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(Paper No. 2150.)

Water-Purification; its Biological and Chemical Basis.

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ALTHOUGH the purification of water has received much attention during the past thirty years, it is only now that the complexity of this subject is beginning to be realized.

The earliest attempts to purify water had for their object simply the clarification of the liquid, *i.e.*, the removal of suspended particles visible to the naked eye. In this purification there was

no endeavour to remove dissolved matters, and suspended particles invisible to the naked eye were not then thought of. It cannot be doubted that, in most cases, this primitive conception of water-purification has still been retained, the sole idea of the operator being to produce a liquid clear and sparkling to the eye.

The advances of chemical science caused attention to be paid to the matters present in water in the state of solution, and more particularly to those of an organic nature. In the first place, it was supposed that organic substances were capable of imparting alteration and decay to other organic substances with which they were placed in contact; this being the theory of fermentation advanced by Liebig. Thus Liebig conceived that ordinary alcoholic fermentation was brought about not by the living and growing yeast, but by the dead yeast-cells undergoing decomposition. As long as this theory was the accepted doctrine of the day, it was not surprising to find chemists attaching great importance to the organic matter in water which analysis revealed, and which was known to have been derived from decomposing vegetable and animal substances with which the water had been in contact. It was naturally supposed that such decomposing organic matter in water would tend to set up putrefactive and other injurious changes in the digestive organs through which it passed.

The theory, or rather dogma, of fermentation enunciated by Liebig, was soon broken down by the classical researches of Pasteur, by whom it was shown that the processes of fermentation and putrefaction were due not to decomposing organic matter, but to living organisms, and that living organisms were also certainly the cause of some and probably of all zymotic diseases. Under these circumstances, the organic matter present in water came to be viewed in a different light, and instead of being regarded as in itself unwholesome, it could now only be taken as affording more or less evidence of the possible presence of organisms, endowed with virulent properties. As it was further established beyond doubt, by bitter practical experience, that certain zymotic diseases—notably typhoid fever and cholera—could be communicated by means of sewage-polluted water, the chemical examination of water was prosecuted with a view of ascertaining the presence or absence of such contamination by means of the organic matter which the water was found to contain. Through refinement in the processes of chemical analysis it has, moreover, been rendered possible to discriminate with a very considerable degree of certainty between organic matter of vegetable, and that of animal origin. The detection of animal matter in water was not

supposed to carry with it *ipso facto* the certainty of danger, but in the absence of any precise knowledge concerning those organisms which produce zymotic disease, the presence of such animal matter obviously indicated the possibility of danger.

It is thus seen that in this second stage of progressive knowledge, the purity of water was at first gauged merely from a chemical point of view, and that afterwards, through the researches of Pasteur and others, it came to be understood that chemical purity was really of less importance than biological purity; but owing to the absence of any satisfactory means of examining waters biologically, the chemical standard was the only one by which they could be judged.

Under these circumstances, it was natural that means should be devised to render water as chemically pure as possible, on the assumption that the conditions which tended to improve the chemical quality, would similarly affect it biologically. This is essentially the period of the late Rivers Pollution Commission, in which so many methods of water- and sewage- purification are fully discussed by the light of chemical analysis. In these discussions, the importance of the biological side of the subject is fully recognized, but owing to the absence of any reliable methods at that time, the examination was not pursued in this direction.

It is to the vastly improved methods of biological examination that the only great step which has been made in the knowledge of the purification of water since the researches of the last Commission is to be attributed. These methods of biological examination, which are largely due to the genius of Dr. Robert Koch, of Berlin,¹ enable the merely chemical investigation of the subject of water-purification to be supplemented in a manner that was never possible before.

This method of examination is based upon principles of such exquisite simplicity, that a very brief description will suffice to render it intelligible.

The microscopic living particles known as "micro-organisms," or "microphytes," which it is the object of a biological examination to study, possess such an astonishing power of rapid multiplication when they are placed in a medium fitted for their growth, that within a very short period of time it becomes impossible to form an opinion as to the number of original organisms from which the vast population is descended.

Thus, if such micro-organisms be distributed throughout a medium suitable for their multiplication, and if each individual

¹ Mittheilungen Kaiserl. Gesundheitsamt, 1882.

organism be then immediately deprived of the possibility of movement, the number of colonies arising from the multiplication of these isolated individuals indicates the number of organisms introduced, whilst, by the nature of the colonies formed, the kinds of organisms of which the original importation consisted may be ascertained.

If the conditions here indicated can be complied with, it is obvious that all the means are at hand for determining the effect of any method of water-treatment upon these lowest forms of organic life. This imprisonment, so to speak, of each individual and its subsequent progeny, which is thus the key to the whole problem, can be readily effected by adding to a nutritive liquid, such as extract of meat, a sufficient quantity of gelatine to render the whole solid at the ordinary temperature. The process consists, in short, in taking a known volume, *e.g.* 1 cubic centimetre of water, and mixing it with a quantity of such nutritive gelatine, that has been melted at the temperature of the hand, and then pouring the mixture upon a glass plate on which it sets in the course of a few minutes to a solid mass. The plate is placed under a glass-cover, so as to protect it from dust, and is kept at a temperature of about 20° to 25° Centigrade. In the course of from three to five days the colonies, each originating from a single organism, attain such dimensions that they may be recognized and counted with the naked eye or by means of a microscope of low magnifying power.

It is thus evident that the purification of water must now be regarded from two distinct points of view—the chemical and the biological—and that whereas formerly the biological side was almost wholly of a speculative character, it is now nearly, if not quite, as tangible as the chemical side. Thus, perhaps a concrete example will most clearly illustrate how the purification of water should be regarded. Supposing that water, derived from a source which is altogether unimpeachable as regards contamination with animal matters, is yet so highly impregnated with vegetable constituents as to be objectionable for drinking-purposes, the question will arise how this water may be treated so as to render it suitable for domestic supply. In a case of this kind it is obvious that chemical purification will be of paramount importance, whilst the removal of organic life from the water will be of less pressing consequence. On the other hand, if water, which is known to have received sewage matters is to be supplied for dietetic use, and if this water, as is so often the case, is not objectionable on account of the absolute quantity of organic matter which it con-

tains, but only because of the suspicious origin of a part of this organic matter, then it is evident that in the purification of such water the point to be taken primarily into consideration, is how the organic life it contains can be reduced to a minimum.

In estimating the value of such processes of purification, it has hitherto been customary to assume that those processes which effect the greatest chemical improvement in water may also be safely considered to be biologically the most excellent; and conversely, that those processes which effect little or no reduction in the proportion of organic impurity are not calculated to be of any service in removing organized matters.

In the experiments which the Author has for some time been conducting on the removal of micro-organisms from water, the first results of which he communicated to the Royal Society in May 1885,¹ he has found that this assumed law, or at least its converse, is very far from being correct. Thus the Author discovered that some materials were capable of filtering out all the organisms in water without appreciably altering its chemical composition.

The Author's inquiry into the chemical and biological purification of water may be conveniently considered under four heads:—

1. Purification by filtration.
2. Purification by agitation with solid particles.
3. Purification by precipitation.
4. Purification by natural agencies.

I. PURIFICATION BY FILTRATION.

Until the method of water-examination by gelatine-culture was devised, there were no available means by which the relative efficiency, for the removal of micro-organisms, of different filtering materials could be estimated on a quantitative basis.

The Author has submitted to examination, as regards their efficiency in this respect, a number of filtering materials, employing in all cases equal thicknesses of the various substances, which were also prepared in the same state of division. The filtering stratum was constructed exactly 6 inches in depth, and the filtering material was, with a few exceptions, made to pass through a sieve of 40 meshes to the linear inch. The results obtained in these experiments were:—

¹ Proceedings of the Royal Society of London, vol. xxxviii. p. 379.

Filtering material.	Efficiency.	Organisms per cubic centimetre.		Reduction per cent.	Approximate rate of filtration per square foot per hour.
		Unfiltered water.	Filtered water.		
Ferruginous green-sand (from Red-hill, Surrey).	Initial	80	..	100·0	Gallons. ..
	After thirteen days' action .	8,000	1,000	88·0	0·73
	After one month's action	1,280	780	39·0	1·14
Animal-charcoal .	Initial	Too numerous to count.	..	100·0	..
	After twelve days' action .	2,800	..	100·0	0·46
	After one month's action	1,280	7,000	Increase 447·0	0·86
Iron sponge . .	Initial	80	..	100·0	..
	After twelve days' action .	2,800	..	100·0	0·40
	After one month's action	1,280	2	99·8	0·45
Brick-dust (pulverized red brick) .	Initial	3,000	730	76·0	..
	After five weeks' action . . .	6,000	400	93·0	0·48
Coke	Initial	3,000	..	100·0	..
	After five weeks' action . . .	6,000	90	98·5	0·50

The Author has made further experiments on the efficiency of coke as a filtering material. In these experiments the filters employed were of similar construction to those already described, but an aqueous extract of garden-soil was employed instead of urine-water.

Two similar filters (a) and (b) were submitted to examination, under conditions as similar as possible:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water 26,000 organisms per cubic centimetre.

Filter (a) 0 " "

Filter (b) 0 " "

Reduction (a) = 100 per cent.

" (b) = 100 "

Approximate rate of filtration (a) = 0·89 gallon per square foot per hour.

" " (b) = 0·67 " "

AFTER THREE WEEKS' ACTION (TWENTY-FIRST DAY).

Unfiltered water : 2,230 organisms per cubic centimetre.
 Filter (a) 339 " "
 Filter (b) 219 " "
 Reduction (a) = 85 per cent.
 " (b) = 90 "

Approximate rate of filtration (a) = 1·32 gallon per square foot per hour.
 " " (b) = 1·03 " "

On comparing these latter experiments with those previously obtained, it will be seen that although the initial efficiency was in both cases the same, the greater rate of filtration which prevailed in the latter experiments caused the efficiency to deteriorate more rapidly, the filter (a), which was the most rapid, breaking down to a greater extent than the less rapid filter (b).

The unfiltered and filtered waters, respectively, were also submitted to chemical examination, at the time that the filters were exerting their greatest efficiency in the removal of micro-organisms; the results are given in the following Table, together with those obtained by the filtration of the same water through fine vegetable-charcoal, and through a mixture of fine and coarse vegetable-charcoal, respectively:—

RESULTS of ANALYSIS EXPRESSED in PARTS per 100,000.

	Unfiltered Water.	Water from Fine Coke.		Water from Fine Wood Charcoal.	Water from Coarse and Fine Wood Charcoal.
		A.	B.		
Total solids	24·80	24·60	25·00	24·68	24·64
Organic carbon	0·144	0·118	0·107	0·090	0·098
,, nitrogen	0·050	0·040	0·038	0·024	0·031
Ammonia	0	0	0	0	0
Nitrogen as nitrates and nitrites	0·190	0·209	0·202	0·221	0·217
Total combined nitrogen . .	0·240	0·249	0·240	0·245	0·248
Chlorine	1·9	1·9	1·9	1·9	1·9
Temporary hardness . . .	11·3	11·3	11·3	12·5	12·3
Permanent ,, . . .	5·6	5·6	5·6	4·6	4·6
Total	16·9	16·9	16·9	17·1	16·9

These results show that filtration through coke exerts but an

insignificant chemical action, even when the purification from a biological point of view is complete.

Vegetable-Charcoal.—The very favourable results obtained with coke led the Author to investigate the filtering power of the still more porous vegetable- or wood-charcoal. This material was also passed through the same sieve, and employed in filters of similar construction. In the first experiment urine-water was used, with the following results:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water	9,700 organisms per cubic centimetre.
Water filtered through fine charcoal	0 " "
Reduction = 100 per cent.	

Later experiments were made with an aqueous extract of soil, the following results being obtained:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water	2,898 organisms per cubic centimetre.
After filtration through fine wood- charcoal	0 " "
Reduction = 100 per cent.	

Approximate rate of filtration = 0.22 gallon per square foot per hour.

AFTER ONE MONTH'S ACTION (TWENTY-NINTH DAY).

Unfiltered water	2,230 organisms per cubic centimetre.
After filtration through wood-charcoal	107 " "
Reduction = 95 per cent.	

Approximate rate of filtration = 0.22 gallon per square foot per hour.

It is thus seen that the efficiency of the fine charcoal at the end of one month is less than that of the coke with the slow rate of filtration, but greater than that of the more rapid coke filters at the end of three weeks, the rate of filtration in the case of the charcoal being markedly less than in any of the coke experiments.

In order to obtain a more rapid charcoal filter, an intimate mixture was made of equal parts of coarse and of fine charcoal, the former having passed through a sieve of 9 wires by 30 wires to the square inch, and the latter through one of 40 meshes to the linear inch, and this was introduced into a glass tube, so as to form a stratum of filtering material 6 inches in depth. With this filter the following results were obtained:—

INITIAL EFFICIENCY (SECOND DAY).

Unfiltered water	26,000 organisms per cubic centimetre.
Filtered through coarse and fine charcoal	0 " "
Reduction = 100 per cent.	

Approximate rate of filtration = 0.26 gallon per square foot per hour.

AFTER THREE WEEKS' ACTION (TWENTY-FIRST DAY).

Unfiltered water	2,230 organisms per cubic centimetre.
Filtered through coarse and fine } charcoal	506 " "
Reduction = 77 per cent.	

Approximate rate of filtration = 0.59 gallon per square foot per hour.

Thus with wood-charcoal, when the rate of filtration approaches that through coke, the improvement, from a biological point of view, is markedly less. The effect which this material has upon the chemical composition of the water, as exhibited in the above table, is greater than that of coke, but is also not very considerable.

It has generally been supposed that most filtering materials offer little or no barrier to micro-organisms, and that the latter are capable of passing without sensible obstruction through the pores of filters containing pulverized materials. These experiments, however, show that it is extremely simple to construct filters which shall possess the power of removing micro-organisms, in the first instance at least. This power is, moreover, possessed by substances which exercise scarcely any chemical action on the organic matter present in the water, *e.g.*, coke, vegetable-charcoal, and biscuit-porcelain, as well as by those which reduce both the organic and the mineral ingredients of the water to a very marked extent, like animal-charcoal and iron.

Especially noticeable is the case of vegetable-carbon, whether in the form of charcoal or of coke; this material has been generally regarded as of but little value for water-purification, owing to its chemical inactivity, but as biological filters these substances occupy a high place, and owing to their cheapness and the facility with which they may be renewed, and profitably disposed of as fuel, they are, in the Author's opinion, destined to be of great service in the purification of water.

These materials, coke and vegetable-charcoal, are also especially well fitted for use in breweries and distilleries, where it is so necessary to have a water which, though perfectly free from organic life, is at the same time free from antiseptic substances, such as iron, which militate against fermentation. Coke has already been used, at the Author's suggestion, with marked success.

These experiments, however, show most distinctly the necessity of frequent renewal, even in the case of the best filtering materials, and this is a point which, unfortunately, is too often lost sight of.

Lastly, they furnish abundant confirmation of the principle which has been long known to waterworks-engineers, viz., that what is gained in rapidity, is lost in efficiency, and *vice versa*.

II. PURIFICATION BY AGITATION WITH SOLID PARTICLES.

This method of water-purification has recently been brought prominently before the public by Mr. W. Anderson, M. Inst. C.E., who has patented a process for agitating water with scrap-iron in a revolving cylinder. Some of the results obtained by this method have been brought before the Institution of Civil Engineers by Mr. W. Anderson¹ and Mr. G. H. Ogston, Assoc. Inst. C.E.² In this process, however, the purification is probably due almost entirely to chemical action, inasmuch as a portion of the iron passes into solution, and is subsequently precipitated in a settling-tank by contact with the air. This process is employed on a large scale at the Antwerp Waterworks, where it has superseded filtration through spongy iron; and on a large experimental scale it may be seen in operation at the Lee Bridge works of the East London Waterworks Company.

The Author has not himself examined this particular method of purification, but he has made a number of experiments in order to ascertain whether, and to what extent, the organized matters in water may be removed by agitation with finely-divided solid particles of various kinds.

It appeared probable, from the results of the filtration-experiments already described, that organized substances might be largely removed by mere contact with finely-divided matter. A series of experiments was consequently undertaken with a view to ascertain to what extent this was the case, and in some instances the reduction was found to be much greater than could have reasonably been anticipated.

In these experiments water containing micro-organisms was shaken up for a definite length of time with a given quantity of the finely-divided matter, which was used in the same state of subdivision as in the filters already described. The water was then allowed to subside, and the clarified water submitted to examination, as soon as possible after complete subsidence had taken place, as it appeared probable that if the organisms were

¹ Minutes of Proceedings Inst. C.E. vol. lxxxi. p. 279.

² *Ibid.* p. 285.

simply carried to the bottom by the subsiding particles without suffering any injury, they would rapidly again become distributed through the upper layers of water by multiplication. This supposition has been amply verified by experiment.

Agitation with Spongy Iron.—The water was shaken with one-tenth of its weight of this material for fifteen minutes. The water was allowed to subside for half-an-hour before examination.

Untreated water contained . . .	609 organisms per cubic centimetre.
After fifteen minutes' agitation . . .	63 " "
Reduction = 90 per cent.	

On another occasion Thames water from Hampton was shaken with spongy iron for fifteen minutes, with the following results:—

Thames water	155 organisms per cubic centimetre.
After fifteen minutes' agitation . . .	10 " "
Reduction = 93 per cent.	

Agitation with Chalk.—Urine-water was shaken for fifteen minutes with one-fiftieth of its weight of chalk, and then allowed to subside for five hours:—

Untreated water	8,000 organisms per cubic centimetre.
After agitation	270 " "
Reduction = 97 per cent.	

Agitation with Animal-Charcoal.—Urine-water was shaken with one-fiftieth of its weight of animal-charcoal for fifteen minutes, and then allowed to subside for nearly five hours:—

Untreated water	8,000 organisms per cubic centimetre.
After agitation	60 " "
Reduction = 99 per cent.	

Agitation with Vegetable-Charcoal.—Water containing soil-extract was shaken with one-fiftieth of its weight of ordinary wood-charcoal for fifteen minutes, and was then allowed to subside for twenty-seven hours:—

Untreated water	3,000 organisms per cubic centimetre.
After agitation	120 " "
Reduction = 96 per cent.	

Agitation with Coke.—Urine-water was shaken with one-fiftieth

of its weight of fine coke for fifteen minutes, and then allowed to subside for forty-eight hours :—

Untreated water	Too numerous to be counted.
After agitation with coke	None.
Reduction = 100 per cent.	

Further experiments made with water containing soil-extract have shown that this process of purification is unreliable, owing apparently to the numerous conditions which are necessary for its success. In some cases the number of organisms in the clear liquid was greatly increased, this being doubtless due to a re-ascension and multiplication of those which were at first carried down. Thus in one series of experiments the following results were obtained :—

Untreated water	3,000 organisms per cubic centimetre.
After agitation with coke and } twenty-six hours' subsidence	20,000 " "

Further experiments of a similar nature were made, but less time (only five hours) was allowed for subsidence :—

Untreated water	655 organisms per cubic centimetre.
After agitation with coke and five } hours' subsidence	28 " "
Reduction = 96 per cent.	

Thus, although a most remarkable purification may be accomplished by this simple process of agitation with the various substances specified, yet owing to the uncertainty of its success its efficiency cannot at present be relied on.

Water was also agitated with several other substances, such as china-clay, brickdust, plaster of Paris, oxide of manganese, &c. ; all of these, however, yielded unsatisfactory results.

The conclusion to be drawn from these experiments is that very porous substances like coke, animal- and vegetable-charcoal, are highly efficient in removing organized matter from water when the latter is exposed to their contact in agitation.

The removal of micro-organisms through the surface-attraction of suspended particles, naturally leads to a consideration of what takes place when the suspended particles are generated in the water itself by precipitation.

III. PURIFICATION OF WATER BY PRECIPITATION.

As by far the most common and most important method of water-purification dependent upon precipitation is the well-known process of Dr. Clark, the effect of this on organized matters was made

the subject of special study. With this view the Author has examined the process both in the laboratory as well as on the large scale as practised by manufacturers and by water companies.

Laboratory Experiments.—For testing the efficiency of the process on the laboratory scale, three stoppered Winchester quart bottles were taken, and to each were added 2 litres of ordinary London (Thames) water, to which a convenient proportion of organisms had been imparted by the addition of urine-water. To two of these bottles, 100 cubic centimetres of clear lime-water were added, this being calculated to remove 11·6 parts of carbonate of lime per 100,000 parts of the water. Each of these bottles was violently shaken, and the contents were then allowed to subside for eighteen hours. The bottle, to which no lime-water had been added, was tested without disturbing the precipitate, as was also the third bottle which had been left at rest in the same place as the other two. These tests showed the following numbers of organisms to be present in the water before and after treatment:—

Untreated water	85 organisms per cubic centimetre.
After eighteen hours' rest	1,922 " "
Water after treatment by Clark's Pro- cess and eighteen hours' subsidence}	42 " "
Reduction on original = 51 per cent.	

In order to appreciate the value of the treatment by Dr. Clark's process, it is necessary that the treated waters should be compared not only with the original water, but also with the untreated water after eighteen hours' rest; for the latter obviously indicates what the condition of the water would have been at the time of examination, if no lime-water had been added. It appeared probable that, after the subsidence of the carbonate-of-lime precipitate had taken place, the organisms which had been carried down by the latter would again become distributed throughout the upper layers of the water. In order to ascertain whether this was the case or not, the same waters which had remained stoppered up and at rest, were again examined after the lapse of ten days. It was then found that the untreated as well as the softened waters contained immense numbers of organisms in their upper layers.

In another series of experiments carried out under the same conditions, excepting that twenty-one instead of eighteen hours were allowed for the subsidence of the carbonate of lime, a reduction in the number of organisms amounting to 41 per cent. was obtained.

Experiments on an Industrial Scale.—It appeared to be of great interest to ascertain what results could be obtained by Dr. Clark's process on the large scale. For this purpose the process of softening as practised at the Colne Valley Waterworks at Bushey, near Watford, was investigated, as well as the new modification of Dr. Clark's process, devised by Messrs. Gaillet and Huet, which was lately in operation at Mr. Duncan's Sugar Refinery, Clyde Wharf, Victoria Dock. The Author is indebted to Mr. Verini, of the Colne Valley Waterworks, as well as to Mr. Duncan, and Mr. Newlands, for their kindness in permitting him to carry out these experiments.

At the Colne Valley Waterworks, the hard water (see analyses given below) obtained from a deep well sunk into the Chalk, is mixed with the requisite proportion of clear lime-water, and then allowed to settle in open tanks. The subsidence is so rapid that under favourable circumstances the upper layers of water are, after three hours' time, fit for distribution. On the occasion of the Author's visit, however, boring operations were being carried on, and the water was in consequence milky, and the necessary subsidence after softening had to be increased to two days.

A perfectly representative sample of the water before softening could unfortunately not be obtained, and the number of organisms found in the untreated water is probably in excess of that which was present in the unsoftened water. The following results were obtained :—

Unsoftened water	322 organisms per cubic centimetre.
Water after softening and two days' } subsidence (from main) . . . }	4 " "
Reduction = 99 per cent.	

In Gaillet and Huet's process, as carried out at Mr. Duncan's, the water from an artesian well, sunk into the Chalk below the London Clay, is mixed with a suitable proportion of lime-water and caustic soda, the mixture being then made to pass upwards through a tower provided with oblique diaphragms, which accelerate the precipitation of the carbonate of lime. The passage through this tower occupies a period of about two hours. Samples of the water before and after treatment, were examined with the following results :—

Well water from tanks	182 organisms per cubic centimetre.
Softened water	4 " "
Reduction = 98 per cent.	

These results, and especially those obtained on the industrial

scale, conclusively prove that Clark's process is a most valuable agent for purifying water biologically, and the value of the process from a chemical point of view is illustrated by the following analyses:—

PARTS PER 100,000.

	Total Solids.	Organic Carbon.	Organic Nitrogen.	Hardness.
Caterham water-supply before softening	27·68	0·028	0·009	21·2
After softening by Dr. Clark's process .	8·80	0·015	0·003	4·4

GAILLET and HUET's PROCESS.

	Well at Clyde Wharf, Victoria Dock.	Ditto after Softening.
Total solids	58·76	44·20
Organic carbon	0·111	0·084
„ nitrogen	0·017	0·016
Ammonia	0·050	0·060
Nitrogen as nitrates and nitrites	0	0
Chlorine	16·7	17·3
Hardness { Temporary	19·8	2·4
Permanent	8·0	6·0
Total	27·8	8·4
Sulphuric acid	3·96	4·01
Silica	1·44	0·69
Alumina and oxide of iron . . .	0·22	0·14
Lime	12·57	5·96
Magnesia	2·82	0·57
Potash	0·93	1·06
Soda	13·13	15·76
Carbonate of soda	0	2·0
Carbonate of lime	21·32	5·39
Carbonate of magnesia	1·43	1·20
Suspended matter:—		
Mineral	0·22	turbid
Organic	0·10	
Total	0·32	

On comparing the reduction of the organic matter, as indicated by chemical analysis, with the diminution in the number of micro-organisms revealed by the biological examination, it will be seen that the biological efficiency of Dr. Clark's process is markedly superior to its power as a chemical purifier. This is obviously a matter of great importance, as it shows the value of methods of precipitation in removing micro-organisms; it must, however, be borne in mind that the particular precipitation process referred to above, is carried out with the greatest care and cleanliness, and it is a rule, to which there is no exception, that satisfactory results, as regards the removal of micro-organisms, can only be

obtained when the most scrupulous care and continuous attention are given to the matter, and failure will inevitably result when such processes are not under proper supervision.

IV. PURIFICATION BY NATURAL AGENCIES.

It is a matter of common knowledge that of natural waters the purest, as regards organic matter, are those which have undergone prolonged filtration through porous strata. Such waters obtained from deep wells and deep-seated springs often contain the merest trace of organic matter, which is only discoverable and capable of being quantitatively determined by the most refined analytical methods. It has also been shown by Pasteur that many of these waters are entirely destitute of organic life, or are in other words sterile.

Of a number of waters of this kind, the Author has only met with isolated samples in which absolutely no organic life was revealed by cultivation with the gelatine mixture, although many have closely approached this ideal state of things. It must, however, be remembered that the collection of natural waters of this kind in a sterile condition is fraught with great difficulty, inasmuch as the places where such waters issue are almost invariably surrounded by conditions which favour the communication of organized matters to the water. Thus the damp, earthy surfaces with which the issuing water comes in contact form a favourable seat for the development of many growths. It is probably in consequence of such contact at the surface that subterranean waters, like that of the Kent Company, are found to contain their complement, a small one only, it is true, of organic life capable of growth and multiplication in the gelatine-peptone medium. Thus the water collected direct from the Kent Company's well at Deptford contained—

June 4th, 1885 (temperature 12·4 C.)	6 organisms per cubic centimetre.
Oct. 29th „ („ 12·0 C.)	6 „ „
Nov. 25th „ („ 11·7 C.)	8 „ „

Again, the water from a spring in the Upper Greensand near Reigate contained—

June 5th, 1885	8 organisms per cubic centimetre
And water from a deep well in the	
Chalk at Sudbury, March 16th, 1886,	25 „ „ „
contained	

It has often been urged as an objection to the bacteriological examination of water, that such an examination fails to distinguish

between organisms which are dangerous and those which are harmless. This is, however, not the case, for there are several pathogenic or disease-producing organisms which may be readily discovered; indeed, in the case of cholera in India, this has already been done by Dr. Koch, who found the "Comma Bacillus" in a water-tank which was being used by persons suffering from cholera. The organisms of several other diseases, of which splenic fever "*Bacillus anthracis*" may be specially mentioned, are also capable of identification. It is only a matter of time and further investigation that other diseases shall become similarly recognizable, inasmuch as every day more precise knowledge of these forms is being acquired. The energy and enthusiasm with which this branch of study is being prosecuted is nowhere more apparent than in the Hygienic Institute of Berlin, which is directed by Dr. Koch under the auspices of the German Government. This institute has as much space and accommodation devoted to the interests of bacteriology alone as, in a Government institution in this country, would be accorded to nearly all the sciences put together.

In the application of the gelatine process to the examination of potable water, the Author points out that an opinion as to the biological purity of the water should be based not only upon the aggregate number of organisms found, but also upon the number of different varieties which the cultivation reveals. A water containing only one or two varieties is, *cæteris paribus*, to be preferred to one in which there are many varieties, as in the latter case it is evident that the water has been subject to numerous sources of contamination, and that it has not been exposed to influences inimical to the life of a number of different classes of micro-organisms. In his experiments on the artificial purification of water, he has always found that it is more difficult to remove some classes of organisms than others. The following case illustrates this point in a most striking manner. In the experiments on filtration through vegetable-charcoal it has been already seen that the—

Unfiltered water contained . . .	2,230 organisms per cubic centimetre.
Filtered " " " " "	506 " "
Reduction = 77 per cent.	

If, however, only those organisms which cause liquefaction of the gelatine be taken into consideration, it is found that—

Unfiltered water contained . . .	785 organisms (liquid) per cubic centimetre.
Filtered " " " "	1 " "
Reduction = 99·87 per cent.	

Gelatine Process applied to London Waters.—For more than a year past the Author has made periodical examinations by this process of all the waters supplied to the Metropolis, and the results obtained since September last have been officially furnished to the Local Government Board.

These examinations are of peculiar interest, when they are studied side by side with the results of similar examinations made of the river waters from which the Metropolitan supply is mainly derived. It is, of course, impossible to obtain perfectly representative samples of the water before and after treatment by the companies, but the plan adopted has been to collect samples of the river-water as it passes the companies' intakes on the same day as that on which the samples of the water actually supplied to the consumer are collected. In this manner the samples, taken over a considerable period of time, will be representative of the average quality of the river-water on the one hand, and of the actual supply on the other. A mere glance at the results of these observations, which are embodied in the following Table, will distinctly show the striking improvement, as regards the number of micro-organisms, which the river-waters undergo in passing through the companies' works. During the last four months of 1885, the average reduction in the number of micro-organisms effected by the treatment of the companies was as follows:—

1885.	Thames.	Lee (East London Co.)
September	97·8 per cent.	—
October	96·5 "	—
November	98·9 "	98·5 per cent.
December	98·5 "	88·8 "

These regular periodical examinations have already yielded some exceedingly important results.

Thus for the first time a definite conception has been obtained of the effect of sand-filtration upon these lower forms of life. Hitherto those who were acquainted with the size of these minute microscopic organisms on the one hand, and with the dimensions of the pores in a sand-filter on the other, have believed that little or no barrier could be offered to these organisms by the comparatively spacious pores of the filter, and even the strongest advocate of sand-filtration could not have reasonably anticipated that mere filtration through a few feet of this material could effect the remarkable reduction in the number of micro-organisms to which the above Table bears witness.

It is most remarkable, perhaps, that these highly satisfactory results have been obtained without any knowledge, on the part

of those who construct these filters, as to the conditions necessary for the attainment of such results. In the construction of filter-beds, waterworks-engineers have certainly never been guided by an acquaintance with the habits of micro-organisms, and yet by carefully improving their methods, so as to secure the removal of visible suspended matter, they have hardly less successfully, although unconsciously, attacked the invisible particles, and reduced them to an extent which is surprising.

The Table, however, also shows that, great as has been the intuitive wisdom of the engineers, there is still much to be learnt in the purification of water from this new point of view. A glance at the Table shows that there is a certain uniformity in the position which the various companies occupy as regards freedom from micro-organisms, and on referring to the statistics of the various companies published in Sir Francis Bolton's manual of the "London Water Supply," it is found that there is an unmistakable relationship between this position of each company and certain factors in the mode of working, which might be anticipated from theoretical considerations.

The factors which, in the Author's opinion, are more especially calculated to influence the number of micro-organisms present in the distributed water are the following :—

1. Storage capacity for unfiltered water.
2. Thickness of fine sand through which filtration is carried on.
3. Rate of filtration.
4. Renewal of filter-beds.

1. *Influence of Storage Capacity for Unfiltered Water.*—The influence which this factor may exercise upon the organized matter in water is manifold. In the first place, through greater storage-capacity, the necessity of drawing the worst water from the river is avoided, a matter which in the case of a river like the Thames, which is liable to frequent floods, is of great importance. During the period of storage, subsidence takes place, the water becoming poorer in suspended particles of all kinds. Again, in these storage-reservoirs a process of starvation may go on, for the organisms present in the impounded water find themselves imprisoned with a limited amount of sustenance, which they rapidly exhaust, and then perish in large numbers, falling to the bottom. This phenomenon is sufficiently familiar to all who have made the cultivation of micro-organisms a subject of study.

2. *Influence of thickness of Fine Sand.*—That the thickness of the filtering stratum should exercise an important influence on the number of micro-organisms passing through the filter, will be

sufficiently obvious to every one. In referring to his laboratory experiments on filtration, the Author has already pointed out that comparatively thin strata of various materials are capable of largely, and sometimes of wholly, removing the micro-organisms in the water passing through them, but that this power is gradually lost; it is only reasonable to suppose that a thicker stratum will lose this power less rapidly than a thinner one. In estimating the thickness of the filtering stratum, the fine sand only should be taken into consideration, as it is only this portion of the filter which can have any effect in the removal of micro-organisms.

3. *Influence of Rate of Filtration.*—That the removal of micro-organisms is less perfect when the rate of filtration is increased, and *vice versâ*, has been illustrated by the results obtained in the experiments already referred to.

4. *Influence of Renewal of Filter-beds.*—As already pointed out even the most perfect filtering media sooner or later lose their power of retaining micro-organisms, and hence the importance of frequent renewal is sufficiently apparent.

In considering how the differences in these various factors, which the statistics of the Water Companies exhibit, may be expected to influence the results obtained in the removal of the micro-organisms, attention must be restricted to the five companies drawing water from the Thames, as it is only these which have approximately the same raw material to deal with; for from the above Table it is seen that the amount of organic life found in the River Lee at the intake of the East London Company is very different from that in the Thames at Hampton, and the difference in the case of the New River Company is doubtless even still greater, besides the problem being there complicated by the admixture of a very considerable proportion of deep well-water.

The close proximity of the intakes of the five Thames companies, however, furnishes a favourable opportunity for instituting a comparison.

The factors in the mode of working, which have been pointed out as of special importance in exercising an influence upon the result obtained, are given in the following Table, the figures being taken from the statistical Table given in Sir F. Bolton's "London Water Supply," 1884.

MORE IMPORTANT FACTORS in MODE of TREATMENT PRACTISED by THAMES WATER COMPANIES.

Name of Company.	Average Daily Supply, in Millions of Gallons.	Available Storage Capacity, in Millions of Gallons.	Average Storage in Days (Calculated).	Rate of Filtration per Square Foot in Gallons per Hour.	Thickness of Fine Sand.	Renewal of Filter Beds (Calculated). Acreage cleaned per Month.
Chelsea	9.5	140.0	14.7	1.75	Feet. Ins. 4 6	Total Acreage. 0.59
West Middlesex	12.8	117.5	9.2	1.5	3 3	0.90
Southwark	19.9	66.0	3.3	1.5	3 0	0.90
Grand Junction	14.1	64.5	4.6	1.75	2 6	0.81
Lambeth	14.2	128.0	9.0	2.0	3 0	0.50

By means of this Table the companies may now be classified with respect to each of the four factors in question, thus:—

Company.	Storage Capacity.	Thickness of Fine Sand.	Rate of Filtration.	Renewal of Filter-beds.
Chelsea	1	1	3	4
West Middlesex	2	2	1	1
Southwark	5	3	1	1
Grand Junction	4	5	3	3
Lambeth	3	3	5	5

From this the general order of merit can be deduced, by adding these figures together for each company, and arranging them according to their average position, thus:—

Companies.	Average Position.	Order of Merit.
Chelsea	2.25	2
West Middlesex	1.5	1
Southwark	2.5	3
Grand Junction	3.75	4
Lambeth	4.0	5

From the theoretical considerations here instituted, it would be anticipated, therefore, that dealing with the same raw material, the West Middlesex Water Company should, on the whole, obtain the best average result, from a biological point of view, and that the results obtained by the other four companies would follow in the order of Chelsea, Southwark, Grand Junction, and Lambeth. On comparing this series with the number of micro-organisms

found during the last four months (September to December) of the past year, it will be seen that this series is in precise accordance with the results obtained, thus :—

	Average Number of Micro-organisms found during the four months, Sept.-Dec. 1885, in 1 cubic centimetre.
West Middlesex	6
Chelsea	15
Southwark	37
Grand Junction	64
Lambeth	70

The same series is obtained if the results are taken over the whole year, but in that case the figures for the Grand Junction and for the Southwark in March must be omitted, as on these occasions accidental contamination of these supplies had taken place, an exceptionally large number of micro-organisms being found in these months.

This coincidence between theory and practice most conclusively proves that in attempting the removal of micro-organisms from water it is no longer necessary to work in the dark, but that the problem is as tangible as the removal of those larger suspended particles which have for long past occupied attention. The only difference between the two, is that the larger suspended particles are visible to the naked eye, whilst these minute living particles require the assistance of science to render them apparent. It will also be obvious from the facts brought forward, how necessary it is that these micro-organisms should now receive careful attention, with a view to the success in practice of the improved processes indicated by scientific research. It is necessary that waterworks-engineers should become experimenters in this field, with the view of ascertaining how their processes may be carried out so as to yield the best results. It is not intended by this that they should be expected to carry out the actual bacteriological operations, for which special training is necessary, but that they should sufficiently acquaint themselves with the subject in order to carry out the necessary arrangements for such experiments on the large scale.

It must be pointed out that valuable as are the results obtained when the whole supply of each company is thus periodically submitted to examination, a much deeper insight into the working of the filters is to be obtained by the frequent examination of each individual filter-bed. The examination of the whole supply only gives a summary of the working, and the individual conditions more or less obliterate each other, but by a careful periodical

examination of each filter-bed, any defect in a detail of the process of purification would be at once detected and remedied. In fact, it is desirable that the history of each individual filter-bed should be carefully studied both for present and future guidance.

The regular biological examination of the water-supply of Berlin has now been carried out for upwards of a year under Dr. Koch, and the importance of this supervision is there duly recognized both by the State authorities and by the waterworks-engineers. England has hitherto occupied the first place in the world for the excellence of her sanitary institutions, this place she still maintains; but in future, unless practice goes more hand-in-hand with science, there is every prospect that, as already in industrial prosperity, so in sanitation, she will year by year lose ground in favour of her aspiring neighbours.

The principal conclusions to be drawn from the experiments referred to, are:—

I. That the complete removal of micro-organisms from water by filtration is unattainable without frequent renewal of the best filtering materials, and duly restricting the rate of filtration.

II. That a very great reduction in the amount of organized matter in water may be accomplished by filtering materials which have hitherto been generally regarded as almost ineffectual.

III. That organized matter is to a large extent, and sometimes to a most remarkable extent, removable from water by agitation with suitable solids in a fine state of division, but that such methods of purification are unreliable.

IV. That chemical precipitation is attended with a large reduction in the number of micro-organisms present in the water in which the precipitate is made to form and allowed to subside.

V. That if subsidence, either with agitation or after precipitation, be continued too long, the organisms first carried down may again become redistributed throughout the water.

APPENDIX.

MICRO-ORGANISMS in 1 CUBIC CENTIMETRE of METROPOLITAN WATERS.

1885.	Jan.	Feb.	Mar.	May.	June.	Sept.	Oct.	Nov.	Dec.
Thames at Hampton . .	..	..	..	..	..	1,644	714	1,866	4,650
Chelsea	8	23	10	14	22	81	13	34	9
West Middlesex	2	16	7	3	..	26	2	2	15
Southwark	13	26	246	24	..	47	18	24	73
Grand Junction	382	57	28	3	21	18	43	40	134
Lambeth	10	5	69	30	..	38	103	26	124
Lee at Chingford Mill .	..	..	..	..	..	..	..	954	2,831
New River	7	7	95	3	..	27	3	2	11
East London	25	39	17	121	..	22	29	53	14
Kent (well at Deptford)	..	..	..	..	6	..	..	6	8
„ (Supply)	10	41	9	20	26	..	14	18	..

SUMMARY of FILTRATION EXPERIMENTS.

Name of Material.	Initial Efficiency.	Rate of Filtration.	Efficiency after	Rate of Filtration.	Efficiency after	Rate of Filtration.
	Reduction per cent.	Gal. per Sq. foot per hour.		Gal. per Sq. foot per hour.		Gal. per Sq. foot per hour.
Ferruginous green-sand	100	..	{ 13 days. Reduction of }	88 0.73	{ 1 month. Reduction of }	39.0 1.14
Animal charcoal	100	..	{ 12 days. Reduction of }	100 0.46	{ 1 month. Increase of }	447.0 0.86
Iron sponge	100	..	{ 12 days. Reduction of }	100 0.40	{ 1 month. Reduction of }	99.8 0.45
Brick-dust (pulverized red brick .)	76	..	..	..	{ 5 weeks. Reduction of }	93.0 0.48
Coke (A)	100	..	..	..	{ 5 weeks. Reduction of }	98.5 0.50
„ (B)	{ 2nd day 100 }	0.89	{ 3 weeks. Reduction of }	85 1.32	..	..
„ (C)	{ 2nd day 100 }	0.67	{ 3 weeks. Reduction of }	90 1.03	..	..
Vegetable charcoal (A)	{ 2nd day 100 }	..	..	..	..	..
„ „ (B)	{ 2nd day 100 }	0.22	..	..	{ 1 month. Reduction of }	95.0 0.22
„ „ (C)	{ 2nd day 100 }	0.26	{ 3 weeks. Reduction of }	77 0.59	..	..

[DISCUSSION.