

FILTRATION AND OTHER METHODS OF PURIFICATION, ON A LARGE SCALE, OF RIVER WATER USED FOR DRINKING PURPOSES.*

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POLLUTION OF RIVERS.

THERE are a number of English towns which still derive their water supply from a river source. London derives its water supply from the New River and the Rivers Thames and Lea, and inquiries which I have recently made show that the following provincial towns obtain their water supply from rivers: Darlington, Stockton and Middlesbrough (this town derives the larger part of its supply from a moorland source) from the Tees; York from the Ouse; Shrewsbury, Worcester, Tewkesbury and Cheltenham from the Severn (the last town for only a portion of the year); Plymouth from the Mew; Sandown from the Yare; and Hereford from the Wye. Lincoln also derives its water supply partly from the Upper Witham River. The water supply of Dublin is derived from the River Vartry, near its source in the Wicklow Mountains. Certain towns, which previously derived their water supply from rivers, now obtain it from another source—*e.g.*, Durham, Carlisle, Ripon, Wakefield, Ely and Leamington.

All rivers are polluted to a greater or lesser extent. The worst form of pollution is that of crude sewage which is allowed to flow into rivers from towns or villages on the banks; then there is pollution from isolated houses on the banks, privies, refuse heaps, manured fields, sewage farms, etc., and streams which in turn receive refuse and other filth from farms and houses on their banks. The pollution is increased at times of heavy rain and snow, when matter of all sorts is washed into a river.

It is important where river water is used for drinking purposes that it should be kept as free from pollution as possible. Sewage from towns or villages and any isolated houses on the banks should be treated before being allowed to flow into a river. In the case of smaller houses where biological treatment would be too costly, and where privies are in use, earth closets should be substituted. Refuse should not be allowed to be deposited on the banks of a river, as during times of flood this material is washed in.

At various times outbreaks of typhoid fever have occurred through the contents of privies

or crude sewage finding their way into a river and so reaching the waterworks of the town obtaining its supply from such a source. An outbreak occurred at King's Lynn and Gaywood (Norfolk) in 1892; the water from the Gaywood River flowed through cultivated fields and gardens. The intake was within the borough and filtration was insufficient. Before the outbreak occurred the contents of privy pits, into which the excreta from some typhoid fever patients were thrown, had been spread on part of a market garden abutting on the river and only one mile above the intake.

The Tees Valley epidemic which occurred in 1890 and 1891 is well known; at that time, either directly or indirectly, the drainage of some 20 villages and hamlets, as well as that of the town of Barnard Castle, was poured into the river above the intake of the water company. Heavy floods, due to abnormal rainfall and melting of snow, washed down accumulations of filth, and shortly afterwards typhoid fever became prevalent.

In the report of the Board of Health of Massachusetts for 1901 an account is given of outbreaks which occurred at Lowell and Lawrence. Prior to the outbreak the Lowell water supply had been contaminated by the fæces of typhoid fever patients discharged into a brook only three miles above the intake of the waterworks. This pollution was followed in about three weeks by a very rapid increase in the deaths from typhoid fever at Lowell and about six weeks later by an alarming increase in the number of deaths in Lawrence, nine miles below where the Lowell sewage enters the River Merrimac. The amount of sewage entering the river was estimated to be one gallon in 600 gallons of river water passing Lawrence, and there was no more impurity in the water than could be detected by chemical analysis in about half of the drinking water supplies of the State obtained from pools and streams. Even with the small amount of organic impurity in the water as shown by chemical analysis it was considered that the germs of this disease were able to pass from one city to another.

A recent example is that of Lincoln, and during 1904 and 1905 900 cases of typhoid fever occurred. It was found by Dr. Reece, who was appointed by the Local Government Board to inquire into the cause of the outbreak, that the River Witham and its tributaries were polluted by drainage from ground highly cultivated and occasionally manured with night soil. In the autumn of

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1904, and in January, 1905, there was opportunity for typhoid germs to gain access to the water supply, which, owing to increased acceleration due to heavy demands, was not effectively filtered in the sand-beds. A stream, termed the Catch-water Drain, which flowed into the River Witham ran alongside the water-works, and the river sometimes passed up this stream and also another tributary called the Pike Drain; both these streams were polluted at the time of the outbreak, and germs resembling the bacillus typhosus were found.

SELF-PURIFICATION OF RIVERS.

Boyce and his colleagues (from the result of a large number of experiments carried out in 1899 to 1901 in connection with the River Severn before and after its waters pass the town of Shrewsbury) have shown that a certain amount of natural purification occurs in connection with river water. They showed that a reduction in the number of bacteria in the river takes place as the result of dilution, sedimentation, side-adhesion, and vegetation and light. Boyce considers that sedimentation and side-adhesion are most important factors in ridding the water of bacteria. It was also found that, although conditions for the multiplication were not met with, *B. Coli* and Typhosus could remain alive for a considerable length of time both in the mud and the river water, and it was considered that their presence in the mud might be the means of keeping up a tendency to pollution. Whilst in the purification the greatest sphere was taken by bacteria, in the case of *B. Coli*, and presumably also in the case of other pathogenic germs generally, temperature and environment were unfavourable to their multiplication; in substances like mud, teeming with bacteria, the available food was monopolised by the more hardy bacteria, and the putrefactive products formed acted detrimentally upon the pathogenic germs. In the case of the Severn, it was pointed out that the dilution of the sewage was considerable, and that the organic matter sufficed only for a comparatively small number of bacteria. Whilst the greater sphere in self-purification was taken by bacteria, help was also rendered by protozoa, higher forms of animal life, sewage fungi and river plants.

Sedimentation is also assisted when a river passes in a shallow stream over beds of gravel or rock.

Although a certain amount of self-purification goes on in connection with river water, it was shown by Boyce that Shrewsbury, with a popu-

lation of 29,000 persons, caused an average pollution of 600 *B. Coli* per c.c. in the case of the River Severn at the maximum point of pollution, and that this was felt sixteen miles lower down, as shown in the following table:—

Position of Examination.	Average total number of Bacteria per c.c.	Average number of <i>B. Coli</i> per c.c.
Asylum, 2 miles above Shrewsbury	7,000	13
Waterworks, opposite Shrewsbury	13,000	46
Ferry I., 0.6 of a mile lower down	20,000	177
English Bridge, 1.6 miles lower down	23,000	321
Ferry III., 2.5 miles lower down...	19,000	600
Uffington, 4.7 miles lower down...	17,000	142
Alcham, 9 miles lower down ...	13,000	48
Cressage, 16 miles lower down ...	5,000	36

The effect of the Shrewsbury pollution at Cressage had not had time to disappear before another town—Ironbridge—poured its sewage into the river, and it was in this way that rivers became gradually polluted from source to mouth.

It is important to remember that where pollution occurs—*e.g.*, from the sewage of a town flowing into a river with a flow of two miles an hour—the effect in the case of a town twenty to thirty miles lower down might be slight; but at times of flood, with the rate of flow of the river increased to, say, eight miles an hour, the effect of the pollution higher up would be more marked.

Bacteriological examinations made of water from the Thames and other rivers show that the total number of bacteria, including sewage organisms, is considerably increased at times of flood; and in respect to London, Sir Shirley Murphy has found distinct increase in notified cases of typhoid fever following floods above the water intakes. It is therefore most important to stop pollution as far as possible. The recent Royal Commission on Sewage Disposal, in connection with the question of river pollution, have recommended that there should be a central administrative authority to deal with the whole question, and that the Local Rivers Board should, in accordance with the regulations framed by the Central Department, act as a Central Tribunal. Amongst the questions to be dealt with are:—

1. Protection of water supplies from pollution.
2. The settlement of standards for different reaches of water.

In addition to a chemical standard, a bacteriological standard of pollution would be useful.

In the fifth report of the Sewage Commission it is shown that from a bacteriological point of view land treatment of sewage is the most

efficient, provided suitable land is in use—*e.g.*, sand, gravelly loam, or soil and sand; clay is unsuitable. In the case of seven farms chosen for purposes of observation there was a reduction in the total number of organisms in the crude sewage of 94 to 99 per cent., and the number of *B. Coli* in the effluent varied from 1,000 to 10,000 per c.c. (at Altringham and South Norwood from 100 to 1,000 per c.c.). If the average number of *B. Coli* present in crude sewage be taken as 100,000 per c.c. (Houston), the reduction in the number of *B. Coli* was over 80 per cent. In the experiments referred to it was also shown that there was greater retardation in the passage of excremental organisms through soil than through artificial filters—"a factor of importance in the life and virulence of certain pathogenic germs."

Various tables are given in the above report showing the number of *B. Coli* after treatment by various artificial methods. The best bacteriological results obtained were by septic tank treatment and contact beds. In the case of Leeds, where the primary bed was of clinker and the secondary bed of coke, the number of *B. Coli* was 1,000 to 10,000 per c.c.; and similar results were obtained at Manchester, where clinker was used in both the primary and secondary beds. The results of these and other analyses show that a reduction of from 75 to 80 per cent. in the number of *B. Coli* in the crude sewage can be obtained with contact beds after preliminary septic tank treatment or chemical precipitation. Good results were also obtained by using percolating filters, the number of organisms present in the filtered effluent being on an average 1,000 to 10,000 per c.c., and sometimes the number was from 100 to 1,000 per c.c. Although the number of *B. Coli* was diminished, these germs were never entirely eliminated.

Klein, McConkey and others have shown that crude sewage or sewage effluent which has been sterilized is not a favourable medium for the growth of the *B. Typhosus*, and that this bacillus tends to die out quickly in the presence of other organisms. McConkey, as the result of experiments, concluded that if typhoid bacilli did find their way into a bacterial system of treatment they met with conditions hostile to their multiplication, and that even if these bacilli found their way on to biological beds or septic tanks they were present in small numbers, and the conditions were so adverse to their existence that they would not survive the treatment; "but if from any cause they

arrived at the beds or tanks in such large numbers as *B. Coli*, then they might appear in the effluent as *B. Coli* does, and, as in the case of the latter so in the case of *B. Typhosus*, there is no tendency to multiply."

There is reason to believe that as the reduction in the number of *B. Coli* is considerable in the case of sewage treated by either land or other artificial methods, in the case of *B. Typhosus* it would be still greater. Where septic tanks and filter beds are in use, there would be a delay of at least eighteen to twenty-four hours from the time the sewage entered the septic tanks till it left the filter beds.

To still further reduce the number of pathogenic organisms in an effluent, additional land filtration would be useful, especially if a gravel soil were available; and this method has been adopted at Hereford. The sewage of the town is treated by means of septic tanks and filter beds, and the effluent from the beds passes through gravel soil on its way to the River Wye. A greater degree of bacteriological purification of effluents could be obtained by means of sand filtration or by the addition of chloros or other chlorine preparation, although the Royal Commission on Sewage Disposal came to the conclusion that further purification of effluents by sand filtration or sterilization was not usually required.

In the case of a single house on a river bank the sewage could be allowed to flow first into a tank and afterwards over a bed of clinker, the flow being regulated automatically; and by its passage through gravel soil on its way to a river the effluent would still further be purified.

Whilst everything should be done to reduce the amount of river pollution, neither self-purification of the river nor the various methods of treatment adopted to reduce it will, in the majority of cases, purify the water sufficiently for drinking purposes, and various methods of storage and filtration must be adopted to render the water suitable for drinking purposes.

PRELIMINARY TREATMENT OF RIVER WATER.

River water generally contains a certain amount of sediment and this is largely increased at times of flood; at such times were the suspended matter not removed it would readily choke any good filter-beds and interfere with their bacterial action. It is therefore most important to get rid of the suspended matter.

Houston has shown that storage of river water will cause a reduction in the number of bacteria in the water, and that pathogenic germs, such as *B. Coli*, when the water is stored

for several weeks, will eventually die out. In addition the suspended matter is got rid of by sedimentation, algæ and other vegetable growths are gradually destroyed, and the chemical composition of the water is improved, free albuminoid ammonia and organic matter being reduced in amount.

The longer the water is stored the greater will be the reduction of the pathogenic germs, and whatever system of filtration is afterwards adopted, previous storage should be made use of as a safeguard, as recommended by Houston.

In the case of eight provincial towns in England already referred to, where information was obtained, either storage reservoirs or sedimentation tanks were used, but in most cases the reservoirs would only allow of a period of storage of the river water not exceeding a few days. The Dublin water is obtained from an artificial lake formed by damming the River Vartry near its source in the Wicklow Mountains, and after filtration through sand the water passes into a service reservoir holding three weeks supply. In two towns, York and Hereford, the water is passed through gravity mechanical filters before passing to a reservoir for further sedimentation. In two towns sedimentation tanks are not used, and the water flows direct to the sand filter-beds.

Other methods have been adopted in America and England to remove suspended matter—*e.g.*, preliminary filtration through graded beds of coarse gravel and coke. Polarite has also been used for this purpose.

In America, coagulant in the form of sulphate of alumina of a strength of $\frac{3}{4}$ to $2\frac{1}{2}$ grains per gallon, the amount varying according to the turbidity of the water, is sometimes added to raw river water for ridding it of sediment; the water is then allowed to settle in large sedimentation basins before passing either to slow sand or mechanical filters.

The use of the coagulation basin usually prevents difficulty in the cleaning of the slow sand-filters through the coagulant getting into the beds.

At Steelton in America the water supply is derived from the Susquehanna River and the water is passed through roughing filters before flowing on to slow sand filter-beds. The roughing filters are 12 ft. 2 in. wide and 29 ft. 6 in. at the bottom, and contain 5 ft. of fine anthracite coal of low specific gravity; they are suitably underdrained by a number of parallel 2-in. galvanized iron pipes with $\frac{1}{4}$ -in. holes. The pipes are surrounded by 4 inches of $\frac{1}{4}$ -in. to $\frac{3}{4}$ -in.

gravel, and this rests on a second layer or fine gravel. At certain times of the year the river water contains a considerable amount of fine suspended red or yellow clay, and at this time the use of coagulant is unnecessary; when the water is fairly clear coagulant is added. There are special arrangements for washing the filters. A large amount of suspended matter can be got rid of by the use of pressure or gravity mechanical filters, even without the addition of coagulant. Greater clarification of the water can be obtained by the addition of a small quantity of coagulant, but it must be arranged so that the amount added is not in sufficient amount to remove the bulk of the bacteria, otherwise the formation of the gelatinous film on the surface of any slow sand filter-beds in use will be interfered with.

SLOW SAND FILTRATION.

This is usually called the English system as opposed to mechanical filtration, which is largely used in America. This system of passing the water through sand filter-beds is in use in connection with the London water supply, and inquiries which I have made in regard to the provinces show that in the case of ten towns using river water this method has also been adopted. In seven of these towns as I have already mentioned, preliminary treatment of the water in storage reservoirs or sedimentation tanks is in use. In one town the water is passed into a large storage reservoir and afterwards through fine copper screens into the mains without further filtration.

The sand filter-bed is a water-tight reservoir suitably underdrained and usually containing about 6 ft. of filtering material. The material is graded, and contains usually 3 ft. to 4 ft. of fine sand at the top, then pea gravel, and coarser grades of gravel passing downwards. The gravel serves the purpose for lateral movements of the water to the under-drains. The bottom and sides of the reservoir must be water-tight; it is useful to have tiles at the bottom, and these must be covered with gravel so as to allow the water to pass on to the bed gradually. The London filter-beds contain on an average from 2 ft. to 3 ft. of fine sand. It is important that the sand should not contain too much carbonate of lime, as this will tend to make the water hard, and it should not be too fine, as fine sand quickly clogs.

The important point of the process of sand filtration is the formation of a gelatinous cover on the surface of the bed, as it is in this cover that the suspended matter and bacteria

are entangled; in addition, the organic matter in solid form and in solution is attacked by the nitrifying organisms which form this layer of the surface. A new filter is of little use until the bacterial jelly has formed; this takes about a week, and during this time the water should not be allowed to pass into the mains.

The following analyses made by Kummel in connection with a filter-bed in which the sand had been renewed are quoted by Newman:—

	Organisms per c.c.			
Before cleaning	42
One day after cleaning	1,880
Two days after cleaning	752
Three days " "	208
Four days " "	156
Five days " "	102
Six days " "	84

As the result of a large number of experiments conducted by the State Board of Massachusetts, it was found that not more than two million gallons per acre daily of water should be allowed to pass through a slow filter-bed, and experiments made by Koch in Germany have confirmed these views. The bacteriological standard recommended by Koch is that not more than 100 organisms per c.c. should be present in the filtered water. It is also important that *B. Coli* should be absent from 100 c.c. of the water.

After a certain time, depending on the amount of sediment and algæ in the water, the beds must be scraped. In the case of river water, even with preliminary treatment, suspended matter passes on to the filter-bed, and this may sometimes necessitate cleaning the beds once a month. At certain times of the year algæ present in the river water may form a thick layer on the surface like a blanket, and this prevents the water passing through the filters. On an average it will be necessary to clean the filter-beds every six to eight weeks.

The cleaning of the bed consists of scraping a fraction of an inch off the surface, and this is done by means of sharp, wide iron shovels. The sand can be cleaned and replaced, but this is not necessary until several inches have been removed. In the Massachusetts experiments it was shown that 85 per cent. of the bacteria were present in the upper quarter of an inch. There should be means for measuring the head of water in the bed; usually 4 ft. or 5 ft. are allowed. If the head exceeds this amount and the filtration becomes slower, there is indication that the beds need cleaning, and this will also be shown by the result of bacteriological analysis, as a number of organisms exceeding

100 per c.c. will be found in the effluent, and probably also *B. Coli*. Should the bed not be scraped when necessary, the pressure of the water will force it through at the sides of the reservoir and through boreholes which will be formed in the filter-beds; the water will then pass through unfiltered. At times of frost, if the beds are being cleaned, there is a danger, after cleaning, of the upper layer of the sand becoming frozen, and so the water passing over the bed is not properly filtered; it was such an accident as this in one of the filter-beds that caused the outbreak of cholera at Altona. In America the filter-beds are usually covered on account of the severe degrees of frost which are sometimes reached, but in this country that precaution does not seem necessary, although at times of frost, as a safeguard, it might be useful to run hot water from condensers on to the beds after cleaning. At Leeds there are special means of backing up the water from below after cleaning so as not to disturb the bed, and in addition there is an arrangement for regulating the flow of water on to the beds. After cleaning, to commence with, only a few inches of head are allowed, and this is gradually increased during the first few days until a head of 3 ft. or 4 ft. is reached.*

A sufficient number of beds should be available, so that, whilst some beds are being cleaned, too much water may not be passed over the remaining beds. On this account it is better that the individual beds should not cover too large an area. Beds 100 ft. to 200 ft. by 150 ft. will be found sufficient.

It is important that means should be provided for taking samples for analysis separately from each bed. After cleaning, the bed takes about three days to attain proper efficiency. Koch recommends that the water should be allowed to stand for the first twenty-four hours on the bed, and that during the first three days the water should not be used for drinking purposes.

Samples should be taken frequently from each bed for bacteriological analysis; the finer degrees of pollution of the water can only be detected by this means.

The following figures showing the results of slow sand filtration are taken from Dr. Houston's report to the Metropolitan Water Board on the examination of the London waters for the twelve months ending March 31st, 1909.

* Further particulars in regard to slow sand-filtration are given in "Water Supplies," by Thresh.

	Unfiltered Water.	Filtered Water.
1. <i>From the Thames</i> :—		
Number of samples ...	244	—
Average number of organisms on gelatine per c.c. ...	2,558	11'3
Percentage reduction ...	—	99'6
2. <i>From the Lea</i> :—		
Number of samples ...	245	—
Average number of organisms on gelatine per c.c. ...	8,794	18'9
Percentage reduction ...	—	99'8
3. <i>From the New River</i> :—		
Number of samples ...	245	—
Average number of organisms on gelatine per c.c. ...	1,118	6'1
Percentage reduction ...	—	99'4

In connection with the raw river water, *B. Coli* was present, in 1 c.c. (or less), in 47'8 per cent. of samples from the New River; in 87'5 per cent. of those from the River Thames; and in 93'9 per cent. of samples from the River Lea.

Out of 7,081 samples of all London waters which had been filtered, typical *B. Coli* were absent from 100 c.c. in 84'6 per cent.

MECHANICAL FILTRATION.

This system has been largely adopted in America, where a number of towns obtain their water supply from a river source.

There are two forms of mechanical filter in use—gravity and pressure. The following particulars relate to English filters. The pressure filter consists of a closed cylindrical tank, with sloping sides and domed top and bottom, constructed of cast-iron or steel and containing several feet of filtering material. The height varies from about 4 ft. to 15 ft., and the diameter from 1 ft. to 12 ft. The smaller size filters can deal with about 250 gallons per hour; the largest size can deal with as much as 15,000 to 20,000 gallons of water per hour. The term "gravity" explains the action of this filter, which is open at the top and contains fine sand or graded quartz (finest at the top and coarsest at the bottom). In the case of the pressure filter the water is forced through under pressure.

At the bottom of each filter there is usually an iron plate on which rests several feet (usually 3 or 4 ft.) of fine sand or quartz. Cleaning of the filters is affected by means of a reverse current of water, and can best be carried out by means of a number of nozzles placed close together and fixed at the bottom of the filter. Another method of cleaning is by passing a reverse current of water through a perforated grid-plate, and, in addition, by means of a steam blower large volumes of high-pressure air are passed through the filtering medium. It is

claimed for this method that during the process of cleaning the sand is thoroughly agitated, and no rakes are necessary for stirring up the surface of the sand. Rakes are usually provided in order to thoroughly stir up the sand when it is being washed; these are worked either by mechanical power or hand, and when arranged in two directions are more efficient. In some of the filters the upper few inches of the sand or quartz are raked; in others the rakes penetrate the whole thickness of the filtering medium. It is claimed for fine quartz that it is more readily cleaned on account of the particles being more angular. Sand particles are round and more adherent.

In addition to sand or quartz, other materials are used—*e.g.*, filters are constructed by one firm in which the filtering material consists of sand, quartz and charcoal, resting upon a layer of fine copper gauze supported on a perforated grid plate. In the case of another filter oxidium or polarite are used along with layers of specially selected and graded silica, held in position by perforated and slotted grids. The oxidium is a granular black powder imperishable and porous, consisting of silicates of alumina, magnesia and lime, along with iron oxide and alkalies and carbonates. The polarite is a black porous magnetic oxide of iron. Five feet of filtering material are used.

It is claimed for these filters that as the water passes through the filtering material it is saturated with oxygen, which is forced into the pores and interstices of the filtering material; that the organic matter is effectively oxidized, and suspended matter and micro-organisms are in part removed. No coagulants are used in connection with this filter, but in certain cases hypochlorite is added to the water before filtration; it seems more adapted for getting rid of colouring matter (*e.g.*, that caused by peat) and acid. The cleaning is effected by water under pressure, no stirrers or arms being used.

Mechanical filters such as those described above can be used with or without coagulant, but in the former case they have only a rapid straining action and there is no bacterial efficiency. At the same time they are very useful for removing suspended matter from river water and so preventing any sand filter-beds in use from becoming clogged.

USE OF COAGULANTS.

The coagulant is used to form a gelatinous cover on the surface of the sand or quartz of a mechanical filter, and takes the place of the scum formed by bacteria in the case of the

sand filter-beds. The coagulant generally used is sulphate of alumina; this combines with the carbonates in the water and forms alumina hydrate, which forms a white flocculent jelly-like precipitate and has a clearing action.

It is important that carbonates should be present in the water, as otherwise the formation of hydrate of alumina does not take place; and should there be no carbonates present in the water, or only a small quantity, some soda ash or its equivalent in lime should be added in equal or greater amount, depending on the composition of the water. About $\frac{1}{2}$ grain to 1 grain of sulphate of alumina per gallon may be sufficient for purposes of clarification, but, in order that bacterial efficiency may be attained, the addition of 2 grains to 4 grains per gallon to the water will be necessary.

In America the usual method for mixing the coagulant with the raw river water is as follows: The chemical is first placed in a dissolving tank or box holding about 240 gallons, and from this the fluid passes into two solution tanks, usually of concrete, and thence to an orifice box which is used for controlling the feed of the solution, which mixes with the raw river water. The water afterwards passes to coagulating basins built of concrete.

Water filtration plant has recently been erected at Sandusky, Ohio, a city of 25,000 inhabitants. A description of this plant will give an idea of the size of the various tanks and other apparatus in use in America. The dissolving tank or box is 4 ft. by 8 ft. by 1 ft., and holds 240 gallons. The solution tanks are built of concrete, and are 8 ft. square by 7 ft.; the bottom is in the form of a truncated pyramid, making a total depth of 8 ft. Paddles are placed at the bottom of each solution tank to agitate the fluid.

The orifice tank for controlling the feed of the coagulant solution is located underneath the solution tanks, and is 3 ft. by 2 ft. by 20 in. It contains an adjustable brass orifice for regulating the feed; from the orifice the solution is conducted by a 2-in. acid-proof pipe to a small chamber in the pump well, where it is carried by 2-in. lead pipes to the suction of the raw water pumps.

The coagulating basins are constructed of concrete, and are each 160 ft. long by 28 ft. 6 in. wide, with an average depth of 15 ft. 6 in. The floor slopes 2 ft. in its length so as to aid in flushing out the basins, which can be done by gravity. Each basin holds 500,000 gallons of water, and four hours' sedimentation are

allowed. The water finally passes to six gravity mechanical filters, each 18 ft. by 20 ft. at the sand line, and having a nominal capacity of 1,000,000 gallons per twenty-four hours. The above particulars are taken from the *Engineering Record* of October 16th, 1909.

Rakes with suitable teeth are usually placed in the dissolving tanks, and paddles in the solution tanks to facilitate solution and maintain a uniform strength. The coagulation or settling basin should be of a sufficient capacity to allow of the water remaining long enough for the chemical action to be complete. A certain proportion of heavy gelatinous matter produced by the coagulant settles to the bottom, and in doing so carries with it a considerable amount of suspended matter and a certain proportion of the bacteria.

The water afterwards passes from the coagulation basin to the filters, which are formed of wood, iron or concrete. The above account describes the process usually adopted in America. In England the process in connection with the use of the coagulant is not so elaborate, and after it has been dissolved in a wooden tank designed to hold from about 300 to 600 gallons, it is injected into the rising main to mix with the raw water on its way to the filters. Rakes or paddles to aid solution do not seem to be favoured. In America the various processes referred to are considered necessary, and are the results of experience over a considerable number of years.

Shrewsbury is the only town in England where mechanical filters are in use along with coagulant for filtering raw river water: a battery of pressure filters has recently been erected there.

In a paper which was read by Ross and Raymond, analytical chemists to the Burnley Corporation, before the Health Congress held at Leeds in 1909, the results of the filtration of the moorland water supplied to the town were given. At Burnley, both mechanical pressure filters (made by two different firms) and slow sand filters are in use. About one-tenth of a grain of sulphate of alumina and a certain amount of carbonate of soda were added to the water before mechanical filtration, and the bacteriological analyses of ten samples of filtered water taken during April, May and June, 1909, show that there was a percentage reduction of the total number of organisms of 79 per cent. in the case of one set of mechanical filters, and 72 per cent. reduction in connection with the other set. Three samples taken after

slow sand filtration showed a percentage reduction of 98.8 per cent.

The average number of organisms which grew on gelatine in the case of the unfiltered water was 44. *B. Coli* was only present in one instance in the unfiltered water, and was not detected in the water after filtration.

The same authors quote the results of bacteriological analyses from moorland water filtered through slow sand filters and through pressure mechanical filters at Bolton. In the case of the mechanical filters 2 grains of lime and 2 to 3 grains of sulphate of alumina were added to the raw water. The percentage reduction as shown by the results of the analyses of fifteen samples taken monthly from April, 1908, to June, 1909, was 96 per cent., and in the case of the sand filters 89 per cent. The average number of organisms in the unfiltered water was 311 per c.c., and the average number of *B. Coli* was 7 per c.c.; in no case were these organisms found in the water after mechanical filtration, and in three instances after sand filtration the number was 2 and in another case 1 per c.c.

It is stated by the writers that where the main object is the elimination of a considerable number of organisms, a large amount of sulphate of alumina must be added. In moorland waters the main consideration is the treatment of plumbo-solvency.

River water is at times very turbid, and unless the filters are cleaned every six hours a large number of bacteria will be found in the filtered water. The cleaning takes about ten minutes, and under ordinary circumstances once in ten or twelve hours is usually sufficient; the filtered water is used for cleaning purposes. The time a filter can go without cleaning depends on the turbidity of the water, and can only be ascertained by frequent bacteriological analysis, and it is also only by this means that the amount of sulphate of alumina necessary to be added can be ascertained. The water might be perfectly clear, and yet, through an insufficient amount of coagulant having been added, might contain large numbers of bacteria and sewage organisms. Any breakdown in the mixing apparatus and the water comes through unfiltered. Where mechanical filters are in use, preliminary storage of the raw water would appear to be a useful safeguard in the case of a river water.

Alumino-ferric is sometimes used as a coagulant, and also iron in combination with

lime. The use of iron is more troublesome than that of sulphate of alumina.

USE OF DISINFECTANT AS AN ADJUNCT TO WATER PURIFICATION.

In several towns in America bleaching powder is used for the sterilization of the raw river water before it passes to mechanical filters. When bleaching powder is added to the water the loosely formed combination splits up into chloride of calcium and hypo-chlorite of calcium. Chloride of calcium being inert, the hypo-chlorite is acted upon by carbonic acid, and splits up into carbonate of calcium and hypo-chlorous acid, which is a powerful oxidizing agent. Bleaching powder usually contains about 35 per cent. available chlorine and 40 to 44 per cent. of lime, which represents 7.9 per cent. available oxygen.

Sodium hypo-chlorite formed from sodium chloride electrolytically has the same effect, and to produce 1 lb. of available chlorine takes about 5 lb. to 8 lb. of common salt.

Experiments on the use of hypo-chlorite of lime have been recently carried out by the Baltimore County Water Company in America, and it has been found that by the application between the sedimentation tank and the filter beds of 1 grain of hypo-chlorite of lime, and with the alum solution reduced to .7 grains per gallon, and running the hypo-chlorite solution on the beds every other day, an absolutely sterile water can be turned out. The water first enters a coagulation basin providing four hours' sedimentation, and then passes to two 10 ft. by 20 ft. mechanical filters. The alum solution is added in the influent chamber of the coagulation basin, and the hypo-chlorite of lime solution is added to the water as it passes from the coagulation basin to the filters.

During 1908 and 1909 Clarke and Gage carried on a series of experiments, for the State Board of Health of Massachusetts, in connection with the sterilization of water. The water from the Merrimac River was used in connection with the experiments, and this was passed through a mechanical filter using sulphate of alumina as a coagulant along with soda. It was found that a clarifying effect could be obtained by the use of .5 to 1 grain of sulphate of alumina per gallon, but that an effluent containing low numbers of bacteria could be obtained only by the use of about 2 grains of coagulant per gallon. By the use of sulphate of alumina in these proportions a fairly satisfactory effluent was obtained, although one not as good bacterially at all times as those

obtained from sand filters operating at lower rates without coagulants.

In 1908 1·8 grains of sulphate of alumina and 1·5 grains of soda were used; in 1909 9 grains of sulphate of alumina, 1·7 grains of soda, and bleaching powder equal to 1 part per million of available chlorine. Comparing the two results, it was found that in the former case there was a greater reduction in the colour of the raw water and in the organic matter present. Both waters were free from turbidity, and, although the organic matter and albuminoid ammonia were greater in the latter case, they were no greater in amount than in the case of a good many water supplies considered to be of good quality. There was 99·7 per cent. reduction of organisms using bleach, and 99·8 per cent. without. The effect was most noticeable in the character of the water as it flowed to the filter from the coagulation basin, the percentage of bacteria removed being 99·5 per cent. compared with 66·7 per cent. during the period when coagulants were used.

In conclusion, the authors state that complete sterilization of a highly polluted river, such as the Merrimac, cannot be obtained by the use of either permanganate of potash or bleaching powder, except in large amounts. They consider that the disinfection which occurs in the coagulation basin before the water reaches the filter introduces a factor of safety.

In the case of bleaching powder it was found that the power was exhausted in one or two hours if small amounts were used. When larger amounts were used four or six hours', or even longer, storage was necessary before the action was complete. Better results were obtained if '9 grain of alum and '7 grain of soda per gallon were used along with 1 part of bleaching powder per million available chlorine than when double amounts of sulphate of alumina and soda were used without the addition of disinfectant.

Rideal, in a paper before the recent Health Congress held at Leeds, showed that in the case of polluted waters the chlorine and hypo-chlorites act upon any free ammonia and other organic nitrogenous matters in the water to form chloramine (NH_2Cl) and other allied compounds having strong bactericidal properties. These substances produce an odour which is generally noticed in chlorine disinfection, but after a time it disappears and forms hydrazine (N_2H_4), which is inodorous, but has a strong bactericidal power. For killing typhoid

germs chlorine was found to be roughly 240 times stronger than carbolic acid, but was useless in the presence of sulphuric or hydrochloric acid, although its value was increased in the presence of urea. Rideal found that most drinking waters could be sterilized by sodium hypochlorite in the proportion of 1 part in a million available chlorine, and that after standing for two hours no smell or taste was perceptible.

At the time of the Lincoln epidemic in 1905 chloros, a crude preparation of sodium hypochlorite, was added to the water as it passed on to the filter-beds. The supply of disinfectant was continuous; the sand filter-beds were also treated. At first a strength of 1 in 10,000 was used, but later the amount was reduced to 1 in 50,000 before filtration and 1 part in 100,000 in the case of the filter-beds. At first, when the water was hot or cold, a smell and a musty taste were perceptible; but in the course of a few weeks, either on account of the organic matter present in the filter-beds being used up or oxidized, or on account of the lesser quantity of chloros used, the smell and taste became less, and on the first week of May, 1905, could not be detected. The scent was said to resemble the smell of nuts in an earthenware vessel which had been brought up from storage in a damp cellar.

COMPARISON OF THE VARIOUS METHODS OF PURIFICATION.

Whether mechanical or slow sand filtration is adopted in the treatment of river water, it would seem to be a useful plan to allow preliminary storage of the raw water in reservoirs of large capacity, capable of holding a supply for several weeks or longer, and such storage would act as a safeguard in the case of a breakdown in the filtering arrangements.

The only objection to the use of large storage reservoirs is the expense of construction, and and in the case of a small town such a scheme on this account might prove impracticable.

At times of flood river water becomes turbid, and some preliminary treatment is necessary where sand filter-beds are in use. Storage would considerably reduce the amount of suspended matter, but where reservoirs only capable of holding several days' supply are in use sufficient time is not available to allow of the bulk of the suspended matter being got rid of by means of sedimentation. In such a case mechanical filters, with the use of a small quantity of coagulant, would be useful to rid

the water of suspended matter before passing it on to the sand filter-beds.

In America use is made of large settling basins of considerable capacity to allow the chemicals and the coagulating organic matter to settle before passing the water on to the filter-beds, and basins of smaller size are thought necessary in connection with mechanical filters also. In England, in connection with the use of coagulant in mechanical filters, no settling basins are usually employed.

In comparison with mechanical filtration slow sand filtration appears on the whole to be safer, and the beds usually only need cleaning every six to eight weeks. In the case of mechanical filters the cleaning of the filters is necessary every ten or twelve hours, and in some cases oftener. The bacterial efficiency of the mechanical filter depends on the coagulant which has been added to the raw water, and any breakdown in the apparatus for mixing the coagulant and injecting it into the water causes the water to come through unfiltered. The amount of coagulant to be added and the frequency of cleaning of the filter will depend on the degree of turbidity of the water. These matters will require careful attention, and the amount of coagulant necessary can only be ascertained by means of bacteriological analysis carried out in a properly equipped laboratory.

With mechanical filtration, if samples are only examined bacteriologically once a month or at longer intervals, there would appear to be a greater element of risk than in the case of slow sand filter-beds, although in both cases frequent analyses are necessary.

At certain times of the year, generally during the summer, algæ and other minute plants often develop on the surface of sand filter-beds, forming an entangled mass; other minute vegetable growths develop in the filter and produce a peculiar odour in the filtered water. Preliminary storage of the water for several weeks would get rid of this difficulty to a large extent; and where this was not possible, the use of mechanical filters would prevent this trouble arising.

Mechanical filters take up less space than slow sand filter-beds—viz., 400 to 600 sq. ft. of space per million gallons of water filtered in comparison with half an acre of filtering area necessary in the case of slow sand filter-beds.

During periods between cleaning, in the case of slow sand filter-beds, minute vegetable growths grow on the surface of the sand, especially in the summer, and may form a thick

layer on the surface, which in the case of the green algæ can be rolled off like a carpet.

In comparison with slow sand filtration, if installation and working expenses are taken into account, the cost of mechanical filtration would appear to be less, but this will depend on the amount of coagulant used; and the cost of the chemical where a river water is used forms a considerable item.

In this country, the system which has been adopted in America of allowing the raw water after the coagulant has been added to stand in a settling basin for several hours is not in general use; in the settling tank a certain proportion of the suspended matter and bacteria are entangled in the precipitate of hydrate of alumina and fall to the bottom of the basin through sedimentation, and this process used in connection with either mechanical or slow sand filtration would appear to be necessary.

In certain cases the use of disinfectant such as bleaching powder in addition to the coagulant would appear useful, as the cost of the coagulant is reduced thereby, and in any case where there was a breakdown in the filtering arrangements the water could be sterilized by means of disinfectant, although the presence of even a slight amount of taste or smell in the water is a drawback.

A polluted water containing on an average several thousands of organisms per c.c. at all times, and with *B. Coli* in 1 c.c., will obviously require more careful treatment than a moorland water which contains on an average 100 to 300 organisms per c.c. and *B. Coli* only in small numbers. In the latter case the chief consideration is to get rid of the plumbo-solvency, and for this purpose mechanical filters would appear to be very useful.

In regard to river water, a high degree of bacterial purity of the filtered water and absence of pathogenic germs at all times and under all conditions is essential.

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