Quantity of sludge left in the tanks. Tons. 59	Percentage reduction in the amount of sludge effected by "septic" action. 60
23	Hyde	Septic	June, 1899, to 1902	3 years	75,000	...	11 tons in 14 months	
24	Keighley ...	Settling Septic	... July, 1900, to April, 1902	... 91	3,840 Varies			
26	Leeds	Septic 1	1899 27 Feb., 15 Aug., 21 Sept., 1900		 250,000 125,000 250,000	134 million gallons	807	28
			10 Dec.,	(End of experiment)				
		Septic 2	1899 28 April, 12 May, 18 Dec., 1900		 125,000 250,000 125,000	...	838	18
			Nov.,	(End of experiment)				
		Septic 3	1899 3 May, 12 May, 18 Dec., 1900		 125,000 250,000 500,000	...	586	28
			Nov.,	(End of experiment)				
		Septic 4, 5, 6, 7, Closed septic	1889 12 June, 4 Aug , 6 June		 2,000,000 ... 40,000	(Tanks working in series)		
27	Leicester ...	Septic	1899 5 June and 13 Oct.	(125 working days)	156,503	...	149	
28	Lincoln ...	The tanks are filled and allowed to stand 12 hours, the sewage is then drawn off and the sludge is run into low-lying lagoons and dug in						
30	Manchester ...	Septic 2	1900 16 May to 14 Nov.	...	2,500,000	425,000,000	...	21·6
			14 Nov., 1900 to 24 Jan., 1901	...	2,000,000	142,000,000	...	33·5
31	Middleton ...	Settling	...	...	1,000,000			
32	Nelson ...	Settling	...	...	600,000 (dry weather flow)			

TABLE V.—*continued.*

No. 52	Name of town or district. 53	Name or number of tank used. 54	Dates between which the tanks were in use. 55	Length of time during which the tanks were used. Weeks. 56	Rate of flow of sewage through the tanks. Gallons per day. 57	Quantity of sewage passed into the tanks. Gallons. 58	Quantity of sludge left in the tanks. Tons. 59	Percentage reduction in the amount of sludge effected by "septic" action. 60
33	Oldham ...	Detritus	...	...	22,500			
		Septic	June, 1900 to June, 1901	52 weeks	350,000	127,750,000	(2 feet deep)	
35	Oswestry ...	Settling	...	...	29,531			
37	Reigate ...	Settling	...	...	18,000			
38	Rochdale ...	Septic	...	2 years	200,000 (3 months) 160,000 (afterwards)	130,000,000	200 of pressed sludge of 60 per cent. moisture	26·5 (total solids) 62·0 (suspended solids)
39	Salford ...	12 Settling	...	...	12,000,000			
43	Wolverhampton	Septic	31 May, '99 to 16 Oct., '00	68	250,000 (average) 50,000 to 500,000	...	...	33·0
47	York	Closed Septic	21 April, 89' to 31 Aug., '01	123	From 13,000 to 40,000	14,500,000		
		Open Septic	26 June, '00 to 12 Mar., '01	89	182,000 to 318,000	105,000,000	390 cubic yards.	

No.	Name of town or district.	Remarks.
1	62	63
1	Accrington	The same amount of sewage is being passed through the beds as when they were first constructed. Storm water is separate from sewage. The whole of the sewage is treated in a permanent manner, and the results are satisfactory to the Rivers Board. An attempt is being made to reduce the cost of treatment by dispensing with pumping; the coal bill is a very heavy item.
2	Aldershot	No account is taken of the number of fillings. The system having gone beyond the experimental stage, the beds are brought into use as required.
3	Acton	The experiment was successful, and the effluent which was delivered into the tideway of the river at Chiswick Ait was approved of by the Thames Conservancy. Arrangements are being made for open septic tanks and continuous beds to treat the whole of the sewage.
4	Aylesbury	The result is considered satisfactory, and the installation is now permanent.
5	Barnsley	This is a temporary experiment, and the result is considered satisfactory. The tanks and coke-beds have not been sufficiently long in use to afford opportunity for judging proper results. It is expected that a reduction in the capacity of the beds will occur.
6	Birmingham... ...	Sewage is applied to 1,828 acres of farm land. Within the last two years precipitation tanks have been converted into "septic" tanks, and the "septicised" sewage has been applied to the land. The results obtained from the experimental bacteria-beds, which are not included in these tables, were perfectly sufficient to show that the sewage could be efficiently treated in bacteria-beds.
7	Blackburn	The temporary beds have been thrown out of use, and 24 beds 120 feet long by 60 feet wide and 3½ feet deep, are now in course of construction.
8	Bloxwich district of Walsall.	The population of the area drained is 2,200. A large septic tank is in course of construction. First class results have been obtained up to the present.
9	Bristol—	
	At Knowle... ...	The effluent discharges into a brook which passes through a village; an application for an injunction to stop the works was dismissed, as the judge was satisfied as to the purity of the effluent.
	At St. John's-lane...	The works are surrounded by dwelling-houses, one being less than 50 feet distant.
10	Burnley	"We are convinced that the scheme adopted by your committee will prove an efficient one, and that the treatment of the sewage of the borough will be carried out in a more satisfactory manner and with less cost by this system ("septic" tanks and bacteria-beds supplemented by land) than it could be by any other which has come under our notice." Report to the Highways and Sewage Committee of the Burnley Corporation on Sewage Disposal, 23rd April, 1901, p. 20.
12	Bury...	From the results obtained, the Corporation have decided to extend the works on similar lines.

No.	Name of town or district.	Remarks.
61	62	63
15	Croydon	About 450,000 gallons are dealt with daily. The effluent is passed over land once or twice by surface irrigation. Throughout the year the beds are in use for three weeks continuously and then rest for one week.
16	Darwen	The sludge from the precipitation tanks is allowed to flow into a large lagoon formed in the deep bed of coarse gravel on which the sewage works are situated. A great deal of liquefaction takes place in this bed, thus causing the disappearance of the greater part of the sludge. The beds were originally of coke, but owing to the diminution caused by the breaking down of the coke, hard vitrified clinker has been substituted.
20	Haslingden, Rawtenstall and Bacup	After two years' working it was found necessary to clean out the tanks on account of large upheavals of black sediment. The black sediment had a strong odour of sulphuretted hydrogen. It had a tendency to choke both the artificial and the land filters. Periodical cleaning out has since been adopted.
22	Huddersfield ...	That by no process can the formation of sludge be obviated. That by the open "septic" process 38 per cent. of the sludge is destroyed. That the best results have been obtained by chemical precipitation, sedimentation and double contact-bed treatment. That the difference between the effluents from the contact-beds and the trickling-bed treating the "septic" sewage is very slight. That during the past six months the effluents from 1. Chemical precipitation and double contact-beds, 2. Open "septic" tank and double contact-beds, 3. Open "septic" tank and trickling-bed have been non-putrescent when subjected to the incubator test. That when the crude sewage is treated in contact beds, the rapid accumulation of matter in the beds renders the process impracticable. That the contact beds used for the purification of the "septic" sewage or the effluent after chemical precipitation will not retain their capacity indefinitely, and that in the course of a number of years they will be reduced to such an extent as to render necessary the washing or riddling of the material.
23	Hyde	A complete scheme of sewage treatment based upon these results has been submitted to the Local Government Board for approval.
24	Keighley	The Borough Engineer states—"In my opinion, bacterial treatment ought to satisfy any river authority. My Council do not intend putting down a permanent installation so long as our present system of intermittent land filtration is satisfactory. There is no doubt the bed will gradually become choked, but to cleanse or renew I think would be cheaper than chemical treatment."
25	Kettering	The bacteria-beds have recently been examined and found to be quite clean inside and without any accumulation of sludge beyond some fine deposit on the surface. "The provision of filter-beds has very much improved the character of the effluent."
26	Leeds	The Chairman of the Leeds Sewage Committee states that the results from a process of continuous bacteria-bed treatment "are very good indeed, giving a purification of 95 per cent."

No.	Name of town or district.	REMARKS.
61	62	63
28	Lincoln	The City Surveyor says—"The external authorities (through whose districts the effluent stream runs), who previously had been dissatisfied with our farm and polarite-bed effluents, have expressed themselves satisfied with our bacteria-bed effluent, we therefore are completing an installation to deal with all our sewage." By the end of 1903 it is expected that a sufficient number of bacteria-beds will have been constructed to deal with all the sewage, *i.e.*, an ordinary day's supply. There is already sufficient tank accommodation.
30	Manchester	The sewage before treatment of any kind, was at first screened by a bar screen of half-inch mesh, but since October, 1899, unscreened sewage was supplied to the experimental "septic" tanks. On the working scale they receive screened sewage. There are now at Manchester 32 half-acre beds in regular operation, and many more are in course of construction. There are also 12·75 acres of storm beds which receive about one filling per day of chemically treated and settled sewage in fine weather and a greater quantity in time of storm. Extract from the Annual Report of the Rivers Department for the year ending 27th March, 1901, p. 74—"The result of the work recorded in the foregoing pages, while emphasising the necessity for care in the construction and management of sewage purification work, gives the Committee every encouragement in carrying out the scheme for the bacterial treatment of Manchester sewage according to the general principles advised in the Experts' Report, 1899, and sanctioned by the Council on September 5th, 1900." The experts recommended preliminary sedimentation and screening followed by bacteria-tank and bacteria-bed treatment.
31	Middleton	If sufficient area of beds is employed and they are properly managed the treatment is satisfactory. It is contemplated treating the whole of the sewage by the bacterial process.
32	Nelson	Results obtained by experimental beds are quite satisfactory.
33	Oldham	Average daily flow of sewage (1900) 4,000,000 gallons. Experiments show that bacteria-beds should be supplied with a tank effluent of uniform strength. Chemicals are an unnecessary expense and rather hinder the work of the bacteria-beds than assist it. It is intended to treat the Oldham sewage by subsidence followed by the action of bacteria-beds. There is a greater uniformity in the strength of the effluent from the septic tank than in that from the sedimentation tanks, and the bacteria-beds act better when an effluent of uniform strength is used. The effluent from the "septic" tank and bacteria-beds seldom putrifies on incubation. There is also a very considerable reduction in the quantity of sludge. Extract from a report entitled, "The Treatment of Oldham Sewage in the year 1900," by the Medical Officer of Health, p. iii.—"With the exception of a few days during the year, when the weather was very dry, the method has been entirely successful."
34	Ormskirk	The results obtained at the farm of the Urban District Council of Ormskirk by passing the sewage through lagoons, into settling tanks, over the land, and through the coke-breeze-beds successively, are very satisfactory and meet the requirements of the authorities (no chemicals are used).
35	Oswestry	Small experimental beds were originally constructed: later, beds for the treatment of the whole of the sewage. There is no doubt as to the success of the bacterial treatment, our results are continuously satisfactory and the effluents keep free from putrescence. Probably a small amount of septic action takes place in the settling tanks.

No.	Name of town or district.	Remarks.
61	62	63
37	Reigate	The sewage is distributed evenly over the surface of the bed by the automatic Candy-Caink sprinkler fed by intermittent valves. Two or three minutes' flow of sewage is held up in a storage chamber and then discharged through the sprinkler in about one minute, so that the bed is in this way both worked and rested in an intermittently continuous manner. There is no water-logging of the bed, and continuous and frequent aëration is insured as is shown by the effluent being practically saturated with dissolved oxygen. "The result of three years' searching trial is so satisfactory as to encourage the Council to sanction the outlay and adopt a scheme for treating the whole of the sewage of the borough on the lines adopted by the experimental plant."
38	Rochdale	The two beds are Whittaker and Bryant's thermal aërobic "filters" (as at Accrington). The sewage passes through a "septic" tank of a capacity of 1½ days' flow. The sewage from the open "septic" tank flows into a small tank and is then pumped up and continuously and evenly distributed over the surface of the two beds by automatically revolving sprinklers, and passes directly through the bed. The "septic" tank was in use too long without the sludge being cleaned out. It will be cleaned out more frequently in future.
39	Salford	Clarified sewage from the precipitation tanks which had passed through a gravel roughing "filter" was supplied to the bed by sprinkler jets making a spray or rainfall over the surface of the bed. Thus clarified sewage and air passed continuously through the beds while they were working. The roughing beds intercept a good deal of fine mud and require cleaning out about every second day. We can fully depend upon the bacteria-beds to give a satisfactory effluent even when working night and day almost without intermission. Permanent beds to treat the whole of the sewage are being constructed.
40	Sheffield	The degree of purification obtained has been uniformly satisfactory. The loss of capacity of the beds continues, and experiments are being conducted with the object of reducing this as much as possible. Permanent works on bacterial principles are contemplated, but working details cannot be decided upon until further experiments are completed.
41	Southport	Only a small proportion of the sewage is treated. The beds have always worked to entire satisfaction, and they have always produced a clear and non-putrescible effluent.
43	Wolverhampton ...	The results from No. 1 bed were good, but, owing to the presence of iron salts in the sewage, a permanent installation is doubtful. It was necessary on account of the iron salts to add lime to the sewage before it passed into the "septic" tank.
46	Worcester	These beds are in use only at the Isolation Hospital. They consist of trenches filled with furnace ashes along which the sewage flows. No measurements as to capacity have been made.
47	York	In a report to the Sewerage Committee, dated October, 1901, the City Engineer states (on p. 41), with respect to an experimental plant consisting of an open "septic" tank and continuous "filtration," that the results were excellent and the "filtrate" was non-putrescible. That the system is adaptable for larger quantities per square yard than any other experiment, and that there is no loss of liquid capacity in the "filter."

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The following additional bacterial information has been obtained by the experimental work carried out by the chemical staff of the London County Council—

I. Reduction in the Number of Bacteria in Sewage by Bacterial Treatment.

It appeared to be a matter of interest to determine whether the total number of bacteria present in the raw sewage underwent a diminution in the process of "septic" and contact-bed treatment.

For this purpose a series of bacterial determinations were made by the chemical department of the Council on cultivations of the sewage, the "septic" effluent, and the coke-bed effluent, put down immediately on the spot from the plant at Christ's Hospital, Horsham.

For the purpose of comparison, the results obtained from bacterial cultivations put down from the same samples 21 hours after their collection, are also reported. The 21 hours' interval is about the average delay which elapses when the samples were sent to the central laboratory for cultivation instead of being put down at the time of collection. It will be seen that the delay in cultivation produced not only a great difference in the actual number of bacteria found in each liquid, but also yielded different relative numbers.

A second series of bacterial determinations is also given, which were made on the feed and effluent of the acre coke-bed at Barking. The cultivations were put down on the spot as soon as the average samples were taken.

The general conclusion which may be drawn from these results is that accurate determinations of the total number of bacteria, and numbers which are comparable for the different liquids, can only be obtained by putting down the cultivations without delay.

The bacteria evidently undergo a considerable decrease in number during the treatment, a decrease which is actually much greater than is apparent from the numbers given in the Horsham table of results, since in this instance the fæces were not broken up, and the fæces are probably the main source of bacteria in a sewage like that at Horsham, which is entirely of domestic origin.

It will be noticed that the decrease in the number of bacteria is much greater in the treatment at Barking, but this may be in part explained by the mechanical action of the compacted material at the bottom of the acre-bed.

The fear which has sometimes been expressed, that bacterial treatment largely increases the number of bacteria, appears therefore to be without foundation, and a properly managed bacterial installation will deliver an effluent which contains fewer bacteria than were present in the crude sewage.

II. Bacterial Examination of Average Samples taken from the Sewage Treatment Plant at Christ's Hospital, Horsham.

The sewage is entirely of domestic origin, and in sampling the sewage the fæces were not broken up and included. Each sample was an average of samples taken every quarter of an hour during the three hours' daily maximum flow of sewage.

The total number of organisms was counted after being cultivated in gelatine at 20° C.

Each figure in Table I. is an average of two cultivations unless it is specially marked with an asterisk (*).

Two results are given under each column for each date. The former gives the number of colonies obtained in cultivations which were put down at the time of sampling; the latter gives the number of colonies obtained in cultivations put down from the same sample after it has been kept for 21 hours.

It will be seen from a comparison of the two sets of results obtained that a very considerable increase occurred in the number of bacteria found after 21 hours' delay in each of the liquids examined, and that the increase occurred at a different rate in each liquid. It therefore appears necessary to put down cultivations without delay if comparable results are to be obtained.

TABLE 1. *Bacterial Examination of the liquids from the Bacterial Treatment Plant at Horsham.*

Date of collection, 1903.	Total number of bacteria in one cubic centimetre of the sample liquid.		
	Crude sewage from collecting tank, not including solid fæces.	"Septic" tank effluent from the whole sewage; no deposit was formed in the "septic" tank.	Coke bed effluent from the whole sewage.
June 9	7,300,000 22,750,000	13,650,000 17,500,000	8,750,000 13,050,000
" 12	9,800 000 28,700,000	10,850,000 12,300,000	*9,500,000 10,750,000
" 16	9,000,000 23,800,000	5,750,000 6,300,000	6,650,000 7,000,000
" 19	8,750,000 16,450,000	9,800,000 *14,700,000	8,050,000 9,300,000
" 23	12,700,000 21,000,000	8,200,000 12,250,000	5,100,000 5,950,000
July 8	16,450,000 23,800,000	3,650,000 16,800,000	3,000,000 6,300,000
" 14	23,450,000 43,750,000	21,700,000 37,950,000	18,200,000 38,850,000
Average number of bacteria found in the above seven cultivations when they were put down at once	12,492,857	10,514,286	8,461,286
Average number of bacteria found in the corresponding seven cultivations when they were put down after 21 hours	25,750,000	16,828,571	13,028,571
Percentage decrease in number of bacteria calculated on the original sewage liquid when put down at once for cultivation	...	15·8	32·2
Percentage decrease in number of bacteria calculated on the original sewage liquid when put down for cultivation after 21 hours	...	34·6	49·4
Percentage increase over 21 hours in each liquid	106	60	54

Further results obtained from eleven samples of Horsham sewage.

Klein's enteritidis change was shown by 0·1 c.c. of crude sewage, of "septic" tank effluent, and of coke-bed effluent on four occasions.

B. coli was found in the 100,000 dilutions of crude sewage on ten occasions, and once in the 1,000,000 dilutions.

B. coli was found in the 100,000 dilutions of "septic" tank effluent seven times. It was not found in the 1,000,000 dilutions, but always in the 10,000 dilutions.

B. coli was found in the 100,000 dilutions of coke-bed effluent on two occasions, and each time in the 10,000 dilutions.

Method used—Primary broth and secondary surface gelatine plate cultivation.

III. BACTERIAL EXAMINATION OF THE FEED AND OF THE EFFLUENT OF THE ONE-ACRE BACTERIA-BED AT THE NORTHERN OUTFALL WORKS (BARKING).

A.—Effluent from the crude sewage which had been mixed with chemicals and subjected to sedimentation, and which then flowed into the one-acre coke-bed at the Northern outfall works, Barking.

B.—The effluent discharged from the bed.

The samples were taken every ten minutes during the filling and emptying of the bed. The samples of each set were mixed together, so as to form average liquids.

The lower portion of this bed consists of very finely divided coke, and possibly acts to some extent mechanically in reducing the number of bacteria.

The cultivations were put down on the spot as soon as the average samples were ready.

TABLE 2. *Bacterial Examination of the Feed and of the Effluent of the One-acre Bacteria-bed at the Northern Outfall Works (Barking).*

Date, 1903.	Description of sample.	Number of micro-organisms in one cubic centimetre of the sample liquid.					
		Total number of bacteria capable of growing at		Aërobic spores	B. coli communis.	Gas-producing bacteria.	Spores of B. enteritidis sporogenes (anaërobic)
		20° Centigrade.	37° Centigrade.				
May 9	A	8,000,000	3,300,000	210	100,000	—	—
	B	70,000	30,000	70	1,000	—	—
" 13	A	11,500,000	6,800,000	170	1,000,000	1,000	—
	B	814,000	527,000	130	100,000	10	—
" 14	A	5,300,000	2,600,000	240	100,000	—	100
	B	829,000	393,000	100	*10,000	—	10
" 16	A	10,000,000	8,000,000	230	100,000	—	100
	B	1,180,000	720,000	140	10,000	—	100
" 19	A	10,800,000	4,900,000	270	1,000,000	100	not 100
	B	Lost	550,000	140	100,000	10	10
" 20	A	6,600,000	4,700,000	230	1,000,000	100	1,000
	B	1,070,000	590,000	70	100,000	10	100
" 27	A	7,900,000	5,400,000	290	1,000,000	1,000	not 100
	B	1,675,000	Lost	120	100,000	100	100
Average number	A	8,585,714	5,100,000	234	614,286	550	†244
	B	939.667	468.333	110	60,143	32	64
Percentage reduction in number of bacteria by passage through the bed.		89·1	90 8	53	90·2	94·2	73·8

* Possibly more, but a higher dilution was not made.

† In this average "not 100" is taken as ten.

IV. The Number of Bacteria in Sewage Sludge Produced at the Northern Outfall Works (Barking).

Between the 27th April and 6th May, 1903, estimates were made by the chemical staff, of the number of bacteria present in five different samples of the sludge which is produced at the Northern Outfall Works by the present treatment. The treatment consists in the sedimentation of the sewage after admixture with solutions of lime and of iron sulphate. The samples were collected in such a manner that they were representative of five different cargoes of sludge, and the bacterial cultivations were put down on the spot as soon as the samples were collected. The results of the bacterial examination are set forth in the following table—

On referring to column 2 of this table it will be seen that the average number of bacteria present in one cubic centimetre of sludge was 141,600,000. Column 3 gives the number of bacteria found when the cultivations were made at 37° C. (blood heat); these bacteria, when found in sewage polluted water, are considered to be mainly, if not entirely, of intestinal origin.

Table 3. *Number of Bacteria in Sewage Sludge produced at the Northern Outfall Works.*

Date.	Total number of organisms in one cubic centimetre of sludge.		
	Bacteria wnich grow at 20° C.	Bacteria which grow at 37° C. (blood heat).	Spores.
1903.			
April 29	121,000,000	60,000,000	6,250
May 2	126,000,000	74,200,000	8,100
May 4	195,000,000	45,000,000	10,550
May 5	131,000,000	64,000,000	11,800
May 6	135,000,000	70,000,000	11,400
Average	141,600,000	62,640,000	9,610

V. Reduction in the Number of Bacteria present in River Water by passage down the stream.

A bacterial examination of the river water below the Sewage Outfall Works has been undertaken by the chemical staff at the Council's Outfalls. The principal object of the examination was to ascertain whether the bacteria, introduced into the river by the discharge of effluents from the Barking and Crossness Outfall Works, underwent diminution in their passage down the river, and whether any species of them entirely disappeared. All samples were taken by dipping into surface water only.

On 3rd, 4th, 5th and 6th of March, 1903, samples of the river water were collected at each of eight different points extending over a distance of about 18 miles, viz., between the Mucking lightship, which is about 21 miles below Crossness and a point about 3½ miles below the Nore or about 39 miles below Crossness. The three series of samples were taken at low water—(*a*) near the southern shore, (*b*) in midstream, and (*c*) near the northern shore, respectively, and the following table shows the number of bacteria found per cubic centimetre of water at each point and the time at which the samples were taken—

TABLE 4. *Number of Bacteria in the Water of the River Thames.*

Locality.	Approximate distance in statute miles from preceding point.	South shore of river.			Midstream.			North shore of river.		
		Time of sampling.	Gas-forming bacteria in one cubic centimetre.	Number of bacteria per cubic centimetre of water.	Time of sampling.	Gas-forming bacteria in one cubic centimetre.	Number of bacteria per cubic centimetre of water.	Time of sampling.	Gas-forming bacteria in one cubic centimetre.	Number of bacteria per cubic centimetre of water.
		3rd March, 1903.			4th March, 1903.			6th March, 1903.		
		p.m.			p.m.			a.m.		
3½ miles below the Nore ...	—	8.55	Absent	100	9.10	Absent	262	10.5	Absent	155
Nore lightship	3½	9.10	"	200	9.25	"	203	10.20	"	213
Sheerness (Garrison-point)	2⅓	9.20	"	300	9.35	"	386	—	—	—
Opposite Southend-pier ...	2	9.35	"	300	9.50	"	493	10.40	"	354
Yantlet-creek	2	9.50	"	800	10.5	"	980	10.55	"	639
Chapman light vessel ...	2½	10.5	Present	2,800	10.20	"	2,120	11.10	Very slight trace	930
Hole Haven	2⅔	10.25	"	5,400	10.40	"	2,830	11.30	Abundant	3,320
Mucking light vessel ...	3	10.40	"	8,300	10.55	"	5,160	11.45	"	5,030
		4th March, 1903.			5th March, 1903.			6th March, 1903.		
		a.m.			a.m.			p.m.		
3½ miles below the Nore ...	—	9.40	Absent	300	9.50	Absent	130	10.45	Absent	82
Nore lightship	3½	sample lost		...	10.5	"	none	11.5	"	212
Sheerness (Garrison-point)	2⅓	10.10	Absent	400	10.15	"	238	—	—	—
Opposite Southend-pier ...	2	10.25	"	500	10.25	"	325	11.25	"	379
Yantlet-creek	2	10.35	"	1,000	10.40	"	390	11.40	"	702
Chapman light vessel ...	2½	10.50	"	2,400	10.55	"	1,140	11·50	"	1,940
								a.m.		
Hole Haven	2⅔	11.5	"	5,200	11.10	"	2,260	0.5	"	3,050
Mucking light vessel ...	3	11.20	"	4,000	11.25	"	4,170	0.20	Abundant	4,090

In proceeding down the river a very great diminution in the number of bacteria present in the water was noticed soon after the Chapman light was passed. The light is about 27 miles below Crossness. When a point off Southend-pier was reached, the bacteria had decreased in number to that not unusually found in the drinking water supplied by the water companies to London consumers after having undergone subsidence and filtration at the waterworks. It should be pointed out that, although the average number of bacteria found by Dr. Houston in the "chemical" effluents discharged in 1898 was 7,500,000 per cubic centimetre, the average number found at the Mucking lightship in the present investigation was 5,125 only, while this number was still further reduced to 752 at Yantlet-creek, just above Southend, and to 172 at a point 3½ miles below the Nore.

The bacterial examination was, however, further extended in order to ascertain whether the intestinal bacteria, which may be referred to in general terms as "gas-forming bacteria," were largely reduced in numbers by the passage of the effluent down the lower river.

In seven only out of the 45 samples of water examined were gas-forming bacteria found, and these seven samples were all taken from the river at or above the Chapman light, which is 4½ miles above Southend. Below the Chapman light these bacteria were not found.

This very considerable reduction in the total number of bacteria, and the disappearance of characteristic intestinal organisms, would lead to the conclusion that danger is not to be apprehended from bacterial contamination of the water of the estuary at or below Southend arising from the metropolitan sewage effluent.

Estimations of the state of aëration of the water of the lower river were also made with the view of discovering the point at which the de-aërating effect of the effluent upon the river water ceased. Two series of estimations were made on samples taken between Greenhithe and the Mouse lightship, but full aëration was not found in any one of these samples. Half-hourly estimations were also made between the time of high water and of low water at a point one mile below Gravesend, at the Mucking light, and at the entrance to the Barrow Deep. It was found that at low water the degree of aëration of the river water increased steadily with the increase of distance below the outfalls, and this result entirely supports the conclusions arrived at from the bacterial estimations, which showed that the purification of the effluent progressed regularly during its passage down the river. This purification is undoubtedly due to the action of bacteria, which are present in the effluent. The estimation of aëration in the samples taken in the estuary at the entrance to the Barrow Deep, many miles above where the sludge is discharged, showed the highest degree of aëration in the whole series, and all these samples contained the maximum amount of oxygen possible in water of that degree of salinity.

It must be remembered that the effluent resulting from the proposed bacterial treatment would contain a smaller number of bacteria than are present in the present so-called "chemical" effluent. But since the effluent would also contain far less organic nutriment for their sustenance, it may be certainly inferred therefore that the bacteria introduced into the river by such an effluent would disappear far more quickly than those which are discharged in the present effluent.

VI. BACTERIAL EXAMINATION OF THE WATER OF THE NORTH SEA AND OF THE WATER, MUD AND SANDS OF THE THAMES ESTUARY IN THE VICINITY OF THE BARROW DEEP

In continuation of the bacterial examination of the water of the lower river, estimations were made of the number of bacteria present in the surface water of the Barrow Deep, where the sewage sludge is deposited, and of the open sea in the neighbournood of the Galloper light vessel.

The three bacterial examinations (*a*, *b*, *c*) of the water of the Barrow Deep were made during and immediately after the discharge of sludge by the London County Council's steamers. The results obtained are given in the tables which follow the description of each series.

(*a*) This water was collected at the last of the ebb tide, and at nearly slack water; the samples of the surface water were taken every two minutes while the Council's steamer *Burns* was steaming the whole length of the Barrow Deep and back again, and the water, which was taken in this way between every two alternate buoys, was mixed, and formed one sample for examination.

The arrangement of the buoys in the deep is such that those denoted by even numbers are situated on the south side of the deep and those denoted by odd numbers are on the north side.

Four of the average or compound samples of water thus obtained were collected in the Barrow Deep, and additional samples were collected at the Mouse light vessel at the entrance to the Deep and at the Nore light vessel about 8 miles nearer the mouth of the river Thames.

The steamship *Burns*, from which the samples were collected, was the last of the Council's steamers to discharge her cargo in the Barrow Deep. She closely followed the other steamers, an interval of not more than twenty minutes occurring between the passing of any point by the preceding steamer and by the *Burns*. It was considered that, since an estimation of the number of bacteria in the sludge itself had already been made, a reasonable number of minutes should elapse between the discharge of the sludge and the collection of a sample of sludge-polluted water in the Barrow Deep.

The following table gives the results of this series of bacterial estimations—

TABLE 5. *Number of Bacteria in the Water of the Estuary of the Thames.*

Date.	No. of sample	Time of collecting sample.	Locality from which the sample was collected.	Number of bacteria per cubic centimetre of water.	"Gas-forming" or intestinal bacteria were absent in
April 2	1	a.m. 5.50 ...	Abreast the Nore light	1,168	Not estimated.
	2	6.25 ...	" Mouse "	4,310	1 c.c. of water.
	3	6.50 to 7.20	Between Nos. 10 and 6 buoys in the Barrow Deep	4,500	$\frac{1}{10}$ c.c. "
	4	7.20 to 7.45	Between Nos. 6 and 2 buoys in the Barrow deep.	7,450	" "
	5	7.50 to 8.20	Between Nos. 1 and 5 buoys in the Barrow Deep	1,050	" "
	6	8.20 to 8.50	Between Nos. 5 and 7 buoys in the Barrow Deep	1,650	" "
	7	9.20 ...	Abreast the Mouse light	30	1 c.c.
April 3	1A	7.30 ...	" Nore light	454	Not estimated.
	2A	8	" Mouse light	1,220	1 c.c. of water.
	3A	8.20 to 8.55	Between Nos. 10 and 6 buoys ...	500	$\frac{1}{10}$ c.c. "
	4A	8.55 to 9.20	" 6 and 2 " ...	4,150	" "
	5A	9.30 to 10	" 1 and 5 " ...	200	" "
	6A	10 to 10.25	" 5 and 7 " ...	400	" "
	7A	10.55 ...	Abreast the Mouse light	115	1 c.c.

(*b*) The next series of samples was collected during periods of 6 hours at the entrance to the Barrow Deep. Single samples were taken at low water and at high water, and between those times samples were taken every 5 minutes and were mixed together every hour to form the average or compound samples for each hour. The samples thus collected represented the water which leaves the Barrow Deep during a flood tide and enters the river, since the collection extended over the whole period of the incoming tide. The points at which these samples were collected were—

(1.) 150 yards west of the Mid-Oaze buoy.

(2.) At the point where a line drawn from the Nore light vessel to the West Oaze buoy crosses a line drawn from the Cant buoy to the south Shoebury buoy.

The following table shows the results of these bacterial estimations—

TABLE 6. *Number of Bacteria in the Water of the Thames Estuary.*

Date of sampling, and position at which samples was taken. 1903.	Time of sampling. Except at high and low water, the samples were collected every five minutes and mixed together for the hourly samples.	Total number of bacteria per cubic centimetre of water.	Tests for Bacillus coli (intestinal bacteria). The cultivations in the following media were incubated for 48 hours at 37° C. (blood heat). A positive result indicates the presence of organisms of the coli group.						Test for Bacillus enteritidis sporogenes in one cubic centimetre of water.
			Cultivations made in "litmus milk."		Cultivations made in "neutral red broth."		Cultivations made in "bile salt broth."		
			With 1 cubic centimetre of water.	With $\frac{1}{10}$ cubic centimetre of water.	With 1 cubic centimetre of water.	With $\frac{1}{10}$ cubic centimetre of water.	With 1 cubic centimetre of water.	With $\frac{1}{10}$ cubic centimetre of water.	
9th April. 150 yards west of the Mid Oaze buoy	Low water 4.30 p.m.	304	Acid and clotting produced	Acid and clotting produced	Changed to greenish yellow	No change	Acid, microbic growth and gas produced	No change	Organism absent.
	4.30 p.m. to 5.30 p.m.	251	do. ...	do. ...	do. ...	do.	No change ...	do.	" "
	5.30 " 6.30 "	347	do. ...	No change ...	No change ...	do.	Acid and growth	do.	" "
	6.30 " 7.30 "	677	do. ...	do. ...	do. ...	do.	No change ...	do.	" "
	7.30 " 8.30 "	836	do. ...	Slight clotting produced	Trace of greenish yellow	do.	do.	do.	" "
	8.30 " 9.30 "	672	do. ...	Acid and clotting produced	No change ...	do.	do.	do.	" "
	9.30 " 10.30 "	519	do. ...	No change ...	Trace of greenish yellow	do.	Acid, growth and gas	do.	" "
	High water 10.30 "	164	do. ...	do. ...	No change ...	do.	do.	do.	" "
10th April. Point where line between Nore light vessel and West Oaze buoy crosses line between Cant buoy and South Shoebury buoy	Low water 5.40 "	361	do. ...	Acid and clotting produced	Change to greenish yellow	do.	Acid and growth	do.	" present
	5.40 p.m. to 6.40 p.m.	646	do. ...	No change ...	do. ...	do.	Lost	do.	" absent.
	6.40 " 7.40 "	397	do. ...	do. ...	Slight greenish yellow	do.	Acid and growth	do.	" "
	7.40 " 8.40 "	381	do. ...	do. ...	Change to greenish yellow	do.	do.	do.	" "
	8.40 " 9.40 "	697	do. ...	Slight clotting produced	do.	do.	Acid, growth and gas	do.	" present.
	9.40 " 10.40 "	315	Acid produced	No change ...	do.	do.	do.	do.	" absent.
	10.40 " 11.40 "	309	Acid and slight clotting	do. ...	Trace of greenish yellow	do.	No change ...	do.	" "
	High water 11.40 p.m.	373	No change ...	do. ...	No change ...	do.	do. ...	do.	" "

(*c*) A series of samples was also collected in the open North Sea in the neighbourhood of the Galloper light vessel, which is about 25 miles distant from the sea end of the Barrow Deep. These samples were taken every five minutes for two hours, and the samples taken during each half-hour were mixed together. In this way were obtained four average or compound samples.

The results of the bacterial examination of these samples is set forth in the following table—

TABLE 7. *Number of Bacteria in the Water of the North Sea.*

Date of sampling and position at which samples were taken. 1903.	Time of sampling. The samples were collected every five minutes and mixed together for the half hourly samples.	Total number of bacteria per cubic centimetre of water.
11th April. In the neighbourhood of Galloper light vessel.	5.5 a.m. to 5.35 a.m....	215
	5.35 „ 6.5 „	191
	6.5 „ 6.35 „	357
	6.35 „ 7.5 „	298

A further examination was made of the water, mud and sands of the Thames estuary in the vicinity of the Barrow Deep from Monday the 31st of August until Saturday, the 12th of September, 1903. It was found impossible, on account of serious stress of weather, to carry out the sampling in the time originally proposed, and a second visit to the estuary was therefore made from the 28th of September to the 1st of October, 1903.

On the 31st of August the s.s. *Burns*, on which the collection and examination of the samples were made, conveyed and discharged a cargo of sludge in the Barrow Deep in the usual way; but on the 28th of September the cargo conveyed by the vessel was discharged immediately before the examination was commenced, and the samples of water were collected in the area of the discharge.

The examinations during September were made with a view to supplementing the results of the examinations of the water of the lower river and of the Thames estuary made during March and April, 1903. On that occasion, the bacterial condition of the surface water only was investigated, but during September the examination was extended to the bacterial condition of the surface and bottom water, of the bed of the estuary, and of the sands which are uncovered at low water.

On the 28th of September, 1903, the s.s. *Burns* anchored in the Barrow Deep, and at low water discharged her cargo of sludge as quickly as possible. To indicate the course traversed by the sludge, a drifter in the form of a cross, and having an area of about eight square feet, was suspended by a fine copper wire from a float, which was small in area compared with the drifter in order to neutralise the effect of wind and sea. The drifter was suspended at a depth of 10 feet from the surface. Throughout the experiment, samples of sea water were taken from a boat which followed the float within two or three yards. The samples were obtained from depths of 10 feet and 40 feet by means of a small hand-pump, to which was attached a flexible hose weighted at the end. The pump was kept at work continually throughout the experiment, and samples were taken every five minutes. These were afterwards mixed so as to produce hourly average samples.

After the sludge had been discharged, the float was placed in the centre of the discoloured area. Samples were taken immediately from the surface, and at 10 feet and 40 feet depths from the surface. The subsequent samples were mixed together so as to produce hourly average samples.

On 29th September this experiment was repeated, the sampling being carried out from the deck of the s.s. *Burns* instead of from a small boat. The ship kept within the area of the sludge which had been discharged by the five other steamers, until the discolouration of the sea-water by the sludge had entirely disappeared.

Methods of sampling.

(*a*) Samples of the bottom were obtained by means of an iron dredge with a canvas bag attached. This dredge had been successfully used on many previous occasions. The average quantity of sample brought up by the apparatus was about 2 cwt., and the working sample consisted of an average taken throughout the mass. In many cases where the bottom was hard a sample was only obtained after several unsuccessful attempts. In the case of samples taken in the Barrow Deep, where the ground was most thoroughly searched, the working sample was made up of averages from several dredgings.

(*b*) Each sample from sands exposed at low water represented sand taken over a considerable area. Roughly 50 samples were collected from just below the surface and from the surface in each case, and these were thoroughly mixed in order to produce the average sample for examination.

(*c*) Samples of water were taken from the surface in a well-washed bucket. At the same time samples were taken at or near the bottom in an apparatus which consisted of a sterilised 8-ounce wide-mouthed glass bottle, with an indiarubber bung. The bottle was enclosed in a heavy cage, which acted as a sinker. A short glass tube, terminating just below the bung, and a longer one reaching to the bottom of the bottle, were each drawn out, bent into a loop and sealed. The end of a fine line was fastened to the two loops. The apparatus having been lowered to the bottom by two strong lines, which were held at a wide angle to avoid twisting, the fine line was jerked in order to break the ends of the glass tubes. The bottle was allowed to remain on the bottom for five minutes. This was found by experiment to be ample time to fill the bottle.

Methods of working.

(*a*) The s.s. *Burns* having been fully fitted with incubators, air and steam sterilisers and other apparatus necessary for the investigation, the work was all done on board. It is important to note in judging the results that the cultivation of each sample was made as soon as the sample had been collected: this was rendered possible by the fact that the ship itself was the laboratory, and no delay in transit from the point of collection to the laboratory was therefore incurred. In this work, dealing with unknown and largely varying numbers of micro-organisms, it was necessary to use a larger number of dilutions in laying down the samples than would have been the case had an approximate idea of the numbers present been known.

(*b*) Dr. Houston's method of decimal dilution was employed. Ten grammes of the sample were added to 90 cubic centimetres of sterile distilled water contained in a plugged conical flask of about 200 cubic cemtimetres capacity, and the liquids were thoroughly mixed. Ten cubic centimetres of this 10 per cent. mixture were added to another flask containing 90 cubic centimetres of sterile water, giving a 1 per cent. mixture; a similar procedure was continued to obtain higher dilutions.

(*c*) The total number of organisms was obtained by mixing 1 cubic centimetre of each of four dilutions ($\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$ and $\frac{1}{10000}$) with 10 cubic centimetres of gelatine medium, pouring each gelatine mixture into a Petri dish, incubating at 20° C. and counting as late as liquefaction of gelatine would allow.

(*d*) *Bacillus Coli Group*—Primary broth cultures were made by adding 1 cubic centimetre of varying dilution to 10 cubic centimetres of flesh peptone broth and incubating at 37° C. for 48 hours. Secondary cultures of those tubes showing growth and diffuse cloudiness were then made on the surface of Bile Salt Agar previously poured and set in Petri dishes. These latter were incubated at 37° C. for 48 hours. Plates showing a growth typical of coli had colonies sub-cultured in "gelatine shake" and litmus milk as confirmatory tests.

(*e*) Organisms causing *Bacillus Enteriditis* change in anaërobic milk cultures.—One cubic centimetre of each of the various dilutions was introduced into a freshly-prepared tube containing 10 cubic centimetres of sterile milk. Immediately before inoculation the tube was boiled to expel dissolved oxygen. After inoculation all the tubes were maintained at 80° C. for 10 minutes, cooled and then incubated for 48 hours at 37° C. under anaërobic conditions.

Statement and tabulation of results.

The following table shows the results of the bacterial examination of the water of the Barrow Deep at various depths immediately, and at stated periods, after the discharge of sludge by the Council's steamers—

TABLE 8. *Examination of the Water of the Barrow Deep.*

DATE. 1903.	Period of time after the discharge of sludge when the samples of water were collected.	Total number of bacteria per cubic centimetre of water at the following depths.		
		Surface.	10 ft.	40 ft. or bottom.
Sept. 28th ...	Immediately	940,000	13,000	140
	One hour, average...	32,700	2,910	690
	Two hours, „	1,470	790	320
	Three „ „	340	140	130
	Four „ „	380	220	—
Sept. 29th ...	Immediately	8,000	2,000	—
	One hour, average...	21,400	580	—
	Two hours, „	6,200	700	—
	Three „ „	5,800	610	—
	Four „ „	5,300	610	—
	Five „ „	1,700	500	—

The hourly average samples were, as already pointed out, composed of samples taken every five minutes during the hour.

Table 9 sets forth the results of the bacterial examination of samples of water taken from other parts of the estuary, and also of samples of mud and other materials taken from the bottom of the estuary, and of sand exposed thereon at low tide.

No bacterial examination of the estuary approaching in completeness and trustworthiness that which is herewith reported has ever been undertaken. The work on board the steamer extended over 18 days, and was completed on shore in about six weeks. Five members of the chemical staff were continually engaged in the work of collecting samples and of bacterial examination. No less than 555 samples in all were taken from the water at different depths, from the bottom and from the uncovered sands of the estuary. Some of the samples collected over a particular area were, however, mixed before the examination was made, and accordingly 119 samples were submitted to individual examination.

General conclusions.

A general survey of these tabulated results proves that, with the exception of one sample taken in the centre of the Barrow Deep, all the samples taken in the estuary were bacterially better than those taken in the river between the Chapman Lighthouse and the Nore Light-vessel. Proceeding downwards from the Chapman, the samples became constantly bacterially better until the centre of the Barrow Deep was reached. The channel north of the Barrow Deep (The Swin) was found to be quite clean, and was, bacterially, in a very good condition; and the same can be said of the southern channels, including the Black Deep, the Oaze Deep, and the Prince's and Duke of Edinburgh channels. In fact, it is not too much to say that the area in the immediate neighbourhood of the Barrow Deep showed no bacterial evidence of sludge. Even the worst sample in the Barrow Deep itself can only be considered to have contained a trace of sludge deposit when it is remembered that sludge itself contains on an average 125 millions of bacteria per gramme.

The results of the experiments made to ascertain the extent of the diffusion or dispersal of the sludge, when considered in conjunction with the results of the examination of both the sea water and the sea bottom in and around the Barrow Deep, show that the present method of disposing of the sludge by discharging it whilst steaming eight or ten miles to No. 1 buoy, on an ebb tide, is a very satisfactory one, and cannot give rise to any pollution of the foreshores of Kent or of Essex. If pollution of the foreshores arises, it must therefore be due to local causes only, since it has now been shown that it does not arise from the discharge of the London effluent or sludge.

The positions at which these samples were collected and the results of the examination of the samples are indicated on the charts which follow Table 9. The charts are printed so that vertical lines run north and south; the direction of magnetic north and south therefore makes an angle of about 15° to the west with the vertical.

The above results do not appear astonishing when it is remembered that the Barrow Deep, into which the sludge is discharged, consists of a mass of water 10 miles in length and 2 miles in breadth, and on the average 60 feet in depth. The dilution of the sludge must therefore be immensely great, and the bacterial results show that by the time the tide begins to flow towards the river the sludge has practically disappeared from the water of the estuary.

TABLE 9. *Examination of the Water, Mud and Sands of the Thames Estuary.*

Date and time of collection of sample. 1903.	No. of sample.	Locality and bearings of point at which sample was collected.	State of tide.	Character of sample.	Total number of bacteria growing in gelatine per gramme or per cubic centimetre of the sample.	Dilution of sample in plate selected for counting.	Number of organisms belonging to B. Coli group per gramme or per cubic centimetre of the sample.	Number of organisms causing "enteritidis" change in anaerobic milk culture.	Tests for B. Coli Communis Group.										"B. Enteritidis Sporogenes" change in anaerobic milk culture.			
									Uniform turbidity in primary broth culture at 37° C.						Secondary Bile Salt Agar.		Confirmatory.					
									Crude.	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{1,000}$	$\frac{1}{10,000}$	$\frac{1}{100,000}$	Typical.	Not typical.	Litmus milk, a = acidity, c = clot.	Gelatine "shake" Gas present (+).	Crude.	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{1,000}$
September 1— 9.35 a.m.	1	At Chapman Light...		Dark sand and shells—trace of mud	47,000	1000	1000	100		+	+	?			$\frac{1}{1000}$		a.c.	—		+	+	
9.45 "	2	In mid-stream, Chapman and E. Blyth Buoy in line		Dark sand and cinders ...	17,000	1000	100	abs. in $\frac{1}{10}$ c.c.		+	+	—			$\frac{1}{100}$		a.c.	+		—	—	
10.10 "	3	At East Blyth Buoy		Very fine sand and mud	58,000	1000	1000	100		+	+	+			$\frac{1}{1000}$		a.c.	—		+	+	
11.0 "	4	At Jenkin Buoy		Black mud	42,000	1000	1000	10		+	+	?			$\frac{1}{1000}$		a.c.	—		+	—	
11.20 "	5	50 yards S. of East River Middle Buoy		Dark sand...	32,000	1000	1000	10		+	+	+			$\frac{1}{1000}$		a.c.	—		+	—	
11.30 "	6	200 yards S. of Southend Pierhead		" "	2,300	100	100	10		+	+	—			$\frac{1}{100}$		a.c.	+		+	—	
0.5 p.m.	7	At Mid Shoebury Buoy		" "	15,000	1000	100	10		+	+	?			$\frac{1}{100}$	$\frac{1}{1000}$	a.c.	+		+	—	
0.15 "	8	In mid-stream, Mid Shoebury Buoy and Nore in line		Sand and mud	24,000	1000	1000	abs. in $\frac{1}{10}$ c.c.		+	?	?			$\frac{1}{1000}$		a.c.	—		—	—	
0.30 "	9	At the Nore Light		" "	47,000	1000	1000	100		+	+	+			$\frac{1}{1000}$		a.c.	—		+	+	
September 2— Noon ...	10	Garrison Point and Grain Fort in line	¼ ebb	Surface water	230	10	1	abs. in 1 c.c.	+	+	—				crude	$\frac{1}{10}$	a.c.	—	—	—		
" ...	11	" "		Bottom "	487	crude	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
1.10 p.m.	12	½ mile E. of Nore Sand By. Nore Lt. and Nore Sand By. in line	4 hrs. ebb	Surface "	864	"	1	" "	+	—	—				crude		a.c.	—	—	—		
" "	13	" " " " " " " ...		Bottom "	198	"	10	" "	+	+	—				$\frac{1}{10}$		a.c.	—	—	—		
2.30 "	14	Southend Pierhead N.N.E.; Chapman N.W. by W. ½ W. ...	5½ hrs. ebb	Surface "	117	"	10	" "	+	+	—				$\frac{1}{10}$		a.c.	—	—	—		
" "	15	" " " " " ...		Bottom "	84	"	10	" "	+	+	—				$\frac{1}{10}$		a.c.	—	—	—		
3.20 "	16	At Chapman Light	Last of ebb	Surface "	189	"	10	" "	+	+	—				$\frac{1}{10}$		a.	+	—	—		
" "	17	" "		Bottom "	213	"	10	" "	+	+	—				$\frac{1}{10}$		a.c.	—	—	—		
3.35 "	18	At East Blyth Buoy	Low Water	Surface "	245	"	10	" "	+	+	—				$\frac{1}{10}$		a.c.	—	—	—		
" "	19	" "		Bottom "	221	"	10	" "	+	+	—				$\frac{1}{10}$		a.c.	—	—	—		
September 3— 10.10 a.m.	20	Nore and Mouse Lts. in line, Upper Admiralty & Cant. Bys. in line		Fine sand and mud ...	26,300	100	1,000	10			+	+	+		$\frac{1}{1000}$	$\frac{1}{10000}$	a.c.	+		+	—	—
10.25 "	21	Nore & Mouse Lts. in line, Lower Admiralty & W. Oaze Bys. in line		Coarse " " ...	6,200	100	100	abs. in $\frac{1}{10}$ c.c.			+	—	—		$\frac{1}{100}$		a.c.	—		—	—	—
10.50 "	22	At West Oaze Buoy		Coarse clean sand ...	1,600	100	abs. in $\frac{1}{100}$ c.c.	" "			— ?	—	—			$\frac{1}{100}$				—	—	—
11.5 "	23	Mouse Lt. & W. Oaze By. in line, E. Oaze just open N. of N. Oaze By.		Fine sand and mud ...	28,600	100	1,000	10			+	+	—		$\frac{1}{1000}$		a.c.	—		+	—	—
11.25 "	24	At North Oaze Buoy		Coarse sand and shells ...	7,300	100	100	abs. in $\frac{1}{10}$ c.c.			+	—	—		$\frac{1}{100}$		a.c.	—		—	—	—
11.36 "	25	" East Oaze Buoy...		Clean coarse sand ...	1,800	100	abs. in $\frac{1}{100}$ c.c.	" "			— ?	—	—			$\frac{1}{100}$				—	—	—
0.10 p.m.	26	" Mouse Light		Sand and a little mud ...	15,700	100	100	10			+	+	—			$\frac{1}{1000}$				+	—	—
0.50 "	27	" Blacktail Spit Buoy		Fine sand, mud and shells	7,900	100	100	10 (? 100)			+	—	—		$\frac{1}{100}$		a.c.	—		+	?	—
1.15 "	28	" Lower Admiralty Buoy		Fine sand and shells ...	7,500	100	100	10			+	—	—		$\frac{1}{100}$		a.	—		+	—	—
1.45 "	29	" South Shoebury Buoy		" " mud ...	2,000	100	100	abs. in $\frac{1}{10}$ c.c.			+	—	—		$\frac{1}{100}$		a.c.	—		—	—	—
September 4— 11.15 a.m.	30	In the Barrow Deep— Between N. Knob Buoy and No. 7 Buoy. Average of 3 dredgings		Sand, clay and black mud	3,000	1,000	abs. in $\frac{1}{1000}$ c.c.	" $\frac{1}{100}$ c.c.				—	—	—		$\frac{1}{1000}$					—	—
11.45 "	31	" No. 7 Buoy and No. 8 Buoy		Fine sand and silt ...	6,000	1,000	100	100			+	?	—	—							+	—
0.40 p.m.	32	" " 8 " " " 5 " Average of 2 dredgings...		" " mud ...	15,000	1,000	abs. in $\frac{1}{1000}$ c.c.	100				—	—	—		$\frac{1}{1000}$					+	—
1.5 "	33	" " 5 " " " 6 "		Sand, with a little clay...	16,000	1,000	1,000	abs. in $\frac{1}{100}$ c.c.				+	—	—	$\frac{1}{1000}$		a.c.	—			—	—
3.30 "	34	" " 6 " " " 3 " Average of 2 dredgings...		Sand and sludge	141,000	1,000	1,000	" "				+	+	—	$\frac{1}{1000}$	$\frac{1}{10000}$	a.c.	+			—	—
1.55 "	35	" " 3 " " " 4 " " 3 " ...		" " mud	28,000	1,000	1,000	" "				+	—	—	$\frac{1}{1000}$		a.c.	—			—	—
2.20 "	36	" " 4 " " " 1 " " 2 " ...		" with a trace of mud	abs. in $\frac{1}{1000}$ c.c.	1,000	abs. in $\frac{1}{1000}$ c.c.	" "				—	—	—							—	—
2.45 "	37	" " 1 " " " 2 " " 3 " ...		" " "	9,000	1,000	1,000	" "				+	—	—	$\frac{1}{1000}$	$\frac{1}{10000}$	a.c.	+			—	—
September 5— 5.55 a.m.	38	E. of E. Redsand By., Girdler Lt. S.E. ½ S., Shivering Sand By. E. by S.		Clay and shells	1,700	100	100	10		+	+	+			$\frac{1}{100}$	$\frac{1}{1000}$	a.c.	—		+	—	—
6.20 "	39	West of Redsand By., Mouse Lt. N.N.W., East Oaze By. N.E. ½ E.		Sand and mud	7,000	1000	100	10		+	+	+			$\frac{1}{100}$	$\frac{1}{1000}$	a.c.	+		+	—	—
6.35 "	40	½ mile W.S.W. of Middle Oaze Buoy...		Sand, mud and shells ...	1,000	100	100	10		+	+	—			$\frac{1}{100}$		a.c.	—		+	—	—
6.45 "	41	Just N. of E. Spile By., Mouse Lt. N.E. by N., W. Oaze By. N.W. ½ N.		Stiff clay	400	100	10	abs. in $\frac{1}{10}$ c.c.		+	+	—			$\frac{1}{10}$	$\frac{1}{10}$	a.c.	+		—	—	—
7.5 "	42	Just N. of E. Cant By., Mouse Lt. E. by N. ½ N., Upper Admiralty B. N. by E.		Sand and mud	7,000	1000	100	100		+	?	—			$\frac{1}{100}$		a.c.	—		+	+	—
7.20 "	43	Just N. of Cant By., Nore Lt. N.W. by W. ½ W., S. Shoebury By. N.N.E.		" "	13,000	1000	1000	100		+	?	?			$\frac{1}{1000}$		a.c.	—		+	+	—
7.35 "	44	Just N. of Middle Cant By., Nore Lt. N. ½ W., Cant Edge By. W. by S.		Broken shells and coarse sand	260	10	10	abs. in $\frac{1}{10}$ c.c.		+	—	—			$\frac{1}{10}$		a.c.	—		—	—	—
7.55 "	45	Off Cant Edge By., Nore Lt. & Garrison Point in line, Cant Edge By. E. by S.		" "	5,700	100	100	" "		+	+	—			$\frac{1}{100}$		a.	—		—	—	—
8.5 "	46	Off W. Cant By., Grain Edge By. and Roman Catholic Church in line, Nore Light and Garrison Point in line		Mud and clay	6,000	100	1000	10		+	+	?			$\frac{1}{1000}$		a.	—		+	—	—
8.20 "	47	Off Sheerness, Martello Tower and Garrison Point in line, Queenborough Pierhead S. by W. ½ W.		" "	1,100	100	100	100		+	+	+			$\frac{1}{100}$	$\frac{1}{1000}$	a.c.	—		+	+	—

TABLE 9. (*continued*).

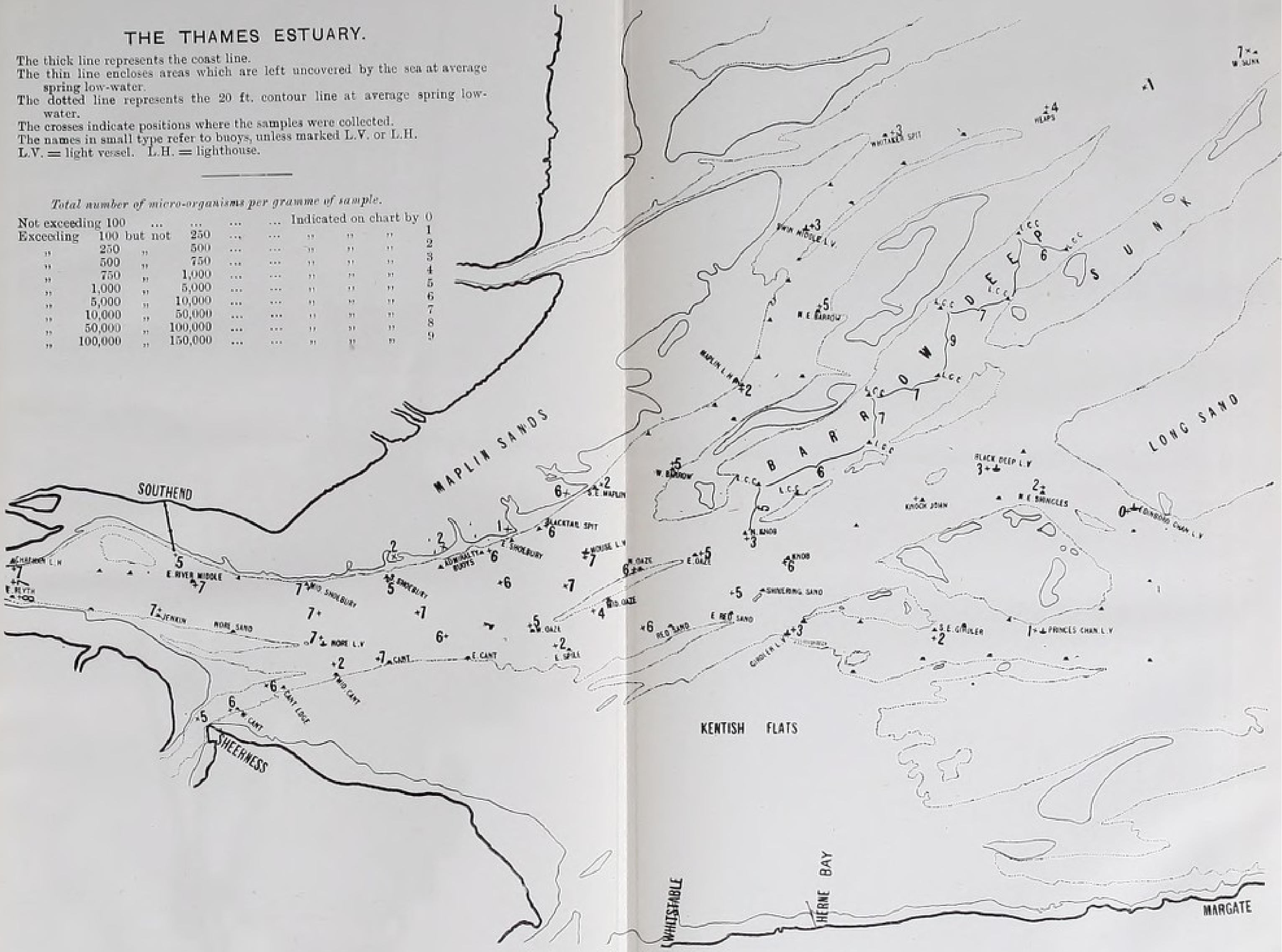
Date and time of collection of sample. 1903.	No. of sample.	Locality and bearings of point at which sample was collected.	State of tide.	Character of sample.	Total number of bacteria growing in gelatine per gramme or per cubic centimetre of the sample.	Dilution of sample in plate selected for counting.	Number of organisms belonging to B. Coli group per gramme or per cubic centimetre of the sample.	Number of organisms causing "enteritidis" change in anaërobic milk culture.	Tests for B. Coli Communis Group.										"B. Enteritidis Sporogenes" change in anaërobic milk culture.			
									Uniform turbidity in primary broth culture at 37° C.						Secondary Bile Salt Agar.		Confirmatory.					
									Crude.	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{1,000}$	$\frac{1}{10,000}$	$\frac{1}{100,000}$	Typical.	Not typical.	Litmus milk, a = acidity, c = clot.	Gelatine "shake" Gas present (+).	Crude.	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{1,000}$
September 7— 11.15 a.m.	48	At North Knob Buoy		Sand and mud	700	100	10	abs. in $\frac{1}{10}$ c.c.		+	—	—			$\frac{1}{10}$		a.	—		—	—	—
11.30 "	49	" Knob Buoy		Clay, sand and shells ...	6,600	100	1000	" "		+	+	?			$\frac{1}{1000}$		a.c.	+		—	—	—
0.10 p.m.	50	" Knock John Buoy (four dredgings yielded no result) ...		Hard bottom—no sample	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0.50 "	51	" Black Deep Light Vessel...		Sand and clay	530	10	100	abs. in $\frac{1}{10}$ c.c.			+	?			$\frac{1}{100}$	$\frac{1}{1000}$	a.c.	+		—	—	
1.10 "	52	" North-East Shingles Buoy		Coarse clean sand ...	410	10	100	10			+	—			$\frac{1}{100}$		a.c.	+		+	—	
1.40 "	53	" Edinburgh Channel Light Vessel...		Sand and shells	60	10	abs.	abs. in $\frac{1}{10}$ c.c.			+	—				$\frac{1}{100}$				—	—	
2.40 "	54	" Prince's " "		Clean sand	160	10	10	" "		+	—	—			$\frac{1}{10}$		a.c.	—		—	—	
3.5 "	55	" South-East Girdler Buoy		Sand and a little mud ...	350	10	100	" "		+	+	—			$\frac{1}{100}$		a.c.	—		—	—	
3.45 "	56	" Girdler Light Vessel		" " " ...	510	10	100	10		+	+	?			$\frac{1}{100}$	$\frac{1}{1000}$	a.c.	—		+	—	
September 8— 7.20 a.m.	57	At South-East Maplin Buoy		Sand and black mud ...	310	10	100	abs. in $\frac{1}{10}$ c.c.		+	+	—			$\frac{1}{100}$		a.c.	—		—	—	
7.35 "	58	" West Barrow Buoy		Sand	1,050	10	10	" "		+	+	—			$\frac{1}{10}$	$\frac{1}{100}$	a.c.	+		—	—	
7.55 "	59	" Maplin Light		Fine sand	430	10	10	" "		+	—	—			$\frac{1}{10}$		a.c.	+		—	—	
8.25 "	60	" North-East Barrow Buoy		Sand and mud	1,660	10	100	" "		+	+	—			$\frac{1}{100}$		a.c.	+		—	—	
8.45 "	61	" Swin Middle Light Vessel		Coarse sand and clay ...	670	10	10	" "		+	—	—			$\frac{1}{10}$		a.c.	+		—	—	
9.20 "	62	" Whitaker Spit Buoy		Fine sand and clay ...	530	10	10	10		+	—	—			$\frac{1}{10}$		a.c.	—		+	—	
9.55 "	63	" Heaps Buoy		Coarse sand and shells ...	910	10	10	abs. in $\frac{1}{10}$ c.c.		+	+	—			$\frac{1}{10}$	$\frac{1}{10}$	a.c.	—		—	—	
10.25 "	64	Heaps Buoy, and West Sunk Buoy in line, Gunfleet Light, N.N.E.		Clayey sand and shells ...	210	10	abs. in $\frac{1}{10}$ c.c.	" "	+	+	—	—			Crude	$\frac{1}{10}$	a.c.	—		—	—	
11.10 "	65	At West Sunk Buoy		Muddy sand, small live mussels and worms	12,200	100	100	" "	+	+	+	+			$\frac{1}{100}$	$\frac{1}{1000}$	a.	—		—	—	
September 9— 9.0 a.m.	66	200 yards south of Southend Pierhead	Low water...	Surface water	4,240	10	100	abs. in 1 c.c.	+	+	+				$\frac{1}{100}$		a.c.	—	—	—		
" "	67	" " "		Bottom "	110	10	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
10.0 "	68	" " "		Surface "	7,180	10	100	" "	+	+	+				$\frac{1}{100}$		a.c.	+	—	—		
" "	69	" " "		Bottom "	210	10	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
11.0 "	70	" " "		Surface "	240	10	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
" "	71	" " "		Bottom "	3,100	10	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
Noon ...	72	" " "		Surface "	2,800	10	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
" ...	73	" " "		Bottom "	2,350	10	1	" "	+	+	—				Crude	$\frac{1}{10}$	a.c.	+	—	—		
1.0 p.m.	74	" " "		Surface "	90	10	1	" "	+	?	—				Crude	$\frac{1}{10}$	a.c.	+	—	—		
" "	75	" " "		Bottom "	50	10	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
2.0 p.m.	76	" " "		Surface "	30	10	abs. in 1 c.c.	" "	+	—	—					crude			—	—		
" "	77	" " "	High water.	Bottom "	30	10	10	" "	+	+	—				$\frac{1}{10}$		a.c.	+	—	—		
September 10— 6.40 a.m.	78	On the Maplin Sands— Mouse Light S. ½ E., Blacktail Spit Buoy S.W. by W.		Dry sand	6,100	10	10	abs. in $\frac{1}{10}$ c.c.		+	+	—			$\frac{1}{10}$	$\frac{1}{100}$	a.c.	+		—	—	
7.30 "	79	Mouse Light S.E. by E. ½ E., East Shoebury Buoy S.S.W.		" "	240	10	abs. in $\frac{1}{10}$ c.c.	" "		+	—	—				$\frac{1}{10}$				—	—	
8.25 "	80	Mouse Light E. by S. ¼ S. Upper Admiralty Buoy S.S.W.		" "	410	10	" "	" "		—	—	—								—	—	
9.20 "	81	Nore Light S.W. ½ W., Upper Admiralty Outer Beacon E. ½ S.		" "	290	10	" "	" "		+	—	—				$\frac{1}{10}$				—	—	
September 11— 4.30 a.m.	82	Lower end of Gravesend Reach, in Higham Bight	First of ebb..	Surface water	1,120	10	100	1 (?)		+	+	—			$\frac{1}{100}$		a.c.	+	?	—		
" "	83	" " "		Bottom "	840	10	100	1		+	+	—			$\frac{1}{100}$		a. (slight)	+	+	—		
5.30 "	84	" " "		Surface "	3,730	10	1000	1 (? 10)		+	+	+			$\frac{1}{1000}$		a.c.	+	+	?		
" "	85	" " "		Bottom "	1,560	10	100	1		+	+	—			$\frac{1}{100}$		a.c.	+	+	—		
6.30 "	86	" " "		Surface "	2,710	10	1000	1		+	+	+			$\frac{1}{1000}$		a.c.	+	+	—		
" "	87	" " "		Bottom "	2,450	10	1000	10		+	+	+			$\frac{1}{1000}$		a.c.	+	+	+		
7.30 "	88	" " "		Surface "	3,420	10	1000	1 (?)		+	+	+			$\frac{1}{1000}$		a.c.	+	?	—		
" "	89	" " "		Bottom "	3,630	10	1000	abs. in 1 c.c.		+	+	+			$\frac{1}{1000}$		a.c.	+	—	—		
8.30 "	90	" " "		Surface "	3,890	10	1000	1		+	+	+			$\frac{1}{1000}$		a.c.	—	+	—		
" "	91	" " "		Bottom "	3,330	10	1000	10		+	+	+			$\frac{1}{1000}$		a.c.	+	+	+		
9.30 "	92	" " "		Surface "	4,660	10	100	1		+	+	—			$\frac{1}{100}$		a.c.	+	+	—		
" "	93	" " "	Low water...	Bottom "	3,810	10	100	1		+	+	—			$\frac{1}{100}$		a.c.	+	+	—		

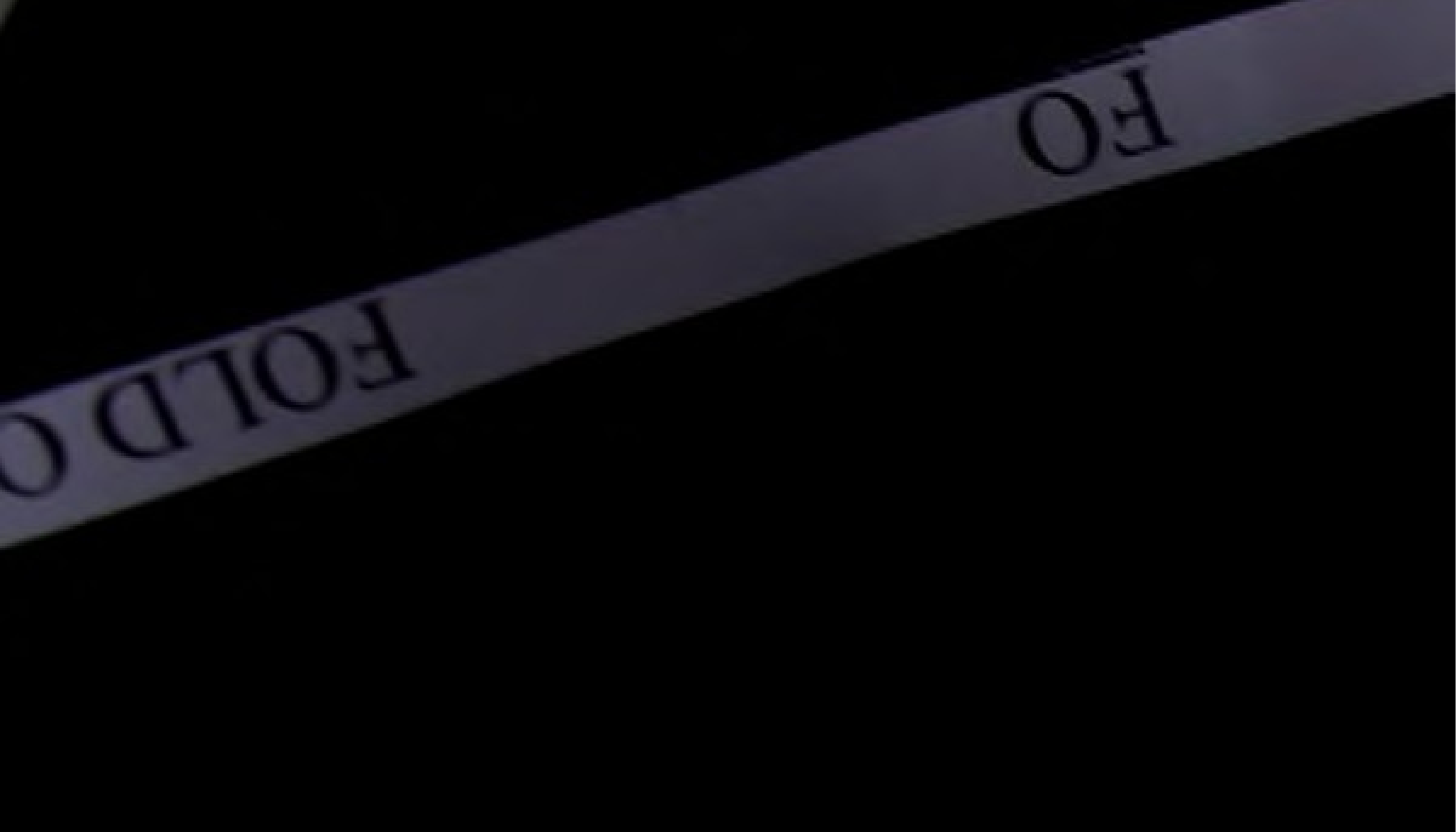
THE THAMES ESTUARY.

The thick line represents the coast line.
The thin line encloses areas which are left uncovered by the sea at average spring low-water.
The dotted line represents the 20 ft. contour line at average spring low-water.
The crosses indicate positions where the samples were collected.
The names in small type refer to buoys, unless marked L.V. or L.H.
L.V. = light vessel. L.H. = lighthouse.

Total number of micro-organisms per gramme of sample.

Not exceeding 100			Indicated on chart by	0
Exceeding	100 but not	250	,, ,, ,,	1
,,	250 ,,	500	,, ,, ,,	2
,,	500 ,,	750	,, ,, ,,	3
,,	750 ,,	1,000	,, ,, ,,	4
,,	1,000 ,,	5,000	,, ,, ,,	5
,,	5,000 ,,	10,000	,, ,, ,,	6
,,	10,000 ,,	50,000	,, ,, ,,	7
,,	50,000 ,,	100,000	,, ,, ,,	8
,,	100,000 ,,	150,000	,, ,, ,,	9

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VII. COMPARISON OF THE EFFECT OF SEA-WATER AND OF FRESH WATER UPON BACTERIAL LIFE.

Two series of experiments were made with the view of ascertaining whether sea-water had any effect upon bacterial life different from that of ordinary fresh water. In the first series 1,000 cubic centimetres of sea-water and 1,000 cubic centimetres of distilled water were sterilised, and were then separately inoculated with 1 cubic centimetre of clarified sewage. The number of bacteria present in a cubic centimetre of each of the two waters was counted immediately after inoculation, and the estimation was repeated subsequently at stated intervals. For the purpose of counting one cubic centimetre of each water was mixed with 10 cc. of gelatine medium, and the mixture was poured into a Petri-dish and incubated at 65° F. The results are entered in Table 10—

TABLE 10. *Comparison of the effect of Sea-water and of Fresh Water upon Bacterial Life.*

Date. 1903.	Time during which the water had been inoculated when the sample was taken.	Time during which the samples were cultivated in gelatine medium.	Number of bacteria per cubic centimetre	
			in the inoculated sea water.	in the inoculated distilled water.
Mar. 13...	Immediately	72 hours	8,748	7,100
„ 16...	3 days	43 „	281,000	288,360
„ 18...	5 „	45 „	531,400	421,200
„ 19...	6 „	48 „	348,000	113,000

In the second series of experiments the number of bacteria present in natural or uninoculated sea-water and in inoculated sea-water was estimated, neither of the samples of water having been previously sterilised. The inoculated sea-water contained one cubic centimetre of clarified sewage per 750 cubic centimetres of water. The number of bacteria was counted in each water immediately after the inoculation and at stated intervals afterwards. The method of counting and the temperature of incubation were the same in both series of experiments. The results are entered in Table 11—

TABLE 11. *Bacterial life in Sea-water.*

Date. 1903.	Time during which the water had been standing.	Time during which the samples were cultivated in the gelatine medium.	Number of bacteria per cubic centimetre	
			in the natural sea water (not inoculated).	in the inoculated sea water.
March 27	Immediately... ...	96 hours	1,115	11,000
„ 28	1 day...	96 „	94,250	238,000
„ 30	3 days	96 „	230	1,976,000
April 1 ...	5 „	48 „	109	2,373,600

In each experiment the number of bacteria in the inoculated sea-water and in the inoculated distilled water increased up to the fifth day after inoculation, and in the case of one of the sea-water samples and of the distilled water, the number had considerably decreased by the sixth day. The two other samples were not counted on the sixth day.

In the case of the natural or uninoculated sea-water, the number of bacteria increased on the first day, but subsequently decreased until it was reduced on the third day to a number which is not unusually found in ordinary drinking water.

The results of these experiments appear to indicate that sea-water does not exert any marked inhibitory effect upon the life of bacteria.

VIII. Determination of Maximum Solubility of Atmospheric Oxygen in Water of Different Degrees of Salinity.

In connection with the aëration estimations of the river water which are referred to on p. 212, it was considered advisable to determine what effect the presence of sea water in the lower river and estuary had on the total amount of oxygen which the water could dissolve. Accordingly a series of determinations of the solubility of atmospheric oxygen was made, and the results are given in the following table, No. 12.

In the first column of this table the character of the water is stated. The sea-water which was used was collected in the estuary of the river Thames, and the percentage mixtures were obtained by mixing sea-water with distilled water in the requisite proportions. The dates which appear in the heading of the table refer to the days on which the estimations were made. The object of making three estimations of the same water on successive days was to ascertain whether the amount of aëration remained constant, since it was anticipated that the organic matter present in the original sea-water might at first reduce the possible aëration, but that the dissolved oxygen would eventually destroy such organic matter, and that a constant degree of aëration would ultimately be found. This appears to have been the case, since the total amount of atmospheric oxygen dissolved by distilled water, to which salt had been added until its chlorine was equal to that in the sea-water sample, was found to be practically equal to the amount found in sea-water sixteen days after its collection.

TABLE 12. *Solubility of Atmospheric Oxygen in Saline Water.*

The following results were obtained by the estimations of the amounts of dissolved atmospheric oxygen in samples of water containing known proportions of chlorine as sodium chloride. The results are stated as percentages of the amount dissolved by an equal volume of distilled water under similar conditions—

Character of water.	22-23 December, 1903. Temperature of water, 16° C.		1-2 January, 1904. Temperature of water, 13·8° C.		6-7 January, 1904. Temperature of water, 14·8° C.	
	Dissolved oxygen. Percentage.	Chlorine. Parts per 100,000.	Dissolved oxygen. Percentage.	Chlorine. Parts per 100,000.	Dissolved oxygen. Percentage.	Chlorine. Parts per 100,000.
Distilled water	100·0	0	100·0	0	100·0	0
" with 10 °/o of sea water	96·4	205	—	—	—	—
" 20 " "	94·0	395	93·4	402	95·9	394
" 30 " "	92·5	590	—	—	—	—
" 40 " "	90·3	780	91·3	781	91·2	772
" 50 " "	87·0	982	—	—	—	—
" 60 " "	83·6	1,163	86·8	1,169	88·1	1,161
" 70 " "	82·4	1,365	—	—	—	—
" 80 " "	80·7	1,555	83·7	1,560	84·7	1,555
" 90 " "	79·0	1,735	—	—	—	—
Sea water	78·1	1,950	81·1	1,950	82·2	1,950

	14 January, 1904.	
Distilled water	100·0	0
" with added sodium chloride...	82·9	1,930

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