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“The Bacterial Purification of Water.”

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INTRODUCTION.

IN April, 1886, the Author laid before the Institution the results of investigations on the bacterial purification of water which he had been carrying out by means of the then new bacteriological methods.¹ He demonstrated the remarkable effect produced by sand-filtration, as performed by the London Water Companies, on the bacteria present in the water derived from the Rivers Thames and Lea; and pointed out that, whilst from a chemical point of view the process of sand-filtration had been regarded as of comparatively little value in regard to purification, his investigations showed that from a biological point of view, on the other hand, such filtration when efficiently conducted was of the very highest importance. He was further able to indicate, from a careful study of the various conditions obtaining at the different London waterworks, some of the principal factors upon which, in his opinion, depended the production of a satisfactory filtrate. The discovery then announced is now universally acknowledged and abundantly confirmed by numerous laborious researches which have been conducted in almost every quarter of the globe; and each year further light is thrown upon this complicated and important subject of water-purification. The present appears, therefore, a fitting time to review what has been accomplished in this direction during the past decade, and to set forth as far

¹ “Water Purification: its Biological and Chemical Basis.” *Minutes of Proceedings Inst. C.E.*, vol. lxxv. pp. 197 *et seq.*

as is possible in a succinct form the existing state of knowledge concerning the conditions, both natural and artificial, upon which the bacterial purification of water depends. For this purpose, the Author will deal with the subject in two parts: first, the bacteriological value of natural, and, second, that of artificial purification processes.

I. BACTERIAL PURIFICATION BY NATURAL PROCESSES.

(a) *The "Self-Purification" of River Water.*—There is probably no subject connected with the hygienic elements of water-supply which has so much engaged the attention of public authorities and excited such warm controversy amongst experts. Until a few years ago, however, the chemical side of the question was the ground upon which most of the discussions were fought out; the biological side of the subject being all but inaccessible in consequence of the rudimentary state of bacteriological knowledge. Now, however, this aspect of the subject may be surveyed also; for, by the rapid strides which have been made in bacteriology, an intimate acquaintance has been gained of the nature and habits of many of those living or organized impurities which may be present in water, and, in comparison with which, the unorganized or lifeless impurities sink into relative insignificance.

The evidence which during the past few years has been accumulated by many different observers on the most varied water-courses, shows almost without an exception that the number of bacteria present in a running stream becomes diminished during its natural flow. This bacterial purification of running water is displayed in the investigations of Frank¹ on the River Spree below Berlin, in those of Prausnitz² on the River Isar below Munich, as well as those of Schlatter³ on the River Limmat below Zurich, whilst the Author, in July, 1892, obtained evidence of the same phenomenon in the case of the River Dee from which the water-supply of Aberdeen is drawn.

Above Braemar the Dee was found to yield only 88 micro-organisms in 1 cubic centimetre, and is, therefore, bacteriologically of great purity. The next sample was taken from the river below Old Mar Castle, and after thorough incorporation of the tributary Cluny, which receives the sewage of Braemar.

¹ Zeitschrift für Hygiene, vol. iii. p. 355.

² Der Einfluss der Münchener Canalisation auf die Isar. München, 1889.

³ Zeitschrift für Hygiene, vol. ix. p. 56.

This accession is marked by a large increase in the number of microbes, as many as 2,829 being found in 1 cubic centimetre. Another sample was taken above the Bridge of Ballater; and it shows that the number of micro-organisms has been reduced by rather more than one-half in the flow from Old Mar Castle to this point, for only 1,139 were found in 1 cubic centimetre. A sample from the Dee 100 yards below the Ballater sewage-pond outfall, on the other hand, shows a large increase in the number of micro-organisms, as many as 3,780 being obtained in 1 cubic centimetre. On following the river down, a sample was taken above the junction of the Neil Burn, and it was found that the number of micro-organisms had again fallen to about the same as that above Ballater, viz., 938 in 1 cubic centimetre. Below the entrance of the Neil Burn, a polluted stream, which at the time of the investigation was a mere dribble, the number of micro-organisms had perceptibly increased, 1,860 being found in 1 cubic centimetre. The river on reaching Invercannie, however, again exhibited just about the same number of micro-organisms as above the Neil Burn or above Ballater, only 950 being found in 1 cubic centimetre. The total length of the river which was covered by the examination was upwards of 40 miles.

The foregoing investigation on the Dee is especially interesting, as the amount of polluting material gaining access at these several points is so small in comparison with the volume of the stream itself, that it was found impossible by chemical analysis to detect any material alteration in the composition of the water of the river, even immediately below each of the above sources of contamination. By means of the bacteriological examination, however, as indicated, each source of pollution was found to have produced an unmistakable, although transitory, effect on the water of the stream.

If enquiry be made into the mechanism by which this undoubted disappearance of bacteria in running water is effected, a number of factors must be taken into consideration, which, although not necessarily all coming into play at one and the same time, or in every water-course, must yet, according to present knowledge, be held responsible for the bacterial improvement which such running waters undergo during their natural flow.

Insolation.—One of the factors to which, perhaps on account of its novelty, great prominence has recently been given in this connection, is the remarkable destructive effect which the sun's rays have been found to exert on bacterial life. It would be impossible to give here a detailed description of the numerous

investigations which have been made on this interesting subject¹; but it will be necessary to review briefly several important researches which have a direct bearing on the question. This is perhaps the more necessary, because solar enthusiasts have been led, especially on the Continent, to take such an exaggerated view of the powers of insolation in effecting the bacterial purification of water, that even the discharge of untreated sewage into rivers and streams has been seriously counselled, in the belief that sunshine would destroy all the noxious organisms which might be present in such pollutions. Now, although the bactericidal action of light is altogether beyond question, it must in the first place be borne in mind that, so far as is now known, microbes are less sensitive to its lethal influence when they are suspended in water than when they are present in ordinary culture-media. Hence it will be necessary in endeavouring to assess the potency of the sun's rays to destroy bacteria in water, to confine attention for practical purposes to those investigations which have been carried out with microbes actually in water.

In pursuing the enquiry in this direction, the fact is at once apparent that the bactericidal action of light is not co-extensive with the penetration of the sun's rays, but is confined to the upper layers of the water upon which these rays are incident. This point has been conclusively demonstrated by Procaccini,² who exposed drain-water containing an abundance of bacteria to bright sunshine in cylindrical glass vessels 50 centimetres in depth. The following Table gives the results obtained. The exposure to bright sunshine extended over a period of six hours, from 9 A.M.

	Insolated Cylinder.	Darkened Cylinder.
	Number of Microbes per Cubic Centimetre.	Number of Microbes per Cubic Centimetre.
Before exposure :—		
Surface	4,900	4,900
Centre	4,510	4,510
Bottom	6,781	6,781
After insolation :—		
Surface	0	7,261
Centre	2	9,051
Bottom	8	12,591

¹ For further information see the Author's work, "Micro-organisms in Water," Longmans, 1894, chap. ix. p. 333.

² Annali dell' Istituto d' Igiene Sperimentale di Roma, vol. iii., 1893.

to 3 P.M. in the month of June; a control-cylinder containing the same water being submitted to precisely similar conditions, excepting only that it was protected from all access of light. Here is unmistakable evidence of the remarkable bactericidal power of the sun's rays when they are permitted to enter a cylindrical column of water, both from above and from the sides under the most favourable conditions. It should be pointed out, in connection with this experiment, that the water employed had been previously filtered, to remove the coarser particles in suspension, the presence of which would have materially intercepted the solar rays. Indeed the presence or absence of turbidity in a water is another circumstance which must be taken into consideration in estimating the bactericidal power of sunshine, a point to which reference will be made later.

In another series of experiments Procaccini¹ endeavoured to ascertain what part in this destruction of microbes is played by those rays which impinge upon the surface of the water. For this purpose he carefully prevented all rays from entering the sides of the glass cylinders in question, hoping thus to determine the depth beneath the surface to which the bactericidal action of the sunshine extends. The results of such experiments are given in the following Table. The exposure extended over three hours (12 noon to 3 P.M.) during the month of June :—

	Insolated Cylinder.	Darkened Cylinder.
	Number of Microbes per Cubic Centimetre.	Number of Microbes per Cubic Centimetre.
Before exposure :—		
Surface	2,100	2,100
Centre	2,103	2,103
Bottom	2,140	2,140
After insolation :—		
Surface	9	3,103
Centre	10	3,021
Bottom	2,115	3,463

Thus it was found that no reliance could be placed on the power of even Italian sunshine, when acting continuously for three hours in the height of summer to destroy microbes in water at the insignificant depth of 50 centimetres. Buchner,² again, in some

¹ *Annali dell' Istituto d' Igiene Sperimentale di Roma*, vol. iii., 1893.

² *Archiv für Hygiene*, 1893.

experiments made on the Starnberger lake near Munich, in water which was relatively clear and transparent compared with that employed by Procaccini, found that at a depth of 5 feet below the surface of the lake, the bactericidal power of the sun's rays, although acting over a period of $4\frac{1}{2}$ hours, was no more recognisable.

Another circumstance which must be taken into consideration, in forming an estimate of insolation as a purifying agent, is that a microbe's power of resistance to any given adverse conditions, is largely dependent on its initial vitality, and on its state of development, *i.e.*, whether it is present in the hardy spore form, or in the form of the comparatively fragile bacillus. Thus the Author has found¹ that anthrax spores produced at a temperature of 18° to 20° C., are far more resistant to sunshine in water than anthrax spores produced at a higher temperature, 35° to 38° C.; whilst numerous investigators have shown that the bacilli are much more readily destroyed by sunshine than their spores. Whilst Procaccini's experiments sufficiently indicate what may be expected of sunshine in the destruction of noxious organisms in water, and whilst due credit must be given to insolation for what it can actually accomplish, it is obvious that its powers are restricted within comparatively narrow limits, especially in a climate like that of England, in which it frequently happens that for days and even weeks at a time no sunshine is recorded.

Before passing to the next factor concerned in the natural purification of water, the Author would briefly point out that some interest has recently been aroused in this subject of the bactericidal action of light in connection with the relative merits of open and closed reservoirs for the storage of water. It has been advanced that if light is capable of effecting this remarkable destruction of bacteria, and that the dangers of potable water are dependent on the possible presence of noxious bacteria; it is surely only logical that all waters should be exposed to the maximum amount of light before distribution for domestic purposes, and that all reservoirs destined to contain such water should be freely exposed to daylight. It must, however, be remembered that by exposing water to light, an opportunity is thereby afforded for the direct transformation of mineral into organic matter through the instrumentality of green plants, which

¹ Report of the British Association for the Advancement of Science, 1893, p. 461.

are only capable of flourishing in the presence of light. By thus inducing the growth of green plants, a door would therefore be opened to the contamination of the water with the products of decaying vegetable matter; a form of contamination which, whilst incapable of directly producing zymotic disease, is nevertheless quite capable of rendering a water so unpalatable as to be unfit for dietetic use, and possibly even of occasioning diarrhoea and similar ailments amongst its consumers. In spite of these recent revelations concerning the bactericidal action of light, it is therefore still to be recommended that the all but universal practice in vogue with waterworks engineers of storing subterranean and filtered waters in reservoirs protected from daylight should be continued, as such waters are liable to suffer most serious deterioration by exposure to this influence.

Sedimentation and Dilution.—In the practice of waterworks engineering, there is no method of improving the quality of surface waters of which so much advantage has been taken, as that of permitting them to remain at rest for a longer or shorter period in large reservoirs. Not only do such waters thereby become comparatively clear and bright by the subsidence of mechanically suspended particles, but, if the storage be sufficiently prolonged, a very considerable reduction in the amount of dissolved organic matter may also take place. In the Author's experiments¹ on the purification of water by agitation with solid particles, it was shown for the first time how, with the subsidence of the materials in suspension, a most remarkable removal of the bacteria present is also effected. It became, therefore, of great interest to ascertain whether this same bacterial purification by means of sedimentation occurs under the natural conditions afforded during the storage of water in reservoirs; and this point the Author had more recently an opportunity of investigating² at the works of the London Water Companies.

A single series of the results obtained in these investigations, will convey a clear impression of what is bacterially effected by such storage. Thus samples of Thames water were collected at the intake of the West Middlesex Company's works at Hampton. This water contained 1,437 bacteria per cubic centimetre. After passing through one storage reservoir, the water contained only 318, and after passing through a second storage reservoir the

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

² Royal Commission on Metropolitan Water-Supply.—Centralblatt für Bakteriologie, vol. xiii. p. 122.

number was further reduced to 177 in 1 cubic centimetre. That such sedimentation also takes place during a river's flow, numerous investigators are prepared to admit, but the extent of the purification thus effected depends upon the opportunities afforded for subsidence, and such opportunities may be present in one water-course and absent in another. Thus Frank¹ has shown how the bacteria of the River Spree, in its flow both above and below Berlin, undergo continual increase in consequence of the numerous sources of pollution to which the water is exposed all along its course until it reaches the Havel Lake. In this lake, which is 7 miles in length, in consequence of the diminished velocity with which the water flows, a subsidence of matters in suspension is effected; and the number of bacteria falls, both in consequence of this sedimentation as well as through the addition of a certain amount of pure spring water. Schlatter,² again, has shown that a similar bacterial purification takes place in the River Limmat; and he states that after a flow of 10 kilometres the microbial condition of the water, in spite of its having received the drainage of Zurich, very often approaches that of the river before contamination with sewage. Schlatter also points out that when the rate of flow of the river is more rapid than usual, and the volume of water passing down the river is correspondingly increased, then the admixture of sewage in the vicinity of Zurich is not bacterially so marked, but that lower down the number of bacteria present is above the average; a circumstance which he attributes to the more rapid current of the water preventing the usual degree of bacterial sedimentation from taking place.

Particularly instructive in this connection are the investigations of Dr. Heider³ on the water of the Danube, in which he found that even 40 kilometres below the point where the sewage of Vienna is admitted, no bacterial improvement could be discovered. This he attributes to the interference with sedimentation processes occasioned by the very rapid flow of the river, and the constant disturbance of the water by steamboats. But perhaps the most striking example of how this now well-recognised process of sedimentation can be taken advantage of practically has been recently furnished by Dr. H. J. van 't Hoff⁴ in connection with the Rotterdam water-supply. This city obtains its water from the River Maas, and the intake is situated

¹ *Zeitschrift für Hygiene*, vol. iii. p. 355.

² *Ibid*, vol. ix. p. 56.

³ *Centralblatt für Bakteriologie*, vol. xv. p. 20.

⁴ *Ibid*, vol. xviii. p. 265.

actually within the tidal area of the river; the water is, however, only abstracted two hours after high water has been reached. During this period the river has been at rest and becomes visibly relieved of much of its suspended impurities, and this sedimentation of the coarser particles is accompanied by an important removal of bacteria, amounting to about 50 per cent. of those present. Dr. van 't Hoff ascribes the satisfactory bacterial character of the filtrate obtained at the Rotterdam Waterworks, in spite of the grossly polluted water employed, largely to this preliminary removal of bacteria by sedimentation. Although the water is submitted to sand-filtration before delivery, yet so great is the demand upon the resources of the waterworks, that the filtration has to be conducted at a considerably greater rate than is now regarded as admissible if a bacterially satisfactory filtrate is to be produced. This question of preliminary purification prior to filtration will be referred to later in connection with the subject of sand-filtration.

That dilution with purer water is also a factor which in some cases largely contributes to bring about the so-called "self-purification" of river-water is too obvious to require further comment; indeed it is very doubtful whether this factor is ever altogether absent in any of the examples which have been cited.

Algae and Chemical Oxidation.—So far, consideration has been given to the parts played by insolation, sedimentation and dilution in purifying water bacterially, but there are other factors which must be taken into account. It has been contended by Dr. von Pettenkofer¹ that sedimentation is in no way concerned in the removal of bacteria from river water, and he entirely traverses Prausnitz's² conclusions as to the causes which bring about the almost complete disappearance of the effects of admitting the Munich sewage into the River Isar within a distance of some 30 kilometres, or during a flow of about eight hours. Thus, whilst Prausnitz ascribes this remarkable purification principally to sedimentation processes, Dr. von Pettenkofer attributes it to chemical oxidation and the action of aquatic vegetation.

As regards the effect produced by algae on the growth of bacteria in water, there is but little direct experimental evidence, but that algae may and do cause a marked removal of organic matter from water has been stated by many experimenters.³ Pfeiffer and Eisenlohr⁴

¹ Archiv für Hygiene, vol. xii. p. 269.

² Hygienische Tagesfragen, vol. ix., Munich, 1890.

³ Zeitschrift für Hygiene, vol. xx. p. 343.

⁴ Archiv für Hygiene, vol. xiv. p. 190.

found algae always abundantly present in the River Isar, in those places where the quantity of organic matter was large. Thus in those parts of the river below Munich in which the pollution of the stream was marked, algae were conspicuous; whilst above the city, before the stream had suffered contamination, as well as lower down after the stream had undergone "self-purification," no algae could be detected. Some direct laboratory experiments bearing upon this point have been carried out by Dr. Hoeber,¹ with a view to ascertain the effect of water weeds and ordinary water bacteria on anthrax germs in water, and the conclusion he arrived at was that they were distinctly prejudicial to the continued existence of the anthrax germs in a living state. The Author also had an opportunity, a few years ago, of making a bacteriological examination of the water of a loch from which a large city in Scotland is supplied. This water was so full of algae as to be practically opaque when viewed in a glass tumbler, and the number of bacteria present was surprisingly small.

It is obvious that, in this branch of the subject, there is room for much further research; but as far as investigation has yet been carried, there would appear to be considerable evidence that green aquatic vegetation is hostile to bacterial life.

Temperature.—Temperature has also been asserted to be of moment in determining the bacterial condition of a stream at different times of the year. Laboratory experiments² have abundantly proved that the multiplication of some water-microbes is greatly stimulated by raising the temperature of the water; and it might, therefore, be expected that streams would contain considerably more bacteria in summer than in winter. But the reverse is almost invariably the case, as the Author showed for the first time ten years ago in the course of his monthly bacteriological examinations³ of the rivers Thames and Lea, *Fig. 1*. He then pointed out that this circumstance was doubtless principally dependent on the fact that during the summer these rivers were largely fed with pure spring water, whilst during the wet seasons of the year they were largely composed of water which has washed the surface of cultivated land. Similar results in the case of a number of other streams have more recently been obtained by various observers.

¹ Centralblatt für Bakteriologie., vol xvii. p. 443.

² "On the Multiplication of Micro-Organisms," Proceedings of the Royal Society, vol. xl. p. 526; "Experiments on the Vitality and Virulence of Sporiferous Anthrax in Potable Waters," Proceedings of the Royal Society, vol. liii. p. 222.

³ Local Government Board Reports, 1886, 1887, 1888.

Movement.—The movement of running water has also been cited as probably acting antagonistically on bacterial life. This is a subject on which, in spite of numerous investigations, a great diversity of opinion still exists; some authorities holding that agitation is favourable to the growth of bacteria in culture-media, whilst others maintain a directly opposite view. In his last report to the Royal Society Water Research Committee¹ the Author gave some results which he had obtained in studying the effect of agitation on the common bacteria present in ordinary water. These went to show that, on the whole, their growth was encouraged

Fig. 1.

MONTHLY BACTERIOLOGICAL DETERMINATIONS OF UNFILTERED WATER FROM THE RIVERS THAMES (HAMPTON) AND LEA (CHINGFORD).

by this movement. In the case, however, of sterilized water infected with typhoid bacilli, agitation appeared to hasten the destruction of these microbes. It is not improbable, therefore, that more extended investigation of this point will show that agitation may be favourable to some and detrimental to other forms of bacteria.

(b) *Filtration through Porous Strata.*—The most perfect, and on the whole the most important, of the natural processes concerned in the

¹ Proceedings of the Royal Society, vol. lviii. p. 265.

bacterial purification of water is filtration through porous strata. The great efficiency of this process is perhaps best illustrated by a bacteriological examination of the water obtained by continuous pumping from deep wells sunk into such porous strata as those of the chalk formation. Such an examination generally reveals the fact that in these waters, even as brought to the surface, bacterial life is almost absent. Thus, in the chalk-wells of the Kent Water Company, the Author has on many occasions found less than 10 microbes in 1 cubic centimetre. To appreciate the relative scarcity of bacterial life implied by these numbers, it is only necessary to recall the fact that such surface-waters as the Thames at Hampton contain, according to the Author's examinations, from 1,000 to 120,000 micro-organisms in the same volume.

Thus, great as may be the purification of surface-waters effected by the united action of the several factors alluded to, their joint effect in removing bacteria does not compare with that which results from the filtration of water through great depths of porous strata. The high efficiency of this natural filtration in removing bacterial life which was clearly set forth in the Author's previous Paper,¹ has been confirmed by the more recent experience gained both by him and by many other observers.

II. BACTERIAL PURIFICATION BY ARTIFICIAL PROCESSES.

In regard to this section of the subject, again a great number of investigations have been carried out in many parts of the world, both in the laboratory and on the large scale at waterworks. It would be impossible within the compass of the Paper to do justice to all these researches; and the Author therefore confines attention to those investigations which have been chiefly instrumental in extending knowledge of the principal factors upon which the bacterial purification of public water-supplies is dependent.

It has been already seen how highly important is the storage of water in reservoirs before submitting it to further processes of purification; so it will not be necessary to enter into further detail on this head. It is interesting, however, to note how the bacteria may vary at different depths of one and the same water-basin, as this is of no little importance in connection with the abstraction of water for purposes of supply. Perhaps

¹ Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 279.

the most instructive experiments in this direction are those of Karlinski,¹ who examined the water of a lake in Herzegovina, the bacteriological determinations being made both aëroically and anaëroically, so that the maximum number of microbes should be discovered. In 1 cubic centimetre of water taken from near the surface of this lake as many as 4,000 bacteria were found; at a depth of hardly 5 metres 1,000 were present, whilst at a depth of 10 metres there were rarely more than 600. Still lower down, between 12 metres and 16 metres, there were only 200 to 300 present in the same volume. At the bottom of the lake, however, on stirring up the mud, as many as 6,000 microbes in 1 cubic centimetre were found. These results, which are fully confirmed by similar observations made by Russell² on the bacterial life present in sea-water at different depths, are highly instructive, showing, as they do, that the water most free from bacteria must be drawn from beneath the surface on the one hand, whilst, on the other hand, any disturbance of the sediment at the bottom should be carefully avoided.

Sand Filtration.—In the Author's communication to the Institution in 1886, after describing the investigation which he had made of the relative bacterial purification effected by the several London Water Companies in dealing with the waters of the Thames and Lea, and taking into consideration their respective modes of procedure, certain conclusions were drawn as to what should be the guiding principles in conducting these purification processes.

The principles then enumerated were:—

(1) To give the maximum period of storage for the unfiltered water.

(2) To filter at a minimum rate.

(3) To filter through a maximum depth of fine sand.

(4) To frequently renew the filtering materials.

In reviewing the numerous investigations since carried out on this subject, it will be shown that the only one of these principles which requires any modification, by the light of more recent research, is the last. In order to facilitate the survey of the recent material gathered together on this subject, it is arranged under the above headings.

(1) *Storage of Unfiltered Water.*—The bacterial improvement which takes place during the storage of waters in natural or artificial reservoirs has been already referred to; and this storage

¹ Centralblatt für Bakteriologie, vol. xii. p. 220.

² Zeitschrift für Hygiene, vol. xi. p. 177.

admits also of the subsidence of the coarser particles in suspension, and thus facilitates the subsequent filtration from a purely mechanical point of view. In addition to the evidence already adduced as to the great practical importance of this storage the Author will only cite the following recent example, which may be of interest in this connection.

At the Altona Waterworks,¹ the water from the Elbe was until recently pumped up to a reservoir from which it flowed into two "strainer-basins," and from these again into the two real "sedimentation-basins," of a capacity of about 5,000 cubic metres each, where it was allowed to remain undisturbed for about six hours. The layer of mud which collected in three months to four months had a depth of between 150 centimetres and 180 centimetres in the first reservoir, 50 centimetres in the strainer-basins, and between 25 centimetres and 40 centimetres in the sedimentation-basins. This mud, as might be anticipated, was found to be enormously rich in bacterial life. Numerous examinations showed that it contained on an average upwards of 17,000,000 bacteria in 1 cubic centimetre; whilst even the slimy layer of water immediately above the mud contained on an average upwards of 1,000,000 bacteria in the same volume. When these reservoirs were being cleaned out, the muddy water passed on to the filters, with the result that unsatisfactory filtrates were obtained. This defect has, however, now been remedied, and only water which has been submitted to proper sedimentation is pumped into the high-level reservoirs to feed the filters.

Adequate storage-capacity is also obviously of great importance on other grounds, inasmuch as it obviates the necessity of abstracting water when the river or other source of supply is turbid and polluted by floods and the like. On this account ample storage-capacity has, in England at any rate, been long recognised as a feature of primary importance in the management of all water-supplies liable to turbidity at their source.

(2) *Rate of Filtration*.—So long ago as 1885, in connection with the Author's laboratory experiments, it was pointed out that the removal of micro-organisms by a given filtering medium is less perfect the greater the rate at which the filtration is carried on; and in 1886 he brought before the notice of the Institution the striking coincidence between theory and practice in this respect as exhibited by the filtration results actually obtained by the several London Water Companies. Since that time a large number

¹ Centralblatt für Bakteriologie, vol. xvi. p. 881.

of investigations on the filtration of water through sand have been carried out both in America and on the Continent, and there has been a gradual tendency to reduce the rate of filtration. Thus, in 1866,¹ leading engineers recommended a rate of 3·11 gallons per square foot per hour. In 1868 the average yield of the London filters amounted to 1·73 gallon per square foot per hour; whilst in 1885 the rate had been reduced to 1·28 gallon per square foot. Since that time, however, it has been slightly increased. The new filters erected at the Hamburg waterworks in 1892-3 were intended to filter at a rate of only 1·27 gallon per square foot per hour; whilst the still more recent filters built at Tegel for the Berlin supply are constructed to yield 2·05 gallons per square foot per hour.

As illustrating the effect of an excessive rate of filtration on the bacterial quality of the filtered water, the following figures were obtained by the Author some years ago in the case of a Scotch water-supply, in which the rate of filtration averaged 5 gallons per square foot per hour:—

	Number of Micro-Organisms per Cubic Centimetre.
Unfiltered water	3,414
Filter-well No. 1	181
" " " 2	232
" " " 3	197
" " " 4	74
" " " 5	324
" " " 6	566
" " " 7	112
" " " 8	42

The efficiency of the filtration, as exhibited by the above results, is markedly inferior to that which he has so frequently found in the case of the London waterworks with the much lower rate of filtration there practised. The elaborate investigations carried out by the Massachusetts State Board of Health² on the working of sand-filters, also conclusively demonstrated that a marked increase in the rate of filtration produces a corresponding increase in the number of bacteria in the filtrate. The increase was shown, moreover, to be due not alone to the more rapid flow of water washing out bacteria which had accumulated or grown in the under-drains or gravel at the bottom of the filter-bed, but to the fact that more bacteria actually passed through the sand when the rate of filtration was increased.

¹ "The Filtration of Public Water-Supplies," by Allen Hazen. New York, p. 43.

² "Experimental Investigations by the State Board of Health of Massachusetts upon the Purification of Sewage, and the Intermittent Filtration of Water, 1888-1890," Part ii. Boston, 1890.

Although on general grounds it is desirable that the rate of filtration should be reduced to a minimum, the rate adopted in actual practice must depend upon the individual character of the water which has to be filtered. Thus admirable results are obtained at the Zurich Waterworks with such a high rate as 5·58 gallons per square foot per hour, owing to the pure and limpid nature of the lake-water there dealt with. Not only, however, must the rate of filtration be kept down, but it is also of the greatest importance that it should be maintained as uniform as possible, and this is a point to which the Author believes engineers give insufficient attention. It must be remembered that fluctuations in the rate of filtration may lead to disturbance of the layer of slime which forms on the surface of the sand, and a rent in this layer may greatly interfere with the bacterial purity of the filtrate.

(3) *Depth of Fine Sand.*—The construction of a sand filter-bed is well known. In the Author's former communication he indicated the importance attaching to the depth of the fine sand employed, and will now only point out how this view has been confirmed by more recent investigations. Consideration of these investigations is, perhaps, specially called for, inasmuch as there has been a tendency in many quarters to attribute the removal of bacteria by sand-filters too exclusively to the layer of slime which forms on the surface, and to altogether disregard the part played by the sand itself. Although there is no doubt that this layer of slime is of the greatest importance in securing the bacterial purity of the filtrate, it must be recognised that the depth of fine sand cannot be unduly diminished without also seriously influencing the purity of the filtrate.

Several investigations have recently been made to obtain decisive information on this matter. At the Zurich Waterworks it was found that a filter-bed, which had hitherto yielded an excellent filtrate, became inefficient when the thickness of the layer of fine sand was reduced to 25 centimetres. It was in consequence decided not to reduce the thickness in future to less than 30 centimetres, and when this limit was reached, in the course of successive scrapings, renewal of the sand was commenced. The investigations made by Reinsch¹ at the Altona Waterworks, show that, not only does an increase in the number of bacteria accompany reduction in the depth of the fine sand employed, but also that any untoward interference with the customary working of the filters is followed

¹ Centralblatt für Bakteriologie, vol. xvi. p. 881.

by far less disturbance of the bacterial quality of the filtrate in the case of filters provided with a thick layer of sand than in those in which the depth of sand is smaller. Thus, on one occasion the filters became clogged in consequence of a large amount of suspended matter in the raw water, and the process of "airing" was adopted to render them more pervious; this process, which cannot be sufficiently deprecated, consists in shutting the filter-valves so as to cause the air entangled in the filter-bed to work its way to the surface, thus opening up the pores of the filter. After this process, the number of bacteria in the filtrates from the several beds increased by the following amounts:—

From 38 in 1 cubic centimetre to 2,936		{ in the filtrate from a filter with }		510 millimetres of sand	
46	"	2,760	"	530	"
38	"	360	"	920	"
38	"	294	"	890	"

Thus, whilst in the case of the first two filters, with their reduced thickness of sand, the bacteria in the filtrate were increased to the extent of 60 to 77 times their former number, the other two filters working with greater thicknesses of sand experienced an increase in the number of the bacteria in the filtrate to the extent of only 7·7 to 9·4 times the number previously present. It is therefore, advisable that in the repeated cleaning of a filter by scraping, the depth of the sand should never be too far reduced. The German Imperial Board of Health has fixed 12 inches as the lowest limit to which the thickness may be diminished, whilst a greater depth is recommended wherever possible. Whilst duly recognising the importance of the thickness of fine sand in producing a good filtrate, there can be no doubt that the layer of slime on the surface of the filter-bed exerts a highly important effect on the bacterial quality of the filtrate. On the one hand, the greater thickness of the sand must be regarded as affording a stronger supporting frame or skeleton for this layer of slime; whilst on the other hand, the more circuitous path which the water has to take through the greater depth of sand doubtless leads to many bacteria attaching themselves to its particles with their glutinous coatings.

Action of Surface-Slime.—The importance of the formation of a deposit of slime on the surface of sand-filters was first experimentally demonstrated by Fränkel and Piefke,¹ who found that

¹ Zeitschrift für Hygiene, vol. viii. p. 1; also "Die Principien der Reinwassergewinnung vermittelt Filtration," Piefke, Berlin, 1887.

until the filter has become clothed with this mantle, the filtrate is bacterially unsatisfactory. Such significance is now attached to this deposit, that in order to promote its formation after scraping, or in the case of freshly built filter-beds, the practice has been recommended of leaving, in the first instance, the unfiltered water undisturbed on the bed for twelve hours, and then to commence filtration at a very low rate. It is also recommended that the first filtrate should be run to waste until the filter has arrived at the condition to yield a bacterially satisfactory filtrate.

As already mentioned, however, too implicit confidence has in some quarters been placed in the microbe-retaining power of this slime deposit, and it is highly important that the other factors contributing to the production of a bacterially satisfactory filtrate should not be neglected. Indeed, Reinsch has shown that the water, after passing through the slime deposit, still contains such numbers of bacteria as would be inadmissible in a good filtrate. This was demonstrated by constructing an experimental filter in which all the conditions obtaining at the Altona works were faithfully imitated; the bed was enclosed in cement, the lateral walls being perforated by eight holes through which tin-lined pipes were passed, penetrating 30 centimetres into the filter at different levels. These pipes, before being thus introduced, were carefully sterilized, so as to avoid complicating the result by importing organisms foreign to the water.

The Table, p. 101, exhibits the number of micro-organisms per cubic centimetre in the raw water with which the filter was supplied, as well as in the water drawn on the same day from the different layers of the filter by the contrivance described. The Table indicates clearly that the surface-layer of slime is not capable of retaining all the microbes present, but that on the contrary considerable numbers succeed in finding their way into the subjacent layers of sand. Thus, on the 24th July, as many as 29 per cent. of the initial number were found in the effluent from pipe No. 2, 30 millimetres beneath the surface. The number, however, gradually diminishes in the effluents from the successive pipes, and of this 29 per cent. at a depth of 400 millimetres (pipe No. 4) less than 1 per cent. remain. In all cases, however, it will be observed that the number present in the effluent from pipe No. 8 (placed in the layer of stones of walnut size) is larger than in the effluents derived from the pipes in the middle of the column of sand. This circumstance is probably due to the larger interstices between the stones affording less opportunity for the surface attachment of the bacteria; and

those multiplying there are more readily washed out from this layer by the current of water. The number of bacteria in the water derived from the delivery-pipe of the whole filter is always in close accord with that found in the water obtained from this last pipe.

NUMBER OF MICRO-ORGANISMS FOUND IN 1 CUBIC CENTIMETRE OF WATER.

Date.	Raw Water.	No. 1 Pipe, 30 Millimetres below Layer of Slime.	No. 2 Pipe, 60 Millimetres below Layer of Slime.	No. 3 Pipe, 160 Millimetres below Layer of Slime.	No. 4 Pipe, 450 Millimetres below Layer of Slime.	No. 5 Pipe, 600 Millimetres below Layer of Slime.	No. 6 Pipe, 700 Millimetres below Layer of Slime.	No. 7 Pipe, ¹ 920 Millimetres below Layer of Slime.	No. 8 Pipe, ² 1,050 Millimetres below Layer of Slime.	The Waterdrawn from the Delivery-Pipe of the whole Filter.
June 16	28,881	3,596	2,976	824	446	314	306	304	1,280	2,212
„ 21	52,328	1,860	752	321	244	152	140	160	592	624
„ 25	60,310	1,994	216	163	40	48	48	62	143	164
July 2	36,320	1,876	446	176	44	46	48	44	86	98
„ 5	36,810	Liquefied	1,148	281	56	34	28	28	80	96
„ 17 ³	13,824	..	2,946	386	102	122	108	116	208	236
„ 20	34,224	..	4,960	242	124	24	22	..	60	58
„ 24	11,840	..	3,472	102	7	11	10	13	11	12

(4) *Renewal of Fine Sand.*—With regard to the renewal and cleaning of the filtering materials, as already indicated, the Author advocated in his Paper ten years ago the frequent scraping of the filters. This opinion was based on the practice of those works at which the most satisfactory results were obtained. Further researches appear to show that the power of arresting bacteria possessed by a filter-bed suffers no diminution with age, so that frequent scraping is not necessary for the maintenance of the efficiency of the individual bed. It is, however, quite

¹ This pipe was placed at the boundary between the sand- and gravel-layers.

² This pipe was placed in the layer of stones of about the size of a walnut.

³ The filter was cleaned on the 12th July, in which operation 30 millimetres of sand were removed from the surface, so that no further samples were obtainable from No. 1 pipe, whilst No. 2 pipe, instead of being 60 millimetres beneath the surface-slime was now only 30 millimetres below. Even when samples were taken five days later (on the 17th July), although the number of micro-organisms in the raw water was considerably smaller than on the previous occasion, the disturbance is reflected in all the samples collected on that day by an increase in the number of bacteria present.

possible that it may be advantageous for the efficiency of the filtration-plant taken as a whole. Thus, by running a filter-bed over a long period of time without cleaning, its yield becomes diminished, and as a certain volume of water must be supplied daily, this may necessitate filtering through other beds at a disadvantageously high rate, and so obtaining a filtrate from the entire works inferior in bacterial quality to that which would result, if scraping were practised more frequently and a more uniform rate of filtration were employed with all the beds.

Influence of the Size of Sand-grains on the Efficiency of Filtration.—This is a subject on which a considerable amount of information has been gained since the publication of the Author's previous Paper, more especially through American investigators. As it has been shown that the sand, quite irrespectively of the slime-layer, takes part in the bacterial purification, it would naturally be inferred that the finer the sand the more perfect should this purification be, and actual experiment confirms this inference. The convention adopted at the Lawrence Experiment Station, for the comparison of the size of the grains of different sands, consists in describing as the "effective size" of the sand such a diameter measured in millimetres that 10 per cent. by weight of the particles of sand have an average diameter smaller, and 90 per cent. by weight of the particles an average diameter larger, than that in question. Further to indicate the degree of uniformity exhibited by a sample of sand, the term "uniformity coefficient" has been adopted, to designate the ratio existing between that size of grain than which 60 per cent. of the sample is finer, and that size of grain called the "effective size" used in the sense given above. Thus, supposing that 10 per cent. by weight of a sample of sand is finer, and 90 per cent. coarser, than 0.36 millimetre in diameter, then 0.36 millimetre would be termed the "effective size" of the sand. Further, if 60 per cent. of the same sample is finer than 0.93 millimetre in diameter, then—

$$\text{Uniformity coefficient} = \frac{0.93}{0.36} = 2.6.$$

Mr. Allen Hazen, formerly chemist in charge of the Lawrence Experiment Station, has made some interesting mechanical analyses of the sand actually employed at many of the most important European waterworks, the results of which are given in Appendix I. The Lawrence experiments show that with very fine sands, having an "effective size" of 0.09 millimetre to 0.14 millimetre, and 4 feet to 5 feet in depth, it is almost impossible to

force more than a very small portion of the bacteria present in the unfiltered water through, even when there was no slime-layer at all. Thus the following results were obtained :—

Effective Size of Sand- Grains.	Millions of Gallons per Acre, filtered between successive Scrapings.	Percentage of Bacteria in Filtrate.
Millimetres. 0·38	66	0·16
0·29	58	0·16
0·26	47	0·10
0·20	..	0·01
0·14	41	0·03
0·09	12	0·02

The above figures clearly show that it is possible to secure greater efficiency of filtration by the use of finer sand. Like nearly all other improvements, however, this involves additional expense, entailing as it does more frequent scraping and a diminution in the yield of the filters.

The selection of the finest sand, consistent with obtaining the necessary daily volume of water by means of the available filtering area, is obviously a matter which deserves special attention by all in charge of filtration waterworks.

Intermittent Filtration.—The brilliant results obtained in the filtration of sewage on the intermittent system have naturally led to the investigation of the efficiency of this mode of filtration for the bacterial purification of potable water. Intermittent filtration consists in the systematic and periodic ventilation of the filtering medium, thus ensuring the contact of the water during filtration with air in the pores of the sand or other material employed. After the lapse of a definite period of time, the application of water is stopped and the filter is allowed to drain and become thoroughly aerated before the application of water is renewed. It is obviously of much interest to ascertain how this process of filtration, which differs so entirely from the ordinary practice of sand-filtration, compares with the latter in respect of the removal of bacteria from the water operated on.

Although extensive experiments on a large scale with the intermittent system have been carried out in America at the

Lawrence Experiment Station, yet at present sufficient data are not available to permit of a final conclusion being drawn as to the relative merits of continuous and intermittent filtration. The rate at which the water must be passed through an intermittent filter in order to produce a given quantity of filtrate, is of necessity considerably higher than with a continuous filter of the same dimensions, on account of the intervals of time during which the intermittent filter is idle; and, as a general rule, the bacterial efficiency of the continuous and intermittent systems respectively, with the ordinary rates used for continuous filtration, has been found at the station referred to superior in the case of the continuous system. On the other hand, with lower rates of filtration, and especially with fine materials, the bacterial efficiency is said to be much greater with the intermittent than with the continuous system as ordinarily practised; but it is quite possible that equally favourable results might be obtained with continuous filtration under like conditions. It appears, however, that the number of bacteria which emanate from the under-drains is generally less, and in hot weather much less, than is the case with continuous filters; and this may frequently account for the apparently superior bacterial results obtained with the intermittent filters. One particularly interesting fact has come to light in connection with these experiments on intermittent filtration, viz., that in spite of the greatly increased vigour of the nitrification process which goes on in these intermittent filters, all the species of bacteria experimented with were nevertheless found to be capable of passing through the filters in a living state. The idea, therefore, which has sometimes been entertained, without there being any experimental foundation for it, that nitrification and the life of other bacteria are incompatible, is wholly erroneous and must be abandoned.

A system of intermittent filtration has been adopted at the Chemnitz¹ Waterworks in Germany. The water in this case is derived from an excessively polluted stream and is even odoriferous, so that the process of filtration is resorted to primarily with a view to effecting chemical purification. In England the fact has long been familiar that highly polluted water, or sewage, cannot be efficiently purified by continuous, but only by intermittent, filtration. The works at Chemnitz partake, in fact, rather of the character of sewage- than of water-works, the filter-beds being actually laid out as irrigation meadows and planted with fruit

¹ Hazen *loc. cit.*

trees. In winter these works become inoperative in consequence of the freezing of the ground, the water not having the high initial temperature of sewage. Thus, such intermittent filtration becomes impossible, exactly at the time of the year when surface-water is generally in its worst condition, and when it stands, therefore, in most need of efficient filtration. It is obvious that the intermittent filtration of water-supplies may be dismissed from practical consideration, imposing as it does greatly increased difficulties on the waterworks engineer precisely at that season of the year when even with continuous filtration his resources are most sorely taxed.

The Influence of Frost on the Bacterial Efficiency of Sand-Filtration.—The Author desires to call attention to a point in connection with sand-filtration, the importance of which has not hitherto been sufficiently recognised, viz., the effect of frost on the bacterial efficiency of the process. It has been repeatedly found at waterworks, where sand-filtration is carried on with great care and with excellent bacterial results, that during frost a very marked increase in the number of bacteria present in the filtered water occurs. Thus in the Author's monthly examinations of the London waters during the years 1886, 1887, and 1888, there were two conspicuous occasions on which exceptionally large numbers of bacteria were found in some of the filtered waters, and on both occasions this disturbance coincided with a very low temperature of the river-water. The accompanying diagram, *Fig. 2*, exhibits, on the one hand, the temperature of the Thames water on the days on which samples were collected, and, on the other hand, the average number of bacteria found in the filtered water of the five Thames companies collected on the same day. From this diagram it will be seen that in January, 1886, and in January, 1887, the average number of bacteria found in the filtered waters was very large, and in both cases it will be observed that the temperature of the river-water at the time was in the vicinity of the freezing-point. On one other occasion, viz., in March, 1886, the temperature of the river-water closely approached the freezing-point, and on this occasion the number of bacteria in the filtered water was also large, although not so excessive as on the two above mentioned.

With so low a temperature of the water in the river, it is highly probable that the water on individual filters was actually frozen. The presence of ice on the filters is well known to be one of the most serious troubles incidental to sand-filtration, the removal of the ice involving sometimes the employment of large

numbers of men, and if the frost actually gain access to the sand-layer, it is only too obvious how its efficiency will become destroyed. In countries with very low winter temperatures open sand-filters are altogether impossible, and the expedient is resorted to of covering them in with masonry. Now, although the usually mild winters in England would not appear to warrant such an

Fig. 2.

expensive proceeding, it is imperative that this danger to the process should be reckoned with and guarded against, for it is precisely at this season of the year that surface-waters are usually in their worst condition, and that the most efficient filtration is necessary.

CONCLUSION.

From the facts adduced, it will be obvious that the bacterial purification of water is a matter in which British waterworks

engineers had made great advances long before the study of bacteriology had been commenced. In the storage and sand-filtration of surface-waters, in the abstraction of subterranean waters by means of deep wells and borings, and by the treatment of hard waters by the Clark process, they had introduced methods of obtaining bacterially pure water, which ten years of bacteriological investigation have not been able to improve upon. It would, however, be wholly unreasonable to conclude that bacteriology has done nothing for the practice of waterworks engineering. Ten years ago the Author was able not only to point out the extraordinary efficiency, from a bacteriological point of view, of the various processes in use, but also to indicate how certain differences in details of management affected this efficiency.

The discoveries now made enable engineers to proceed with confidence, where before they were working entirely in the dark, and to submit their views to exact scientific tests, instead of having to rely solely on intuition and common sense. Bacteriology, moreover, has interposed as the arbitrator between the rival practices of different engineers. It has adjudicated, as has been shown, upon those differences in the details of management which are found, for instance, in the purification of the London water-supply by the several companies. By carefully ascertaining the conditions most favourable to bacterial purification, these systematic investigations, which have now extended over little more than a decade, have already secured greater uniformity in the methods of purification employed and in the results obtained. But, if the English engineers have been before their neighbours in the evolution of the practice of water-purification, and even in the general investigation of the processes involved by the use of modern bacteriological methods, they must not allow themselves to be overtaken in the employment of these processes for the systematic control of the daily routine at the waterworks; for without this control, even in the best-conducted works, inefficiency must at times inevitably result. To indicate how far behind is English practice in respect of employing this systematic control, the Author cannot do better than direct attention to the instructions relating to sand-filtration, which are issued to the authorities of all waterworks in Germany, in which surface-water is employed for the supply of towns (Appendix II).

The Paper is accompanied by two diagrams, from which the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.

ANALYSES OF SANDS USED IN WATER-FILTRATION.

Source.	Effective Size; 10 per Cent. finer than	Uni- formity Coefficient.	Remarks.
	Millimetres.		
London: East London Company	0.44	1.8	{ New sand, never used or washed.
" " " "	0.39	2.1	{ Dirty sand, very old.
" " " "	0.37	2.0	{ Same, washed by hand.
" Grand Junction . .	0.26	1.9	{ Sand from rough filter.
" " " "	0.40	3.5	{ Old sand in final filter.
" " " "	0.41	3.7	{ Freshly washed old sand.
" Southwark & Vauxhall	0.38	3.5	{ " " " "
" " " "	0.30	1.8	{ Freshly washed new sand.
" Lambeth	0.36	2.3	{ " " old "
" "	0.36	2.4	{ New unused sand, washed.
" "	0.25	1.7	{ New extremely fine sand.
" Chelsea	0.36	2.4	{ Freshly washed old sand.
Middlesbrough	0.42	1.6	{ Dirty sand, ordinary scraping.
" "	0.43	1.6	{ Same, after washing.
Birmingham	0.29	1.9	{ Dirty sand.
" "	0.29	1.9	{ Sand below surface of filter.
Reading	0.30	2.5	{ Dirty sand.
" "	0.22	2.0	{ Same, after washing.
Antwerp	0.38	1.6	{ Dirty sand.
" "	0.39	1.6	{ Same, after washing.
Hamburg	0.28	2.5	{ Dirty sand.
" "	0.31	2.3	{ Same, after washing.
" "	0.34	2.2	{ Dirty sand, another sample.
" "	0.30	2.0	{ Same, after washing drums.
" "	0.34	2.3	{ Same, after washing ejectors.
Altona	0.32	2.0	{ Dirty sand, old filters.
" "	0.37	2.0	{ Same, after washing.
" "	0.33	2.8	{ Washed sand for new filters.
Berlin: Stralau	0.33	1.9	{ Dirty sand-pile.
" "	0.35	1.7	{ Filter No. 6, 3 inches below surface.
" "	0.34	1.7	{ Filter No. 7, 3 inches below surface.
" "	0.35	1.7	{ Filter No. 10, 3 inches below surface.

ANALYSES ON SANDS USED IN WATER-FILTRATION—*continued*.

Source.	Effective Size; 10 per Cent. finer than	Uni- formity Coefficient.	Remarks.
	Millimetres.		
Berlin: Tegel	0·38	1·6	Dirty sand, old filters.
" "	0·38	1·5	{ Same, after washing, old filters.
" "	0·35	1·6	{ Same, after washing, new filters.
" Müggel	0·35	1·8	{ Sand from filters below surface.
" "	0·33	2·0	{ Dirty sand, ordinary scraping.
" "	0·34	2·0	{ Dirty sand, another sample.
Charlottenburg	0·40	2·3	Dirty sand.
Chemnitz	0·35	2·6	New sand not yet used.
Magdeburg	0·39	2·0	Dirty sand.
" "	0·40	2·0	Same after washing.
Breslau	0·39	1·8	Normal new sand.
Budapest	0·20	2·0	{ New washed Danube sand.
Zürich	0·28	3·2	Dirty sand.
" "	0·30	3·1	{ Same after washing.
Hague	0·19	1·6	{ Dune sand used for filtration.
Schiedam	0·18	1·6	{ Dune sand used for filtration; dirty.
" "	0·31	1·5	River sand; dirty.
Amsterdam	0·17	1·6	Dune sand.
Rotterdam	0·34	1·5	River sand; new.
Liverpool: Rivington	0·43	2·0	{ Sand from bottom of filter.
" "	0·32	2·5	{ New sand, unwashed and unscreened.
" "	0·43	2·7	{ Washed sand which has been in use thirty to forty years.
" Owestry	0·30	2·6	Dirty sand.
" "	0·31	4·7	Same after washing.

The exceptionally fine sand employed at some of the Dutch waterworks is particularly noteworthy.

APPENDIX II.

REGULATIONS ISSUED BY THE GERMAN GOVERNMENT IN REGARD TO THE FILTRATION OF SURFACE-WATERS USED FOR PUBLIC WATER-SUPPLIES.

1. In judging the quality of a filtered surface-water, the following points should be especially observed:—

(a) The operation of a filter is to be regarded as satisfactory when the filtrate contains the smallest possible number of bacteria, not exceeding the number

which practical experience has shown to be attainable with good filtration at the works in question. In those cases where there are no previous records showing the possibilities of the works and the influence of the local conditions, especially the character of the raw water, and until such information is obtained, it is to be taken as the rule that a satisfactory filtration shall never yield an effluent with more than about 100 bacteria per cubic centimetre.

(b) The filtrate must be as clear as possible, and in regard to colour, taste, temperature and chemical composition, must be no worse than the raw water.

2. To allow of a complete and constant control of the bacterial efficiency of filtration, the filtrate from each single filter must be examined daily. Any sudden increase in the number of bacteria should cause a suspicion of some unusual disturbance in the filter, and should make the superintendent more attentive to the possible causes of it.

3. Filters must be so constructed that samples of the effluent from any one of them can be taken at any desired time for bacteriological examination.

4. In order to secure uniformity of method, the following is recommended as the standard method for bacterial examination :—

The nutrient medium consists of 10 per cent. meat extract gelatine with peptone, 10 cubic centimetres of which is used for each experiment.

Two samples of the water under examination are to be taken, one of 1 cubic centimetre and one of $\frac{1}{2}$ cubic centimetre. The gelatine is melted at a temperature of 30° to 35° C., and mixed with the water as thoroughly as possible in the test-tube by tipping backwards and forwards, and is then poured upon a sterile glass plate. The plates are put under a bell-jar which stands upon a piece of blotting-paper saturated with water, and in a room in which the temperature is about 20° C.

The resulting colonies are counted after forty-eight hours, and with the aid of a lens.

If the temperature of the room in which the plates are kept is lower than the above, the development of the colonies is slower, and the counting must be correspondingly postponed.

If the number of colonies in 1 cubic centimetre of the water is greater than about one hundred, the counting must be done with the help of the Wolffhügel's apparatus.

5. The person entrusted with the carrying-out of the bacterial examinations must present a certificate that he possesses the necessary qualifications, and wherever possible he shall be a regular employé of the waterworks.

6. When the effluent from a filter does not correspond with the hygienic requirements it must not be used, unless the cause of the unsatisfactory working has already been removed during the period covered by the bacterial examinations.

In case a filter, for more than a very short time, yields a poor effluent, it is not to be used until the cause of the trouble is found and corrected.

It is, however, recognised from past experience that sometimes unavoidable conditions (high-water, &c.) render it impossible, from an engineering standpoint, to secure an effluent of the standard quality. In such cases it will be necessary to use a poorer quality of water; but, at the same time, if such conditions arise as outbreaks of epidemics, suitable notice should be given of the condition of the water.

7. Every single filter must be so built that, when an inferior effluent results, which does not conform to the standard, it can be disconnected from the pure-water pipes, and the filtrate allowed to run to waste. This wasting should as a rule take place, so far as the arrangement of the works will permit, (1) imme-

diately after scraping a filter; and (2) after replacing the sand to the original depth.

The superintendent must himself judge, from previous experience acquired by the continual bacterial examinations, whether it is necessary to waste the water after these operations, and if so, how long a time will probably elapse before the water reaches the standard purity.

8. The best sand-filtration requires a liberal area of filter-surface, allowing plenty of reserve, to secure, under all local conditions, a moderate rate of filtration adapted to the character of the raw water.

9. Every single filter shall be independently regulated, and the rate of filtration, loss of head, and character of the effluent shall be known. Also each filter shall, by itself, be capable of being completely emptied, and, after scraping, of having filtered water introduced from below until the sand is filled to the surface.

10. The velocity of filtration in each single filter shall be capable of being arranged to give the most favourable results, and shall be as regular as possible, quite free from sudden changes or interruptions. On this account reservoirs must be provided large enough to balance the hourly fluctuation in the consumption of water.

11. The filters shall be so arranged that their working shall not be influenced by the fluctuating level of the water in the filtered-water reservoir or pump-well.

12. The loss of head shall not be allowed to become so great as to cause a breaking through of the upper layer on the surface of the filter. The limit to which the loss of head can be allowed to go without damage is to be determined for each works by bacterial examinations.

13. Filters shall be constructed throughout in such a way as to ensure the equal action of every part of their area.

14. The sides and bottoms of filters must be made water-tight, and special pains must be taken to avoid the danger of passages or loose places through which the unfiltered water on the filter might find its way to the filtered-water channels.

To this end special pains should be taken to make and keep the ventilators for the filtered-water channels absolutely tight.

15. The thickness of the sand-layer shall be so great that under no circumstances shall it be reduced by scraping to less than 30 centimetres (= 12 inches), and it is desirable, so far as local conditions allow, to increase this minimum limit.

Special attention must be given to the upper layer of sand, which must be arranged and continually kept in the condition most favourable for filtration. For this reason it is desirable that, after a filter has been reduced in thickness by scraping, and is about to be refilled, the sand below the surface, as far as it is discoloured, should be removed before bringing on the new sand.

16. Every city in the German empire using sand-filtered water is required to make a quarterly report of its working results, especially of the bacterial character of the water before and after filtration, to the Imperial Board of Health.

17. The question as to the establishment of a permanent inspection of public waterworks, and if so, under what conditions, will be best decided after such quarterly reports have been furnished over some period of time.