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THE FILTRATION OF PUBLIC WATER SUPPLIES.

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IN the paper on the water supply of Philadelphia, read here two years ago, I referred to the beneficial effects on water by storage and filtration. So rapid has been the progress in this field that even in the brief interval a great deal of additional matter tending towards exactness has been developed. I propose this evening to explain briefly, and to illustrate practical methods of water-purification, methods which have been carried out on so large a scale as to leave no doubt of their entire applicability to existing engineering problems in this field.

Methods of filtration are quite numerous. They may be for purposes of consideration here arranged under two heads: those in which the water is subjected to some preliminary treatment by which more or less of a coagulum or precipitate is formed, which is subsequently entangled in the filtering material and by enclosing the living germs, prevents their transmission to the effluent. Such a process is strictly one of filtration in the laboratory sense of the term; the filter acts practically as a mere straining agent, and although the entangled microbes ultimately die, it is not entirely in pursuance of a normal biologic action. The other method is to supply the water to the filter without previous treatment, and to rely not so much upon mere straining action, but to promote transformations similar to those in soil, by which organic matter is consumed, and rendered innocuous, while at the same time the microbes pass through the stages of development, age and death; the invariable sequence in living matter. Under proper conditions an effluent from such a filter will be continuously almost sterile.

For the first method of filtration, namely, that in which a coagulant is employed, we have several systems depending on the nature of the coagulant. As all these are tolerably familiar to engineers, I need merely indicate them, and briefly discuss their sanitary aspects. The most extensively employed coagulent is probably aluminum sulfate, which is either employed as such or in the form of alum. The chemical changes by which aluminum sulfate acts as a coagulant are quite simple. Almost all natural waters contain carbonates, principally calcium carbonate and magnesium carbonate, more rarely sodium carbonate. When these substances in solution are brought in contact with aluminum sulfate, an interaction takes place by which theoretically aluminum carbonate should be formed, but as this body is apparently incapable of existing in water at ordinary temperature, aluminum hydroxid, a gelatinous, almost transparent precipitate, is produced, while carbonic acid dissolves in the water. Aluminum hydroxid has a high affinity for many varieties of organic matter, rendering them insoluble by adhering to it. The organic matters of the water, at least those in solution, are precipitated by the aluminum hydroxid, and the mass so formed entangles all suspended matter, enabling a subsequent filtration through sand, even at considerable speed and under pressure, to completely remove the microbes. It is obvious that the success of this operation depends largely upon the presence of the carbonates above mentioned, or some equivalent bodies, to precipitate the aluminum hydroxid; and some waters might not be purified by the alum process, simply because they do not contain sufficient material to decompose the aluminum compound.

In practice this process may be carried out on waters, to which it is adapted, by machinery automatically supplying a solution of alum, or aluminum sulfate. Usually from half a grain to a grain of the latter to the gallon will suffice. These methods are especially adapted for the purification of the supplies to large institutions or communities of moderate size; but I am not so satisfied of their adaptability on the very largest scale. Take, for example, the case of Philadelphia and suppose the average daily consumption to be 100,000,000 gallons, which is below the actual figures; at the rate of half a grain of the coagulant to the gallon we would have an employment of 50,000,000 grains, which by a rough calculation is shown to be over three short tons. While I think it is true that so small a quantity of aluminum compound could not be harmful, yet I believe if it were the general practice to introduce daily into the Schuylkill water three tons of chemical material, there would be a tendency to ascribe a great many vague stomach troubles to this practice; doctors unable to determine the cause of various maladies would be too ready to make the excuse that it was the alum in the water.

Some years ago Mr. Devonshire gave to the Club a full account of the iron process of water purification, in which a coagulant analogous to that in the alum process is used, but in which the precipitation depends more completely upon the coagulant itself and does not involve the necessity for any particular mineral ingredient in the water. Briefly, I may say the water is agitated with fragments of iron, and by the action of the dissolved oxygen and carbonic acid, ferrous carbonate is formed, which is suspended in the water in the form of a very fine dark-green precipitate. On aërating the water by allowing it to flow in more or less of a cascade, the ferrous carbonate absorbs oxygen and water and loses carbon dioxid, passing into the condition of ferric hydroxid, a substance analogous to aluminum hydroxid and like it capable of combining with organic matter; this material entangles the suspended matter and the mass is then easily caught upon the surface of the filter. It will be seen that these changes involve the presence of no other ingredients in the water except dissolved oxygen and dissolved carbonic acid, substances which are invariably present in notable amounts in natural waters. This iron process, therefore, is probably more widely applicable, especially to decidedly turbid waters, than any other precipitation method.

Iron compounds, for instance, ferric chlorid (chlorid of iron), may be added directly to water in the same manner as aluminum sulfate; but this method is more particularly employed in the purification of sewage, which I do not propose to discuss here.

I turn now to the discussion of filtration without previous treatment with chemicals. It is now generally admitted that the diseases conveyed by water are produced by living organisms, and that if we remove these living organisms, the water will be safe. In the previous paper to which I have referred, I spoke briefly of the nature of the germ of what is by far the most important water-borne disease (typhoid fever). I am more strongly convinced than I was then that the recognition of this germ is doubtful in many cases, and that it is not yet proved that a specific organism has been recognized as the sole cause of typhoid fever. Whatever may be the truth in this respect, and a discussion for my reasons of this view would not be appropriate here, we may take it for granted that when water is contaminated by real sewage it is liable to convey fatal disease, and this conveyance is by means of microbes. It may be worth while to say in passing that mining or manufacturing refuse proper, except when it introduces poisonous metallic substances, such as lead, arsenic or copper, is of very little sanitary moment, and that quite simple systems of subsidence or straining will rid the water of the objectionable materials. We cannot, however, depend upon so easily removing the living microbes, and when there is discharged into a fairly pure stream, a small amount of infected sewage, the opportunities for multiplication of the living microbes are greatly increased by the dilution, for they have more room in which to develop. Hence we find that very small amounts of pollution will seriously affect large streams.

The chemistry and biology of filtration processes have been so thoroughly elucidated of late years, and have such an important bearing practically, that I must briefly discuss the matter. The organic matters in water, under which term we include a great variety of material, living and dead, derived directly or indirectly from plants or animals, are incapable, under natural conditions at least, of remaining permanent. As soon as a particle of tissue or any soluble organic matter from an animal or plant enters water or soil it becomes the prey of microbes and breaks down into simpler forms. The sequence of these transformations has long been known, having been especially studied in connection with agricultural problems. The dangerous organic matters of water contain nitrogen, and are first converted into ammonium compounds, and finally, by oxidation, into nitrates, often with an intermediate stage of nitrites, though these are rarely present in more than minute amounts. Left to itself, therefore, a polluted water passing through soil will gradually be completely purified, its organic matter will be converted into nitrates, and will become in this way unsuited to the nourishment of dangerous microbes, and these therefore will perish. If we look around us, therefore, observing the natural conditions, we see that subsoil water represents the highest grade of purification when the conditions are at all favorable to natural changes. Rain water, for instance, is always more or less impure; surface water is subject to serious pollution in populated districts, and as long as it remains surface water is very slow to purify itself, while deep or artesian water frequently comes to us, showing evidence of decided pollution, but as this belongs mostly to a remote geologic period we assume with safety that the microbes are all dead. Well waters, when not contaminated by surface drainage, or polluted by direct flow of contaminated water through the crevices of the soil, are rarely capable of conveying disease, and some carefully conducted experiments have shown that when wells are protected from the entrance of microbes from the air and only the water is present which is passed through compact soil, it is practically sterile. It is by applying these principles in the construction of filters that the best results have been obtained. The experiments of the Massachusetts State Board of Health, which are so frequently referred to in discussing this question, have clearly established that our most satisfactory methods of water purification are to be obtained by making the filters represent the soil. The experiments of this Board have covered a question of sewage purification as well as the purification of slightly sewage-polluted water. In the former case great success has been obtained by the employment of what is known as the intermittent system, the flow of sewage on to the filter being interrupted at regular intervals, the filter allowed to drain, by which air enters its pores; the organic matter caught upon the surface of the sand-grains is oxidized, and when this has been accomplished fresh material may be passed through. This alternation of charge and discharge may be kept up for a long while. It is found, however, that if the rate of filtration be slower, the intermissions may be less, and in this way it is possible to maintain a continual system of filtration, interrupting the process only for a moderate amount of filter cleaning.

We owe to the Massachusetts investigators much valuable information as to the chemistry and bacteriology at various points in the filter, as to the effects of rate of speed, and especially as to the size and character of the sand-grains; it appears that a rather fine and somewhat angular sand is most suitable. It is not unlikely that the chemical composition of the materials adherent to the sand, especially the presence of iron oxids, has considerable influence upon the efficiency of filtration, and some experiments that I have been making lately seem to show that a soil rich in iron oxid has especially high filtering activity. I have placed in the room a small model filter containing this material, that the members may see the work it does. A sketch of the construction of the filter is also shown; it is a very convenient arrangement for experimental filters, and was shown to me by Mr. Devonshire, who first saw it in the laboratory of Prof. Kemna, at Antwerp.

Simple sand filtration, therefore, is a process entirely satisfactory for the purification of public water supplies. It is especially adapted to the needs of large cities located on streams which are the drainage channels of a populated water-shed. Such streams form the natural and most convenient sources of supply for the cities through whose limits they pass, but it is equally true that such streams are almost invariably dangerously contaminated. We have hundreds of examples in this country and many in Europe to prove this point. We need not go further than our own city to note the effect of drinking a moderately polluted water. Without desiring to make this discussion of merely local interest, I wish to exhibit here a map which I prepared from the official records of the Board of Health, showing the distribution of death from typhoid fever in this city in 1893. It will be noted that a very large number of deaths occurred in the district north of Callowhill, south of Lehigh Avenue and west of Broad, a district which has long been on what is called the direct distribution, the water being pumped from the river into the mains without opportunity for that moderate degree of improvement which follows subsidence. It will be seen that the district from South Street clear up into the northeastern part of Kensington, which is supplied by the water from the East Park Reservoir, is far less subject to the disease, although the sanitary conditions, other than the water supply, are decidedly inferior to the first district mentioned. The district below South Street, supplied from Fairmount, a small basin, giving probably but little storage, is very seriously affected by the disease. It is also worthy of note that Girard College, which is located in the heart of the direct pumpage district, is almost free from typhoid fever, although it has a population of nearly 2000. All the water supplied to this institution is filtered.

In conclusion, I may say therefore, that the filtration of public water supplies is no longer in an experimental stage; that by imitating the natural processes the destruction of organic matter by microbes and the destruction of microbes themselves we can render even a highly polluted water perfectly safe. Surface water should always be so treated unless an engineering inspection shows absolute freedom from pollution with sewage. Operations on the large scale are now sufficiently numerous to indicate that what holds good in the laboratory will hold good in the largest filters, and the experience of Poughkeepsie indicates that even the winters of our northern climates do not militate against the use of this method.

With a view of illustrating to the Club the practical operations of filtration I have arranged to exhibit by the lantern a few slides kindly made for me by Mr. Prince, to whom I wish to express my thanks. No doubt these views are familiar to some, but will probably be unfamiliar to most present.

I am also able, through the kindness of Mr. George W. Fuller, Biologist of the Lawrence (Mass.) Experiment Station, to show you samples of the standard sands used there. Doubtless the rather coarse grains in some of the samples will excite remark, but it has been found that by a judicious association of oxidation and filtration even these coarse sands may be made efficient.

In a recent communication Mr. Fuller points out that the observations at Lawrence have shown that the disease-producing microbes die at the top of the filter, being apparently less fitted for the struggle than the microbes normal to the water. In fact, there is some reason to believe that some of these disease-producing microbes, for instance the typhoid germ, are but highly differentiated or specialized forms of ordinary water bacteria, and, like other wide departures from the normal, are unable to sustain a severe competition. The observations at Lawrence, therefore, fairly dispose of one objection to filtration. It is often said that if five out of 1,000 microbes pass through the filter these five may be the very ones that are dangerous, but we see that this is not likely to be the case.

The following account of the method of constructing filters for sewage purification has been furnished me by H. W. Clark, Chemist at the Massachusetts Station.

The sands in use in the large filter vary in effective size from .04 to 1.40; that is to say, the finest 10 per cent. of the material is composed entirely of grains whose diameter is less than .04 of a millimeter in the finest material used and less than 1.40 millimeters in the coarsest.

With coarse and medium fine sand the filters contain but one grade throughout the entire five feet. With fine sands trenches are sometimes dug one to two feet deep, and filled with coarser sand; this gives a given area greater filtering capacity.

With what we consider the best grade of sand the applied dose of sewage, 100,000 gallons per acre per day, will pass below the surface of the sand in a time varying from 10 minutes to 1½ hours, depending mainly on the condition of the surface of the filter. The remainder of the twenty-four hours the surface is uncovered.

In the intermittent filtration of water as now practiced at this station the surface of the filter is uncovered two hours out of the twenty-four.