THE SAND FILTRATION AND PURIFICATION OF CHALK WATERS.

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(1 Chart.)

Some deep wells in the chalk are liable to contamination. The pollution may gain access to the wells by means of fissures or "swallow-holes" in the water-bearing stratum, and, through these defects, micro-organisms and organic matter may find their way into the water supply of a town from points many miles distant. The risk of chalk waters becoming contaminated is daily growing more probable: quick and cheap transit is responsible for an exodus from the town to the country which serves as a gathering ground for water supplies; and the chalk uplands and countryside, which formerly were sparsely populated, are in many places becoming covered with collections of houses and small villages, whose only method of sewage disposal is by means of cesspools into the chalk on which the houses are built. If the chalk is sound and unfissured, this method of sewage disposal is not harmful to distant water supplies; but, given a fissure or swallow-hole, the intestinal micro-organisms and organic matter from some outlying village, may make the water from a deep well some miles away unfit to drink. I know at present of five important wells in the chalk in different parts of England, which are, in this manner, liable to intermittent and un-doubted faecal contamination; but, in only two of these places are means taken to purify the water before it is distributed to the consumers. A typhoid carrier or a case of enteric fever might distribute bacilli to a distant town through some imperfection in the stratum, and the con-sequences, without doubt, would be very disastrous; yet probably there

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are many towns in the country which take the risk of such an epidemic.

One of the objects of this paper is to insist on the necessity of frequent bacteriological examinations of chalk water supplies; so that, when intermittent contamination is known to occur, some method may be adopted of purifying the water.

Scope of the present enquiry.

During the first four months of this year I conducted bacteriological researches on a deep well in the chalk, and on three filter beds and two Porter Clark softening plants, by which this well water is treated before distribution.

My object was to gain information into the bacteriology of the well water at different times, to determine whether or not the sand filtration was effective, and to see whether or not the softening of a chalk water by the rapid Porter Clark process caused any purification from micro-organisms. I shall now consider these three main divisions of my work.

The well and the well water.

The well is 200 feet deep, and has a delivery of about 700,000 gallons per day of 10 hours. The water is pumped directly from the well to the filter beds, and thence to a reservoir of five million gallons capacity.

The well is subject to intermittent contamination from swallow-holes. Some years ago an organism, foreign to the well water, was recovered from the well, after having been put down in large numbers and washed into the soil in the neighbourhood of one of these swallow-holes. Sodium chloride and fluorescin have, in a similiar way, been used in the past to demonstrate the connection between these distant swallow-holes and the well. There is no doubt that the well sometimes becomes foul. This, however, rarely happens more than five times a year. Half an inch to an inch of rain in 24 hours causes the well water to become muddy, and on such occasions the bacterial count is very largely increased.

Normally the well water is very pure. *Bacillus coli* does not occur in 100 c.c. *Bacillus enteritidis sporogenes* is not found. Only a few colonies develop on agar in 24 hours, and about a couple of dozen per c.c. on gelatin in 72 hours. Gelatin liquefiers are few in number. The

average count of the well water under normal conditions is seen in the following table:

TABLE A.

Average number of Bacteria in well water—excluding days on which the well was contaminated.

B. *coli* per 100 c.c. ... ... = 0·8
Colonies developing on agar at 37° C. in 24 hours = 4·12 per c.c.
Colonies on gelatin 20—22° C. in 72 hours ... = 24·1 ,,
Gelatin liquefiers in 72 hours ... ... = 0·7 ,,

On two occasions during my four months' work I have found the well to be contaminated. The number of organisms increased very greatly. Tables B and C show the bacterial count at these times.

TABLE B.

Average number of bacteria in well water, during contamination in January 1911.

B. *coli* per 100 c.c. ... ... = 10·5
Colonies developing on agar at 37° C. in 24 hours... =, 97·1 per c.c.
Colonies developing on gelatin at 22° C. in 72 hours = 125·7 ,,
Gelatin liquefiers in 72 hours ... ... = 14·9 ,,

TABLE C.

Average number of bacteria in well water, during contamination in April 1911.

B. *coli* per 100 c.c. ... ... = 25
Colonies developing on agar at 37° C. in 24 hours ... = 383 per c.c.
Colonies developing on gelatin at 20—22° C. in 72 hours = 1213 ,,
Gelatin liquefiers in 72 hours ... ... = 206 ,,

Note :—In Tables B and C the figures are averaged from several days observations.

The filter beds.

There are three filter beds in connection with this well. Each has an area of one-third of an acre. They are immersed and uncovered beds of the ordinary type. The top sand is two feet in thickness and is fine— 50 per cent. will pass a " 30 × 30 Sieve." The head of water required to work the beds is only about 1½ inches. The water flows through the beds at the rate of nearly four inches an hour.

The growth of Algae.

Many difficulties have arisen in connection with the working of these beds—the chief and most important, from the point of view of the owners of this water supply, being the fact that the beds become overgrown with green algae, which decompose rapidly and make the filtered water offensive both to taste and smell. In consequence there have been many complaints from the consumers of the water. When the beds are emptied to be cleaned the remains of the decaying weed are found on the sand. This dead organic matter looks like freshly-passed cow-dung, and smells very foul: so foul is it indeed, that the men who clean the beds say openly that they would rather be working on the sewage farm and cleaning out the septic tanks. These dung-like deposits and the upper inch of the sand are full of the larvae of Chironomus. Such is the material through which the water is filtered before it passes to the consumers.

For a week after cleaning one of these filter beds, no green weed is visible. Then it begins to grow vigorously; and, in a week, the bed is full of it. The more the sunlight, the more the weed. Three weeks from the time of cleaning, the water may begin to smell. In a month it may be intolerable, and the bed will have to be cleaned again. In sunless weather the bed may run as long as three months without cleaning.

The "vital layer."

No "vital layer" forms on the filter beds. It seems that a chalk water is too pure to provide the organic matter necessary for the formation of the layer. The sand, except where it is covered with masses of decomposing algae, remains as free from a vital layer as it was on the day the filter was first used. This seems to be one of the main difficulties in the sand filtration of chalk waters—a vital layer will not form on the filter beds.

The efficiency of sand filtration of chalk waters.

As I have said, the well water is very pure—except on a few days in the year. It can therefore hardly be thought surprising that the water should come from the filter beds more impure bacterially than it enters them. And such is the case. The filter beds certainly abstract some

organisms from the entering water; but at the same time they add other organisms.

The following table shows the bacterial content of the water before and after filtration. The figures are averaged from many observations extending over four months' work, and are exclusive of the high counts observed during the two periods when the well was contaminated.

TABLE D.

	B. coli per 100 c.c.	Colonies developing on agar at 37° C. in 24 hrs.	Colonies on gelatin at 22° C. in 72 hrs.	Gelatin liquefiers
Unfiltered water	0·8	4·12 per c.c.	24·1 per c.c.	0·7 per c.c.
Filtered water	0·27	13·6 ,,	150·0 ,,	37·0 ,,

Now, the addition of some organisms to a water does not necessarily make this water less potable; and, in my opinion, the organisms added by these sand filter-beds do not make the water harmful to the consumers. The point to be settled was, did the beds effect a large reduction of the organisms present in the well water: or, to put the matter in other words, would the filter beds purify the well water, if the latter was heavily infected with—say—the *Bacillus typhosus*?

The sand filtration of an artificially infected chalk water.

To settle this question I determined to infect the water before filtration with some non-pathogenic organism that could be identified easily; and I came to the conclusion that a non-pathogenic variety of *Bacillus coli* would be the most convenient. In its shape and mobility it approaches *B. typhosus*, the organism against which we attempt to secure our water supplies. I had obtained a sucrose-fermenting *B. coli* from the well on a former occasion, and prepared a gallon of sterile peptone water into which I inoculated a pure culture of the Bacillus. Before adding any of the peptone water culture to the filter beds, I drank a pint of water heavily infected with this variety of *B. coli* with no evil results. *B. coli* is most useful as a Test Organism, not only from the fact that it is something like *B. typhosus*, but also because its presence is detected so easily and certainly. In passing I may say, that in isolating the organism subsequently I used neutral-red-bile-salts-peptone-lactose-agar,—the Rebipelagar of Houston,—and lactose-bile-salts-neutral-red-peptone water. Many thousand colonies were counted in all, and several hundred sub-cultured. The peptone water culture for infecting the

filter beds was put through the various sugars and plated on Rebipelagar and Conradi-Drigalski media: it was always determined that this culture was pure before it was used.

The culture of *B. coli* in peptone water was introduced into the filter beds by a long syphon-tube discharging the culture at the mouth of the water inlet pipe. The culture was thus delivered fairly uniformly, and well mixed with the inflowing water. Half-hourly samples were taken from the water at the far side of the bed; and half-hourly samples were taken of the filtered water. *B. coli* was not present in the filtered water before the experiment: it was generally present in the filtrate an hour from the time the culture was first added.

The following table shows the numbers of *B. coli* present in the water before and after filtration. The figures are averages. For further details the reader is referred to Appendix I, at the end of this paper.

TABLE E. *Filter A.*

Average number of *B. coli* in water before sand filtration	33·5 per c.c.
,, ,, ,, ,, after ,,	3·9 ,,
Percentage reduction brought about by sand filtration ...	88·4 %

The above figures refer to Filter A which had been cleaned out a fortnight previously.

A week later I performed a similar experiment on Filter C which had not been cleaned for nearly three months. The following results were obtained; details of which are given in Appendix II.

TABLE F. *Filter C.*

Average number of *B. coli* in water before sand filtration	40·1 per c.c.
,, ,, ,, ,, after ,,	1·28 ,,
Percentage reduction brought about by sand filtration ...	96·9 %

The conditions of these two beds were similar, except in the matter of cleaning. It would seem therefore that the dead organic matter and débris on the second bed acted in some way in place of the vital layer, and caused this bed to be a more effective filtering agent than its more recently cleaned fellow.

I am of opinion that the amount of purification these beds give is not sufficient for safety. That many of the added *B. coli* passed into the town supply is unquestionable, and I do not doubt that, if the organism had been *B. typhosus*, the results would have been deplorable.

The formation of an artificial "vital-layer."

Seeing that the mere sand filtration of a chalk water gave unsatisfactory results, probably on account of the lack of a vital layer on the filter beds, I decided to try the effect of a coating of aluminium hydrate on the surface of the sand, so as to simulate as closely as possible the absent vital layer. The aluminium hydrate was obtained by adding aluminium sulphate to the water as it entered the filter bed. The requisite quantity of the sulphate was suspended in a sack at the mouth of the inlet pipe; and, as the bed was filled, a gelatinous precipitate of the hydrate was deposited over the sand. The chemical reaction that takes place depends on the temporary hardness of the water, and can be expressed as follows:

$$Al_2(SO_4)_3 + 3\,Ca\,H_2\,(CO_3)_2 = Al_2\,(OH)_6 + 3\,Ca\,SO_4 + 6\,CO_2.$$
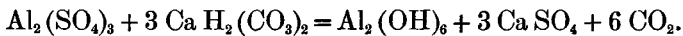
The amount of aluminium sulphate that can be precipitated by a chalk water depends therefore, according to the equation, on the amount of temporary hardness present in the water. If excess of aluminium sulphate is added, it will pass into solution and be detected by the consumers. Practically, for each degree of temporary hardness, two-thirds of a grain of aluminium sulphate can be added to each gallon. The water on which I have been working has a temporary hardness of about 12° Clark's scale. I could add therefore with safety eight grains of aluminium sulphate to the gallon of water, knowing that all would be precipitated on the surface of the filter bed. I added however only one grain to the gallon while the bed was filled after cleaning; but continued the addition daily of a like amount during five days. At the end of this time there was a visible precipitate over the surface of the sand.

I then proceeded to infect the bed with *B. coli* in the same way as beds A and C. *B. coli* was added to the incoming water, and samples were taken of this water before and after filtration. The following table gives the results obtained. For further details the reader is referred to Appendix III.

TABLE G.

Average *B. coli* before filtration through aluminium hydrate and sand	73·9 per c.c.
Average *B. coli* after ,, ,, ,, ,, ,,	0·4 ,,
Percentage purification brought about by filtration through precipitated aluminium hydrate and sand	99·46 %

It will be seen therefore that the purification obtained by filtering through precipitated aluminium hydrate and sand is considerably better than is given by filtration through sand alone.

The growth of algae, however, was not prevented by the precipitated aluminium hydrate. There was growth at the end of a week; and, at the end of a fortnight, the weed was rising to the surface and, doubtless, disturbing the layer of aluminium hydrate on the top of the sand. Three weeks after the first infection of the bed, I infected it again to see whether or not its powers of purifying the water from *B. coli* had been impaired by the growth and movement of the weed. The bed gave a purification of 99·21 %—showing only a slight diminution of its efficiency. I repeated the experiment again at the end of another three weeks, during which interval there had been increased growth and movement of algae. The percentage purification given by the bed was diminished, only 97·64 % of the added *B. coli* being retained. Details are given in Appendix IV.

So it seems that a sand filter bed coated with precipitated aluminium hydrate gives a high purification of infected chalk waters until the surface is broken by the movement of algoid growths. But even after considerable growth of algae the purification remains fairly good—better, at any rate, than that given by beds untreated with aluminium sulphate. Probably some of the aluminium hydrate is carried down into the interstices of the sand, where it is unaffected by the surface disturbances caused by the algae.

Filtration through a layer of fine sand.

Having determined the efficacy of precipitated aluminium hydrate as a filtering medium, I next proceeded to decide whether or not a layer of fine sand on the surface of the filter bed would give equally good results. Some sand was obtained, of which 95 per cent. would pass through a " 70 × 70 sieve." One of the filter beds was cleaned, and the fine sand applied an inch thick over the surface. The bed was filled slowly from below, and, after it had been working for a few days, it was infected as before with a peptone water culture of *B. coli*. Hourly samples were taken of the water before and after filtration. The percentage purification was found to be 93·26 %. (For details see Appendix V.) This is better purification than is given by a clean bed without the addition of the inch of fine sand (Table E); but not so good as is given by a recently cleaned bed that has been treated with aluminium

sulphate (Table G). Possibly, by using a foot or more of this fine sand, a high degree of purification could be obtained : but I do not think the method is economical. The cost of the sand, and of the labour needed in washing it, the loss on washing, and the difficulty of manipulating this fine sand, make the use of it as a filtering medium much more costly than aluminium sulphate. At the same time, it is not so reliable. If sand filters are used for the purification of chalk waters, they should be made effective by the precipitation of aluminium sulphate added to the water, rather than by a coating of some fine sand.

The sterilisation of sand filters.

The filter beds add certain organisms to the water, as well as abstracting some of the entering organisms (Table D). In order to prevent this addition of organisms to the water, I attempted to sterilise one of the filter beds by the addition of bleaching powder after the bed had been cleaned. At first I added bleaching powder, equivalent to five parts of chlorine per million gallons, and filled the bed from below to the level of the top of the sand with this solution. The bed smelt strongly of chlorine. After a preliminary emptying and washing, the bed was filled in the usual manner and samples of the filtrate taken. The bacterial count was largely increased. Another attempt at sterilisation was made some days later, and 10 parts of available chlorine per million gallons were used. In both cases the solution of bleaching powder was left on the bed for 48 hours. In the second case also the bacterial count was largely increased.

TABLE H.

	Average before adding bleaching powder	Average after adding five parts of chlorine per million gallons	Average after adding ten parts of chlorine per million gallons
Colonies on gelatin in 72 hrs.	55·6 per c.c.	515 per c.c.	345·7 per c.c.
Gelatin liquefiers ...	26·5 ,,	133 ,,	62·0 ,,

The only explanation that I can offer for the failure of the chlorine to disinfect the deep layers of the bed, is that, throughout the interstices of the gravel and sand, there is organic matter which combines with the free chlorine. The result is that this organic matter is decomposed, and the contained micro-organisms set free to enter the filtrate. The explanation is not wholly satisfactory; but I wish to put on record the paradox observed—namely, that the attempts at sterilisation of a sand filter by means of chlorine made the bacteriological condition of the filtrate no better, but rather the worse.

Methods of checking the growth of algae in filter beds.

In the earlier part of this paper, I referred to the trouble caused by the growth and decomposition of algae in the filter beds, and remarked how they gave rise to taste and odour in the water, thereby making it necessary to clean the beds at frequent intervals. I have shown also how the growth and movement of the algae interfered with the high purification in the bed treated with precipitated aluminium hydrate. The algoid growths are altogether an evil in the sand filtration of chalk waters.

Before I began my work in January, the owners of the water supply had tried the effect of dilute solutions of copper sulphate, applied to the beds during the process of cleaning. No good results had been obtained: on filling the beds subsequently, no inhibition of the growth of algae was observed. Copper sulphate has never been added to the beds while they were working: it is a substance that is undeniably poisonous, and, despite the assertion that has been made, that it does not pass through the sand into the filtrate, I have been unwilling to add it even in small quantities to the water supply.

To one of the beds which was overgrown with weed, I added chlorine derived from bleaching powder in the amount of ·5 parts of chlorine per million gallons. This addition was continued daily. In ten days time all the weed was dead, and in three weeks it had decomposed and made the water taste offensively. It was necessary then to clean the filter bed. There was no doubt that the addition of bleaching powder killed the weed.

The next point to determine was whether or not the intermittent addition of bleaching powder to a cleaned filter bed would inhibit the algoid growths. Two of the beds having been cleaned, bleaching powder was added to each twice a week in the evening, just before the beds stopped working for the day. Five pounds of bleaching powder were thus put into the 250,000 gallons of water in each bed, and the chlorined water left in contact with the filter for twelve hours. No inhibition of the growth of algae was evident, although the addition of bleaching powder was continued during three weeks.

Covered filter beds.

As I have stated, there is a reservoir of five million gallons' capacity into which the filtered water from the three beds is pumped. This reservoir is covered, no growth of algae takes place, nor does the reservoir need to be cleaned; indeed, on such occasions as it has been entered for purposes of cleaning, it has been found that such cleaning was not required. This reservoir has been in use for more than twenty years.

It seems a justifiable inference to make, that if the beds used for filtering a chalk water were covered, there would be no growth of algae, and consequently no need to clean the beds. The cost of covering is about one-third of the original cost of the beds, or about £3000 an acre. Cleaning an acre of filter beds costs roughly about £300 a year. In ten years' time, therefore, the cost of covering would be saved, and, in each subsequent year, the covering would represent a profit. I see no reason why there should be any need for cleaning a covered filter bed, used in the filtration of a chalk water that is only occasionally contaminated.

The storage of chalk waters.

Chalk waters do not store well. The few micro-organisms present in the water increase rapidly during the first few days of storage, and this increase, after it has reached the maximum, subsides slowly. Miquel, Frankland and Cramer have all found this increase to obtain during the storage of pure water; and their findings are in opposition to the classical results of Houston, who worked on waters which were ordinarily contaminated heavily. The following curve, based on an experiment of my own, shows the increase and decline in the number of micro-organisms in a chalk water on storage: the water was heavily infected with *B. coli*, and kept in the dark at room temperature.

Storage, then, is not to be recommended for a chalk water, which, on most days in the year, is uncontaminated. Should, however, water from a chalk well be found to be heavily contaminated during the majority of days in the year, then storage possibly would be the best method of treatment before filtration. I do not think it likely that there are any chalk wells which show such invariable bacterial contamination as does, for example, raw Thames water; and the conditions under which storage could be recommended for chalk waters must be very rare.

Diagram, showing the effect of Storage on a Coli infected Chalk Water.
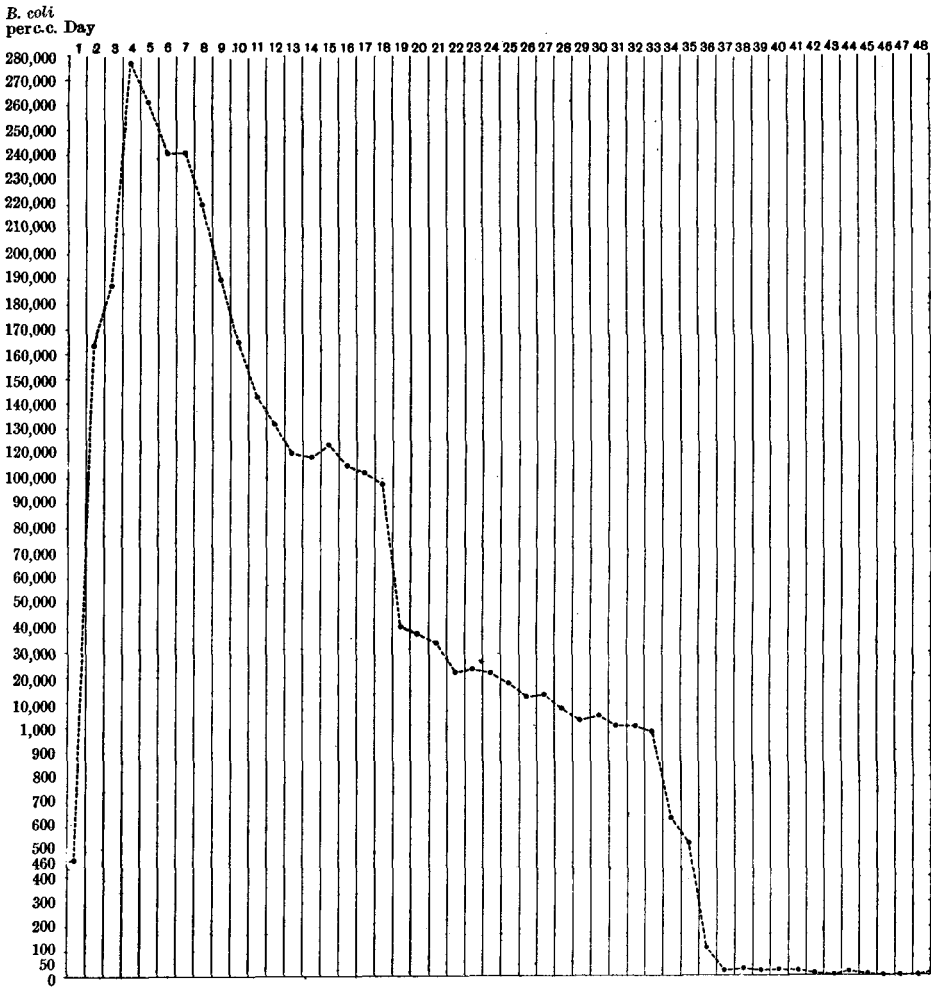
The purification of a chalk water by softening.

During the four months of my research I have had an opportunity of observing the effects of two softening installations on the purification of a chalk water. Both these installations are on the Porter Clark principle, and differ only in constructional details, the broad principles of addition of lime followed by preliminary sedimentation, and filtration

through canvas bags being the same in each. Together the plants soften 60,000 gallons of water per day of ten hours.

The water softened comes from the filter beds, and is greatly purified by its passage through the softening installations. The following table based on daily averages, shows the purification effected by softening:

TABLE J.

	B. coli per 100 c.c.	Colonies on agar 24 hrs.	Colonies on gelatin 72 hrs.	Gelatin liquefiers
Unsoftened water	0·27	13·6 per c.c.	150 per c.c.	37 per c.c.
Soft water	0·00	3·0 ,,	21 ,,	0·6 ,,

This shows a purification of 86 % on the gelatin count, and 98·4 % on the liquefying count.

It has been observed, however, in softening installations, that a pure chalk water is not improved bacteriologically by passing through a softening plant, unless the filtering bags of the latter are sterilised frequently by steam. I did not, therefore, consider that the purification of 86 and 98·4 %, shown by Table J, was absolute, because some of the organisms counted in the soft water might have been added by the softening process. I decided for this reason to determine how far the softening plants would cleanse a water infected with some foreign organism; and, since *B. coli* had never been found in the soft water, I used that for a test organism. Peptone water cultures were added to the water before softening; and the number of bacilli in the water before and after softening was determined.

Briefly, the results obtained were as follows: the water passing through a newly cleaned plant is purified very considerably; but a greater purification takes place after the plant has been working for a few hours, and the bags have become coated with a thin deposit of calcium carbonate.

Softening plants Nos. 1 and 11 were cleaned, and the precipitated chalk washed from the bags. A coli infected water was then passed through them. No. 1 gave a purification of 98·6 %; and No. 11 a purification of 98·76 %. In four hours' time No. 11 gave 100 % purification; and in five hours' time No. 1 also gave 100 % purification. Details are given in Appendices VI and VII.

On another occasion Plant 1 was cleaned again and allowed to work for four hours before the culture of *B. coli* was added. No *B. coli* appeared

in the soft water; the plant gave a purification of 100%. (Details in Appendix VIII.)

On another occasion the water entering the plants was again infected with *B. coli.* No. 1 plant was newly cleaned: No. 11 had not been cleaned for several days. No. 1 gave 98.8% purification, and No. 11 a purification of 100%. (See Appendix IX.)

This last experiment was repeated later. The calcium carbonate was washed from the bags of No. 1 plant. No. 11 was not cleaned, and the bags had a coating of calcium carbonate. During the first $3\frac{1}{2}$ hours of running, the newly cleaned plant gave a purification of 99.08%; during the next hour practically 100%; and after that an absolute purification of 100% of the added micro-organisms. Details are given in Appendix X.

Softening by means of the Porter Clark process is an admirable method of sterilising a chalk water.

Moor and Hewlett have shown in a recent paper that softening by sedimentation alone is not reliable in sterilising chalk waters: the intervention of the filtering bags in the Porter Clark process presumably, therefore, effects the certainty of purification which is lacking in the sedimentation process. The bags very quickly become covered with the finely divided deposit of calcium carbonate, which catches any micro-organism not dealt with by the previous sedimentation. The bacilli do not work their way through this coating of chalk into the effluent; and, when once the maximum purification is reached, the figure is maintained until the plant is cleaned again.

Certain precautions must be taken in using the Porter Clark soften-ing process for the sterilisation of chalk waters. In the first place, it is important that the water passing through a plant during the first four hours or so after cleaning should either be run to waste or else pumped back into the sedimentation tanks. Again, it seems likely that if a plant is overworked or "rushed" the bacteriological condition of the soft water will suffer: for this reason, plants should be installed of capacity sufficient to treat the *maximum* (rather than the average) amount of water to be softened. The canvas filtering bags should be sterilised by steam at regular intervals. If these few simple precautions are taken, in using a Porter Clark installation to sterilise a chalk water, there is no reason why a purification of 100% should not invariably be obtained.

CONCLUSIONS.

1. Some deep wells in the chalk are liable to intermittent contamination. The water of such wells ought to be purified before distribution.

2. Open submerged sand filter-beds, as ordinarily used, are not suitable for the purification of chalk waters. They do not effect a sufficient purification from micro-organisms, and they favour the growth of algae which make the water taste and smell unpleasantly.

3. A vital layer does not form on a filter-bed used in the filtration of chalk waters.

4. Besides abstracting some organisms from the water, sand filters add other organisms. This addition is increased by attempts to sterilise the sand filter by means of chlorine.

5. A sand filter can be made an effective filtering agent by the deposition of aluminium hydrate on the surface of the sand. The filter, thus treated, remains efficient until the aluminium hydrate is disturbed by the growth and movement of algae.

6. A layer of very fine sand one inch in thickness on the surface of the filter-bed does not make the bed an effective protection against the passage of micro-organisms.

7. The best way of adapting existing filters to the purification of chalk waters is, to cover such beds so as to exclude the light, and to cause aluminium hydrate to be precipitated over the surface of the sand. A bed, so treated, should not need to be cleaned. Possibly it may be found advisable to add aluminium sulphate periodically during the working of the bed.

8. Bleaching powder, added continuously to a filter-bed, kills any algae that may be present. The intermittent addition of small quantities of chlorine does not inhibit the growth of algae in a filter-bed.

9. Storage is not to be recommended for chalk waters, as it causes a large increase in the number of micro-organisms originally present. Probably treatment with hypo-chlorites or ozone, or passage through some mechanical filter, would purify a contaminated chalk water; but I have no personal experience of these methods.

10. Softening by means of the Porter Clark process is a very excellent way of sterilising a contaminated chalk water. If certain

precautions are observed, this softening method removes all the micro-organisms from the water, and it is therefore more effective than filtration through aluminium hydrate and sand. The Porter Clark softening process is to be recommended, rather than sand filtration, for the purification of a contaminated chalk water.

APPENDIX I.

The sand filtration of a coli infected chalk water.

	Time	B. coli in 1 c.c. of unfiltered water	B. coli in 1 c.c. of filtered water
Feb. 24th	4.30 p.m.	0	0
,,	5.30 ,, A	10	1
Feb. 25th	7.30 a.m.	24	2
,,	8.30 ,,	56	0*
,,	9.30 ,,	44	5
,,	10.30 ,,	64	5
,,	11.30 ,,	32	8
,,	12.30 p.m.	31	1C
,,	1.30 ,,	26	2
,,	2.30 ,,	40	1
,,	3.30 ,,	46	3
,,	4.30 ,,	52	8
,,	5.30 ,,	24	7
Feb. 26th	9.0 a.m. B	20	5
,,	11.0 ,,	0†	0*
Feb. 27th	11.30 ,,	0	2
	Average	33·5 per c.c.	3·9 per c.c.

Percentage purification caused by sand filtration = 88·4 per cent.

Notes :—Culture of *B. coli* added during time between A and B.

   * = 10 c.c. tubes of lactose bile salt peptone water showed acid and gas, and on subculture gave *B. coli*.

   † = *B. coli* present in 10 c.c.

APPENDIX II.

The sand filtration of a coli infected chalk water.

	Time	*B. coli* in 1 c.c. unfiltered water	*B. coli* per 1 c.c. filtered water	10 c.c. filtered water	25 c.c. filtered water
Wednesday	12.0 m. A	14	0	–	–
	1.0 p.m.	42	0	–	–
	2.0 ,,	36	0	–	+
	3.0 ,,	52	0	+	+
	4.0 ,,	30	1	+	+
	5.0 ,,	104	2	+	+
Thursday	8.0 a.m.	60	0	+	+
	9.0 ,,	64	0	+	+
	10.0 ,,	92	2	+	+
	11.0 ,,	84	3	+	+
	12.0 m.	52	2	+	+
	1.0 p.m.	28	2	+	+
	2.0 ,,	26	0	+	+
	3.0 ,,	10	1	+	+
	4.0 ,,	8	3	+	+
	5.0 ,,	16	1	+	+
Friday	8.0 a.m.	12	2	+	+
	9.0 ,,	10	2	+	+
	10.0 ,, B	12	0	+	+
	11.0 ,,	5	2	+	+
	12.0 m.	4	1	+	+
	2.0 p.m.	1	2	+	+
	4.0 ,,	1	1	+	+
Saturday	8.0 a.m.	0	0	+	+
	10.0 ,,	0	0	–	+
	12.0 m.	0	0	–	–
		40·1	1·28	Percent. purification = 96·9	

Notes :—Culture of *B. coli* added during time between A and B. Averages taken from figures between dotted lines.

+ = Acid and gas in Lactose MacConkey Medium.
– = No change in Lactose MacConkey Medium.

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APPENDIX III.

The filtration through sand and precipitated aluminium hydrate of a coli infected water.

	Time	B. coli per 1 c.c. in unfiltered water	10 c.c. unfiltered water	B. coli per 10 c.c. in filtered water	25 c.c. filtered water
Wednesday	11.0 a.m. A	0	–	0	–
	12.0 m.	64	+	0	–
	1.0 p.m.	88	+	0	--
	2.0 ,,	74	+	0	–
	3.0 ,,	98	+	0	+
	4.0 ,,	94	+	0	+
	5.0 ,,	40	+	0	+
	6.0 ,,	148	+	0	+
Thursday	8.0 a.m.	62	+	0	+
	9.0 ,,	88	+	1	+
	10.0 ,,	110	+	0	+
	11.0 ,,	66	+	8	+
	12.0 m.	12	+	14	+
	1.0 p.m.	8	+	10	+
	2.0 ,,	112	+	24	+
	3.0 ,,	42	+	18	+
	4.0 ,,	124	+	14	+
	5.0 ,,	108	+	20	+
	6.0 ,,	88	+	6	+
Friday	8.0 a.m. B	34	+	2	+
	9.0 ,,	22	+	8	+
	10.0 ,,	0	+	16	+
	12.0 m.	0	+	6	+
	2.0 p.m.	0	+	2	+
	4.0 ,,	0	–	2	+
	6.0 ,,	0	–	14	+
Saturday	8.0 a.m.	0	–	2	+
	10.0 ,,	0	–	6	+
	12.0 m.	0	–	2	+
	2.0 p.m.	0	–	0	+
	4.0 ,,	0	–	2	+
	6.0 ,,	0	--	2	+
Sunday	10.0 a.m.	0	–	4	+
	12.0 m.	0	–	6	+
Monday	10.0 a.m.	0	–	10	+
	12.0 m.	0	–	1	+
	2.0 p.m.	0	–	0	+
	4.0 ,,	0	–	0	+
	6.0 ,,	0	–	0	+

APPENDIX III (*continued*).

Time		B. coli per 1 c.c. in unfiltered water	10 c.c. unfiltered water	B. coli per 10 c.c. in filtered water	25 c.c. filtered water
Tuesday	10.0 a.m.	0	—	2	+
	12.0 m.	0	—	2	+
	2.0 p.m.	0	—	1	+
	4.0 ,,	0	--	0	+
	6.0 ,,	0	—	1	+
Wednesday	8.0 a.m.	0	—	0	+
	10.0 ,,	0	—	2	+
	12.0 m.	0	—	2	+
	2.0 p.m.	0	--	0	+
	4.0 ,,	0	—	1	+
	6.0 ,,	0	—	0	+
Thursday	8.0 a.m.	0	—	2	+
	10.0 ,,	0	--	0	+
	12.0 m.	0	—	2	+
	2.0 p.m.	0	—	1	+
	4.0 ,,	0	--	0	+
	6.0 ,,	0	—	0	+
Friday	8.0 a.m.	0	—	0	+
	10.0 ,,	0	—	0	—
	12.0 m.	0	--	0	—

Average per 1 c.c. = 73·9.   Average per 1 c.c. = 0·4.

Percentage purification = 99·46.

Notes :—The filtered water was examined in quantities of 10 c.c. and 25 c.c. as indicated. The 10 c.c. samples were plated in Rebipelagar – 2·5 c.c. being added to each of four Petri dishes and about 20 c.c. of the Rebipelagar added to each. For the examination of the 10 c.c. of unfiltered water and the 25 c.c. of filtered water, Lactose MacConkey tubes were used.

The averages were taken from the figures between the dotted lines.

The culture of *B. coli* was added during the time between A and B.

+ = Acid and gas in Lactose MacConkey Broth.

– = No change in Lactose MacConkey Broth.

APPENDIX IV.

The filtration of a coli infected water through sand and aluminium hydrate, after there had been much growth of algae in the filter-bed.

	Time	B. *coli* per 1 c.c. of unfiltered water	B. *coli* per 10 c.c. of filtered water	25 c.c. filtered water
Wednesday	11.0 a.m. A	0	0	–
	12.0 m.	12	1	+
	1.0 p.m.	44	0	+
	2.0 ,,	22	4	+
	3.0 ,,	30	12	+
	4.0 ,,	34	12	+
	5.0 ,,	38	16	+
	6.0 ,,	24	20	+
Thursday	8.0 a.m.	22	16	+
	9.0 ,,	38	4	+
	10.0 ,,	42	8	+
	11.0 ,,	30	16	+
	12.0 m.	54	8	+
	1.0 p.m.	60	8	+
	2.0 ,, B	12	13	+
	3.0 ,,	0	16	+
	4.0 ,,	2	8	+
	5.0 ,,	0	5	+
	6.0 ,,	0	3	+
Friday	8.0 a.m.	1	2	+
	9.0 ,,	0	0	+
	10.0 ,,	0	0	+
	12.0 m.	0	0	–

Average = 33 per 1 c.c.   Average = 0·78 per 1 c.c.

Percentage purification = 97·64.

For Notes see Appendix III.

APPENDIX V.

The filtration of a coli infected water through a filter-bed, on the surface of which was an inch of fine sand.

	Time	B. *coli* per 1 c.c. of unfiltered water	B. *coli* per 10 c.c. of filtered water	25 c.c. of filtered water
Friday	10.0 a.m. A	0	0	−
	11.0 ,,	9	0	−
	12.0 m.	10	0	−
	1.0 p.m.	11	0	−
	2.0 ,,	39	10	+
	3.0 ,,	13	0	+
	4.0 ,,	28	15	+
	5.0 ,,	10	20	+
	6.0 ,,	9	5	+
Saturday	8.0 a.m.	17	25	+
	9.0 ,, B	14	15	+
	10.0 ,,	4	8	+
	11.0 ,,	0	0	+
	12.0 m.	0	0	+
	2.0 p.m.	0	0	−
	4.0 ,,	0	0	−
	6.0 ,,	0	0	−

Average = 14·54 per 1 c.c.   Average = 0·98 per 1 c.c.

Percentage purification = 93·26.

For Notes see Appendix III.

APPENDIX VI.

The purification by softening of a coli infected chalk water.
(Plant No. 1.)

Time	B. coli per 1 c.c. of unsoftened water	B. coli per 10 c.c. soft water	25 c.c. of soft water
11.0 a.m. A	25	0	−
11.15 ,,	43	0	+
11.30 ,,	13	3	+
11.45 ,,	4	2	+
12.0 m.	5	0	+
12.30 p.m.	8	4	+
1.0 ,,	9	4	+
1.30 ,,	6	1	+
2.0 ,,	8	1	+
2.30 ,,	12	4	+
3.0 ,,	10	1	+
3.30 ,,	20	3	+
4.0 ,,	19	1	+
4.30 ,,	12	2	+
5.0 ,,	15	0	+
5.30 ,,	14	0	−
6.0 ,, B	15	0	−

Average = 14 per 1 c.c. Average = 0·2 per c.c.

Percentage purification = 98·6.

Note :—The Plant (No. 1) was cleaned before the experiment.

APPENDIX VII.

The purification by softening of a coli infected water. (*Plant No.* 2.)

	Time	B. coli per 1 c.c. of unsoftened water	B. coli per 10 c.c. of softened water	25 c.c. of softened water
Tuesday	11.30 a.m. A	24	0	−
	12.0 m.	36	0	−
	12.30 p.m.	39	2	+
	1.0 ,,	43	3	+
	1.30 ,,	27	5	+
	2.0 ,,	44	10	+
	3.0 ,,	29	2	+
	4.0 ,,	36	0	−
	5.0 ,,	41	0	−
Wednesday	8.0 a.m.	10	0	−
	9.0 ,,	2	0	−
	10.0 ,,	0	0	−
	11.0 ,,	1	0	−
	12.0 m.	0	0	−

Average = 35·44 per 1 c.c. Average = 0·44 per 1 c.c.

Percentage purification = 98·76.

Note :—It will be seen from the above Table and from Appendix VI, that the purification given by these softening plants reaches 100 per cent. after the plants have been working a few hours. This plant was cleaned before the experiment.

APPENDIX VIII.

The purification of a coli infected chalk water by softening.
(Plant No. 1.)

Time	B. coli per 1 c.c. of unsoftened water	B. coli per 10 c.c. of softened water	25 c.c. of soft water
11.0 a.m. A	16	0	–
11.15 ,,	48	0	–
11.30 ,,	44	0	–
11.45 ,,	42	0	–
12.0 m.	42	0	–
12.30 p.m.	50	0	–
1.0 ,,	34	0	–
1.30 ,,	38	0	–
2.0 ,,	44	0	–
2.30 ,,	28	0	–
3.0 ,,	14	0	–
3.30 ,,	36	0	–
4.0 ,,	34	0	–
4.30 ,,	34	0	–
5.0 ,,	24	0	–
5.30 ,, B	20	0	–

Percentage purification = 100.

Note :—The plant was cleaned, and then allowed to work for four hours before the culture of *B. coli* was added. During that time the canvas filtering bags became coated with a thin film of calcium carbonate.

APPENDIX IX.

The purification by softening of a coli infected water. (Plants Nos. 1 & 2.)

Time	B. coli per 1 c.c. in unsoftened water	No. 1 Plant B. coli 10 c.c. soft water	No. 2 Plant B. coli 10 c.c. soft water	No. 2 Plant 25 c.c.
10.30 a.m. A	26	0	0	–
11.0 ,,	190	12	0	–
11.30 ,,	271	20	0	–
12.0 m.	243	30	0	–
12.30 p.m.	150	20	0	–
1.0 ,,	149	30	0	–
1.30 ,, B	151	8	0	

Average = 169 per 1 c.c.   Average = 2 per c.c.

Percentage purification for No. 1 Plant = 98·8.

,,   ,,   ,,   2 ,,   = 100.

Notes :—No. 1 Plant was newly cleaned. No. 2 had not been cleaned for several days.

Owing to a mistake, no samples were taken later on the day of this experiment. The Table, however, shows well the difference between a newly cleaned plant and one on the bags of which there is a precipitate of calcium carbonate.

APPENDIX X.

The purification by softening of a coli infected water. (*Plants Nos.* 1 & 2.)

Time	B. coli per 1 c.c. of un-softened water	No. 1 Plant. B. coli per 10 c.c. soft water	25 c.c. soft water	No. 2 Plant. B. coli per 10 c.c. soft water	25 c.c. soft water
Tuesday 11.0 a.m. A	0	0	—	0	—
11.30 ,,	176	4	+	0	—
12.0 m.	152	12	+	0	—
12.30 p.m.	142	20	+	0	—
1.0 ,,	196	16	+	0	—
1.30 ,,	180	44	+	0	—
2.0 ,,	180	20	+	0	—
2.30 ,,	182	20	+	0	—
3.0 ,,	160	12	+	0	—
3.30 ,,	154	0	+	0	—
4.0 ,,	150	4	+	0	—
4.30 ,,	152	0	+	0	—
5.0 ,, B	154	0	—	0	—
Wednesday 8.0 a.m.	11	0	—	0	—
9.0 ,,	1	0	—	0	—
10.0 ,,	0	0	—	0	—
11.0 ,,	1	0	—	0	—
12.0 m.	0	0	—	0	—
1.0 p.m.	0	0	—	0	—
2.0 ,,	0	0	—	0	—
3.0 ,,	0	0	—	0	—
4.0 ,,	0	0	—	0	—
5.0 ,,	0	0	—	0	—
6.0 ,,	0	0	—	0	—

Average = 164·83 per 1 c.c.   Average = 1·52 per 1 c.c.

Percentage purification given by No. 1 Plant = 99·08.

,,   ,,   ,,   ,,   2 ,,   = 100.

Notes:—No. 1 Plant was cleaned before the experiment. No. 2 had not been cleaned for several days. It is seen from the figures that when once *B. coli* has been eliminated from the water, it does not reappear—in other words that when the softening plants become efficient to the fullest extent they remain so until the layer of calcium carbonate on the filtering bags is disturbed at the next cleaning.

For other notes see Appendix III.