THE EFFICACY OF FILTERS AND OTHER MEANS EMPLOYED TO PURIFY DRINKING-WATER.

A Bacteriological Study.

BY

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OF NEW YORK.

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THE EFFICACY OF FILTERS AND OTHER MEANS EMPLOYED TO PURIFY DRINKING-WATER.

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WATER, even after having been exposed to various chances of contamination, is very generally drunk as it is received from lakes or rivers, wells or springs, tanks or hydrants; and, despite the most disinterested warnings, people are not ready enough to believe that clear, sparkling water may at times be the most harmful of beverages; that it can carry with it, and introduce into the systems of a portion at least of those who drink it, the immediate causes of various impairments of health. Polluted water may be agreeable to the taste and have no visible sediment, yet cause many deaths. Such water the unskilled are slow to suspect, and but for the advance in sanitary science and the warnings conveyed by those familiar with hygienic studies, pure supplies of drinking-water in cities would be much more of a rarity than they are.

[1] Read before the Section on Public Health of the New York Academy of Medicine, April 5, 1889.

At the Hygienic Congress in Vienna, in 1887, M. Brouardel stated that he knew of over sixty epidemics of typhoid fever which had been induced by the drinking of infected water.[1] From typhoid fever thousands of deaths occur every year; and, although scientific physicians are constantly urging these facts, it seems to be necessary that the danger present itself in the form of an epidemic before the people fully realize the immense harm which may result from impure drinking water. The epidemic which ravaged Plymouth,[2] in Pennsylvania, four years ago, attracted great attention at the time, but the history of several similar "visitations" since then would indicate that the full value of this severe lesson has not been properly appreciated.

Water may be very highly colored, and yet, if freshly collected near its source, show no very large number of bacteria. Such is the case with the best of the peaty "juniper" water which I have examined in various parts of the Dismal Swamp of Carolina and Virginia. Although having a large propor-

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[1] Dr. A. Ollivier: Rapport au Conseil d'Hygiène Publique (etc.), Paris, 26 mars, 1886. A valuable monograph on typhoid fever by a scientific practitioner. As different parts of Paris receive water from rivers of very different quality, the careful health reports from garrisons and institutions, which vary only in the purity of the water supplied, are very instructive.

From the abundant evidence as to the influence of polluted water in inducing typhoid, may be cited the report of the Zurich Water Commission of 1885.

[2] Biggs and Breneman: N. Y. Med. Journal, vol. xli. (1885), May 23 and June 6. French and Shakespeare: ibid., June 13. L. H. Taylor: THE MEDICAL NEWS, vol. xlvi. (1885), May 16 and June 20.

tion of organic matter, this water is reputed eminently wholesome, and an inquiry among a portion of those drinking this exclusively, appears to show an unusual degree of immunity from the manifestations of diseases which might be attributed to the effects of improper drinking-water.[1] On the other hand, the turbidity which is common at this season of the year in the streams furnishing the water supply of many of our cities, is almost always accompanied by a large number of bacteria, as in these bottles of water which you see here from the Mississippi and from some of the rivers flowing into the Atlantic. The melting snow and the rain, which wash into the streams an increased amount of organic matter, introduce with it other germs (perhaps pernicious), and bring more nutriment than usual to the microorganisms already in the water, thus increasing their vitality and numbers.

It is believed that, like most of the varieties of bacteria found in water, the still larger forms of animal and vegetable life, ordinarily existing in lakes and rivers, are not prejudicial to hea'th. It is through the products of the decomposition of

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[1] If harmful bacteria be introduced into it, such water favors their increase, while they would not be so apt to multiply in a very pure water having much less organic matter. Despite the gcod reputation which this water has had, and its wholesomeness near Lake Drummond, one who has seen the whole length of the canal down to the lower end, from which the supply for vessels is taken, can realize that the water may undergo considerable contamination before it reaohes that part. I am sure that the present use (in our navy) of distilled water, kept in proper receptacles, is safer than the employment of the swamp water.

many of these, when their life has ceased, that they may become harmful.

Chemistry has long furnished a means of recognizing polluted water, even when it yielded no sediment visible to the unaided eye, and the presence of considerable quantities of chlorides, nitrites, and ammonias, determined by the chemical tests, has shown that many a water had more organic impurity than was permissible; and, when far below the accepted standard in this respect, such a water is very justly condemned. Yet it seems as though enough of the infective element of cholera or typhoid to diffuse an epidemic throughout a community can be added to a drinking-water and not be detectable by chemical tests. A perusal of the very complete and instructive paper by Professor J. W. Mallet (in the report of the National Board of Health for 1882) shows how widely such determinations may vary and how unreliable chemical standards may be.

The known disease-producing bacteria, however, do not appear to increase in water[1] in which there is not more organic matter than the proportion that chemists of constant and large experience regard as permissible in waters which they pronounce to be of fair quality, although these harmful bacteria, if once

[1] In my tests, when I prepared an artificial water, I added the germs directly from a pure culture, unlike Bolton, and like Wolffhügel and Riedel (Arb. aus d. Gesundheitsamte, 1886, i. p. 455), with whose results, however, I cannot so well agree as I can with those of Bolton (Ztsch. f. Hygiene, 1886, i. p. 76). I have in but two out of many trials, with disease-producing species, found typhoid bacilli to increase in sterile pure water, and then only to the extent of thirty per cent.

introduced there, may long retain their vitality and remain dangerous.[1]

Since, as yet, chemistry, when called upon to aid in solving the question of the purity of a water, can at its best only approximately estimate the amount of organic matter present and its state of oxidation, while it fails to inform us whether infective matter be present or not in a given water, it has been hoped that a sure means of recognizing whether a water be in any degree infected was reached when Koch introduced the bacteriological test. This test, while very definite and conclusive under favorable conditions, has thus far been able to decide absolutely in only a small portion of the cases of disease apparently coming from the use of drinking-water.

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[1] Chantemesse and Vidal (Gaz Hebdomadaire de Méd. et de Chir., 1887, pp. 146-150) kept typhoid bacilli alive for "months" in sterilized water from the Ourcq, which is the worst water supplied to Paris, and much impurer than the Croton, in which, when it was sterilized, I have been able to keep typhoid bacilli alive for only two weeks, and usually not over eight or nine days. I have observed that the greater the variation of temperature it was exposed to, the shorter time did this microörganism live in water. It has been found by all observers that oscillations of temperature around the freezing point were much more destructive to these than freezing them in water and allowing the ice to remain frozen. So, I have observed several times that of two flasks of the same typhoid water, the one which was kept at a temperature varying from 37° C. to 10° C., had, at the end of three days, many fewer than were in the flask kept between 16° C. and 10° C. In my last test of this sort, the flask of which the temperature varied most had, after two days, only a few more than a third of those in the one kept at the evener temperature. Heræus: Zeitschrift für Hygiene, i., 2, p. 193. Hochstetter: Arb. aus d. Gesundheitsamte, ii., 1, p. 1.

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Yet in those cases where the bacteria characteristic of distinct disease have been detected in the suspected water, the isolation, culture, and identification of the disease-producing species furnish a convincing proof of the great value of the method.

The method employed is a simple one. Usually one cubic centimetre of the water to be tested is added to ten cubic centimetres of nutrient jelly, made by solidifying very nutritious beef-tea by the incorporation of one-tenth its weight of gelatine. Everything being done with rigid precautions, the water to be tested is added to the nutrient jelly, which has been softened by being warmed to a little more than 30° Centigrade. This is then quickly mixed and poured upon a cooled glass plate, where the fluidified gelatine soon becomes quite solid. Then the germs in the water, being scattered evenly throughout the mass, exercise their functions of rapidly multiplying at the room temperature; and, in the nutritious medium, the minute microscopic individual has perhaps by the third day become a dot as large as a pin-point, or much larger, containing thousands or millions of newly formed bacteria. These are called "colonies," and vary considerably in appearance, as will be seen by comparing the plates made with various waters. With a glass ruled into centimetre squares the number can be counted or estimated. If a large number of thousands be present, as in waters artificially prepared for tests and in sewage contamination of water, the only way to arrive at an accurate estimate is to employ in the eye-piece of a microscope a micrometer square, as first used, I believe, by Dr. Edw. K. Dunham, who combines with it the aid of an automatic counter. After determining the number we isolate and identify the species as in general bacteriological study.

There are many features of the subject which must be omitted in a paper of this scope, for they may not interest all, while the limits of the usual time allowed must be respected; and as the important points are to be discussed by eminent experts, I will not linger over the still unsettled question as to the absolute value of mere numbers of ordinary water bacteria in determining the sanitary merits of a water.[1] It is, however, admitted that the fewer the varieties present, the less is the likelihood of sources of contamination affecting the water. In examining a considerable number of samples of water from various sources, I have observed that the less chance of contamination there was, the fewer bacteria have I found in the waters. Thus, fine mountain lakes and springs have never in my experience, unless under very unfavorable conditions, shown as many as one hundred bacteria in each c. c., while the same quantity of water from a river draining thickly peopled valleys may show more than fifty times as many. While it offers less striking extreme differences than I have seen in the Hudson Valley and

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[1] Gärtner: Correspondenz Bl. d. allg. ärzt. Ver. von Thüringen, 1888; Nos. 2 and 3.

Centralbl. f. Bakt. und Par., iii., 5, p. 161 et seq.

Wolffhügel: Arbeiten aus dem Gesundheitsamte, Band i., iii., 5 Heft (1885), p. 546.

Plagge und Proskauer, Ztschr. f. Hygiene, 1887, pp. 470 and 486.

elsewhere, the Passaic water-shed may be briefly instanced as illustrating what I have just said. I give it because it is the smallest one near us offering every phase of importance in this connection, and because the subject of a supply to come to New York from that source has been seriously considered. The best of the upper lakes of this system showed on a pleasant day of the past winter only fifty-seven germs developing in the nutrient gelatine, while the Pequannock and other tributaries into which these lakes flow showed, in the samples collected as nearly at the same time as possible, over three hundred and fifty germs, which number increased as the water was taken further down stream; while at the Passaic Falls, in Paterson, over a thousand were detected in each c. c. Water from the hydrant in Newark, at the same time, showed nearly four thousand germs of bacteria in each c. c. The Newark water supply is at present derived from the Passaic, some miles below the place where sewage from Paterson is discharged into the river.

As in chemical, so in bacteriological water examinations, those who have had the broadest experience and who are most careful are best in a position to pronounce an opinion. Apart from any personal equation, there are still limitations to the entire comprehensiveness of the method. I may mention that bacteria are recognized as present in the human body and in its products and changed tissues, which bacteria are never found to live on the gelatine or other water plates. Then, too, a water may be submitted for examination when all the obvious infection has disappeared, or has become exceedingly diluted, and hence a most painstaking test then fails to reveal the presence of the characteristic micro-organism. The period of incubation, after the infection and before the symptoms are recognized, may in Asiatic cholera occupy the greater part of a week, and in typhoid often lasts for two weeks or more, so that all traces of the harmful bacteria may have left the water before it is suspected. By reason, also, of its likeness to various harmless species, and its tendency to be overwhelmed by other more rapidly developing forms, the "colony" of the disease-producing species may be hard to identify. In this respect typhoid is decidedly more difficult than cholera to recognize in ordinary water.

For those who believe that bacteria of certain kinds living in water, and with this introduced into the alimentary canal, can in many cases induce disease, this test, being so precise and delicate as it is, must appear the best way of determining whether the filters and other means in common use are efficient or otherwise in removing the dangerous elements from impure water passed through them—in short, whether they act as "disinfectants" of the water.

As various other agencies are used in conjunction with, or as supplementary to, filtration, it is proper that I here indicate how far they serve to purify drinking-water. One of the most prevalent means directly resorted to for this ostensible purpose is the admixture of wine (usually red). Adding this to an equal amount of Croton water, I find that a varying proportion of the bacteria are killed, sometimes less than half, even after the mixture has stood for days. The spirituous alcoholic beverages (having from 45 to 68 per cent. of alcohol), mixed with Croton hydrant water in equal parts, cannot be depended upon to kill all of the bacteria, especially when "earth" bacteria are present, and a small percentage of whiskey (less than 20 per cent.) has very little effect in this direction.[1] In malt liquors, as lager beer, the prolonged boiling in the brewer's kettle has destroyed the bacteria of the original water, even if they be of the most harmful and resistive species which we meet here. Various kinds, however, if present in vats, kegs, and bottles (because of imperfect cleansing), will live in beer.[2] Almost all the artificial mineral waters that I have examined are made of unsterilized water. Pressure of carbonic acid gas, and contact with it for days,

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[1] Koch (Flügge, Chapter V., sec. 3) found that the spores of *Bacillus anthracis* were alive even after months of exposure to the action of absolute alcohol.

Pasteur and Joubert (*Comptes Rendus des Séances de l'Académie des Sciences*, 9 and 16 juillet, 1877) stated long ago that the spores of anthrax would remain alive in absolute alcohol.

Anthrax, however, need not be expected to occur in the water supplied here, and several recent experiments show that it is possibly destroyed by other bacteria which may occur in the water.

Anthrax spores are employed in such tests because they are considered the most resistant of all disease-producing forms of bacteria.

[2] The bacteria from this source which I have found in examining a limited number of beers were mostly of non-liquefying kinds, and there were notably many iridescent "spreading" colonies. [Jan. 1889.]

In these cases water from old surface wells was used to wash out the kegs.

reduces greatly the number of bacteria in a mineral water, yet the typhoid bacillus and others will live ·or days in Seltzer water. In New York I have found many bacteria in the few carbonated beverages that I have examined.

Of the various acids which it is occasionally safe to employ, chemically pure hydrochloric acid must be used in the strength of at least one-half of one per cent. to destroy all the germs in Croton water to which *B. subtilis*, *B. typhoid*, and other bacteria have been added; and may fail to sterilize the water even after hours of standing thus acidulated. Sulphuric acid is more than twice as potent, and usually in the strength of one part to five hundred of water will render this free from living germs. Sometimes, however, it has to be used still stronger, as it is in a certain extensively advertised nostrum, in which, under a fanciful name, it plays the principal part. Alum, lime, and the other chemicals which, by inducing sedimentation of organic and mineral constituents, carry down many of the bacteria in water, do not (as is often believed) insure the annihilation and destruction of organisms present.[1] It is the mechanical action of the film, which the presence of a

[1] Residents of the Mississippi Valley, where the principle of settling water by adding alum has been extensively made use of, have expressed to me their belief that many digestive irregularities are caused by the use of alum. The danger lies in the use of an excess, and probably does not exist with the small amount which is permissible (2 : 100,000).

As was just noted of absolute alcohol, Koch also found that the spores of the *B. anthracis* were not destroyed by prolonged exposure to the action of a four per cent. solution of alum (or a concentrated solution of chloride of lime).

minute amount of these causes to settle sooner than would otherwise occur upon sand in certain large sand filters, which insures their excellence, and the scarcity of bacteria must here not be attributed to a coarse chemical action. When chemicals are added in sufficient strength to destroy speedily all the bacteria which may be present, the water thus treated cannot be recommended as a beverage.

With the imperfection of all other methods, we have in prolonged boiling a sure disinfectant of any water. I have usually found that maintaining a water at the boiling point for even less than fifteen minutes sufficed to prevent any of its germs from developing in gelatine, and this even with bad waters[1]

[1] The employment of silk threads, in and upon which are dried living bacteria with spores, seems to endow these germs with greater resistance to the action of steam heat than when the bacteria are (as in drinking-water) each surrounded by water. Having tested various waters from different cities, I was lead to believe that heating for a very short time sufficed to sterilize them. So I have made several series of experiments on the spore-bacteria usually regarded as most resistant. I used Croton water, sterilized and not sterilized, and bacteria from pure cultures on agar and potato (where the spores were, just before the experiments, seen by the microscope to be very abundant). I added from these cultures a small amount to water in flasks. These flasks were well agitated several times; then several plates made to test the presence of living bacteria. The water was from these poured into sterile tubes and Erlenmeyer flasks plugged with cotton. Several of these were tested before and after the heating. A wire basket, holding eight of these cool test-tubes or flasks (each having from ten to twenty c. c. of the infected water), was placed in a heated steam box. The temperature ranged from 93° upward, but the thermometer did not register above 100° C. These tubes were taken out as rapidly as I could cool the plates at once prepared from them (at intervals of from three to four minutes). While this is not so absolute as are some other methods, it seemed the

from sewage-infected rivers. The process of distillation likewise sterilizes water.

That freezing temperatures destroy only a certain proportion of the bacteria which exist in the water from which the ice we use is formed, must, I think, be evident to those who have read Dr. Prudden's masterly paper on this subject. He there shows that the typhoid bacillus in ice retained its vitality for one hundred and three days. As he will discuss the subject this evening, I shall simply echo his previous warning against putting ordinary ice into water which we are to drink, as many kinds of bacteria may be thereby introduced.[1]

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best for the practical object aimed at. In this way I found that the spores of *B. anthracis* failed to develop on gelatine (in five days) after they had been boiled in clear water for from two to five minutes. That this result was not extraordinary will appear to those who consult a remark by R Koch (and Gaftky and Löffler) in Mittheilungen aus dem Gesundheitsamte (1881), p 322.

My results with *B. subtilis* are likewise not in accordance with the accepted views. I am still experimenting in this direction, but have never found any water bacteria (which would develop in nutrient gelatine) after the water in which it was had been boiled for even a tenth of the time (six hours) which Globig states as necessary to kill (by steaming) the most resistant red-potato bacillus with which he experimented (Globig; Ztschr. f. Hygiene, iii., 2, p. 231). He used silk thread wrapped in filter paper.

[1] Prudden; on Bacteria in Ice, etc., N. Y. Med. Record, March 26 and April 2, 1887.

Bordoni-Uffreduzzi (Centralbl. f. Bakt. u. Parasitenkunde, i., 2 Band (1887), p. 495) insists that in natural (Italian) ice the bacteria which survive the extensive destruction caused by the cold of freezing do not gradually decrease, but that they indefinitely retain their vitality. He states that he agrees with Dr. Prudden's results in that disease-producing forms of bacteria resist freezing better than the harmless ones.

Fränkel—Bakt. des Eises—Zeitschrift f. Hygiene, i., 2, p. 302.

The mechanical separation of impurities is the principal action in all filters, whatever their composition. The amount of oxidation produced by the passage of considerable quantities of water through inconsiderable masses of charcoal, sand, or anything else, seems never sufficient to chemically purify an infected water, although the Berlin system of filtration, by large beds of sand skilfully managed, effects a notable improvement in this respect.

Almost all tissues tend to separate visible particles from water which is turbid, or in which a deposit settles. The fact that such matter is retained from the water passed through filters appeals very strongly to most persons; and the general assumption that such visible matter is dangerous, and that its removal insures the purification of water, seems to explain the extensive use of filters. They are all composed of felt-like matter (filtrum), or of any tissue or substance so woven, composed, or arranged as by its structure to more or less completely arrest the passage of sediment and the floating particles existing in varying amounts in nearly all natural waters. The filters in domestic use may be ranged in two classes. In one class the water runs or is poured into a tank or other receiver over or beside some filtering medium, through which the flow is into a receptacle, and from this the water is taken as needed, or is stored as fit for drinking. Those of the second variety are designed to connect with the faucets, and to strain from the water such impurities as it brings through the hydrant.

One of the most widely used varieties is this simple and portable one, which renders water clearer and more agreeable to the eye. It is composed of a cylinder of pressed carbon, three inches or less in diameter, and having nearly the same depth, which has from its interior a tube passing through the bottom of the funnel in which it rests, and thus requiring all the water passing out of the bottom of the funnel first to go through the mass of carbon. The flow is very sluggish unless use be made of pressure or suction, as, for example, by lengthening the tube taking water out of the filter, which impairs the effectiveness of this so far as purification of the water is concerned. After this has been used for a few days the retardation is very marked, and is due to the clogging of the filter by the various matters which form the sediment of the unfiltered water. This necessitates frequent cleansing.

Taking a freshly sterilized carbon filter of this sort and pouring into the funnel Croton water just drawn after considerable has run from the faucet, and then collecting in sterilized test-tubes the first flow from the filter, adding of this (as already explained) one cubic centimetre to ten parts of softened nutrient gelatine, the mingled gelatine and water being poured upon a cool plate, it is seen that, before three days have passed, several colonies have developed. Comparing the number of these with that found from the original Croton water plated just after being drawn, we find that at least from five to eight per cent. of the bacteria pass through the filter and develop. The percentage rises as more and more water flows through. From fourteen trials made with simple Croton water, I found that through a carbon filter, freshly sterilized and the introduction of germs from the air and other sources of contamination being guarded against, the first flow showed only a small percentage of the bacteria found in the original water used. Then I continued the use of the same filter without resterilizing, and endeavored in every way to have the conditions under which it was tested as much as possible like those which would exist in domestic use, and the supply of water in the funnel was allowed to become exhausted at times, as usually during the night.

In this filter thus used, the number of bacteria in the water passing through is, on the second day and thereafter, much larger than in the water taken after being poured into the funnel and before it has percolated through the carbon block. This excess, when large, seems to bear an inverse ratio to the volume of the flow.

It is a familiar fact that, if fresh hydrant water in a flask covered with cotton (to prevent the entrance of bacteria from the air) be allowed to stand for a day at the temperature of the laboratory, the original bacteria in the water may be found to have increased considerably. So, as a collateral test, after water had been poured into the filter and before it had passed through the carbon, I have taken some of this original water and allowed it to stand in test-tubes and flasks, both stoppered and open, by the side of the filter similarly protected from the entrance of germs from the air, and exposed to the same variations of temperature.

This water, examined at the same time with that coming out of the filter, showed that the bacteria appear to multiply much more rapidly in the substance of the filter than outside in separate flasks, likewise kept at the varying temperature of the laboratory, as it then was. The water poured in rarely contained as many as 225 bacteria in each c.c., and yet in from one to three days from the time when the freshly sterilized filter had begun to be used, the water after passing through the carbon showed several thousand in every case, and at times more than 25,000 bacteria in each c.c.

All sorts of bacteria appeared to pass through, and not alone water species. The bacillus of typhoid fever will not only pass through, but in two of my trials I found that it had increased. For such special tests I used sterilized Croton water, into which bacteria[1] were introduced from pure cultures. For artificial typhoid-water the bacillus of typhoid was added from agar and potato cultures. Harmful bacteria can pass through such filters, can possibly increase in them under certain favoring conditions, and from parallel tests seem to retain their vitality longer when in the substance of the filter than when in a glass vessel beside it.

Clean sand fairly represents the granular masses of filtering material, and has all the advantages of

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[1] B. fluorescens (Oneida) and B. liquef. alb. aq. (Croton) For cocci: Staph. pyog. aureus and a coccus obtained from the water of Salmon River, west of the Adirondacks. For a spiral form: Sp. tyrogenum was used as being harmless, yet similar to the cholera microörganism.

powdered charcoal and magnesia as generally used for filtering considerable quantities of water, while it is more readily cleansed of the accumulated organic matter and, unlike spongy iron,[1] adds nothing objectionable. Unless, as in the case of the large Berlin filters and others acting similarly, rendered more effective by overlying silt and organic matter, beds of sand do not prevent the passage of large numbers of bacteria. I have found many bacteria in waters from various artesian wells coming from a deep stratum of sand. Through a thin sterilized layer, from six inches to one foot in depth, of the finest sand procurable from beaches, all the way from forty per cent. to ninety-five per cent. of the bacteria in the original water pass, even when the level of the water is never more than three inches above the surface of the filtering mass. When a higher pressure is afforded by the water, very few of the bacteria are kept back.

As in nearly all other filters, so through a layer of sand all kinds of bacteria, harmless or harmful, appear to pass easily. Here, too, they can multiply in the moist sand. Thus, I have found the hydrant water, which entered the sand filter with 290 bacteria in each c.c., to come out through the filter (not

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[1] For some of the reasons why spongy iron has fallen into disuse, especially in America, see a very instructive paper by the ate Prof. W. R. Nichols in the Ninth Report of the Massachusetts. Board of Health, 1878, p. 137.

For favorable notice of spongy iron, see Frankland, Proc. of the Royal Soc., No. 338, 1885. I do not care to consider it here, for it is a proprietary preparation as offered upon the market (in London), is variable in quality, and never sold here.

freshly sterilized before using) with sixty and one hundred times as many as entered. In a gramme of sand taken from a filtering bed, I have found more than 10,000 bacteria.

The combination of other substances with sand, as in numerous small and large filters, fails to improve the usefulness of either, except in so far as the elimination of sedimental and other coarser particles is concerned.

Sponge is often employed for this purpose, as well as independently, yet it is incapable of separating bacteria from the water strained through it simply, or through sand or other substances used with it. When a large mass of fine, sterilized sponge is closely packed, the first few ounces of hydrant water that pass through may have a very small percentage of bacteria, but the proportion soon increases, while if the sponge-mass be considerable and loosely packed it may, even in the beginning and under exceedingly slight pressure of water, keep back no more than fifteen per cent. of the bacteria of the original water. This freshly sterilized sponge can at the end of the first day of ordinary use cause the water then flowing through it to contain from increase ten times as many bacteria as the Croton water poured in. The stronger the pressure, and the more rapid the flow, the lower is the ratio of excess due to increase in the filter over the quantity found in the unfiltered supply, which, of course, was here, as in all other tests, regularly plated at the same time with the filtered water. When the flow is sluggish, and when it stops entirely at times because of all the water supplied having passed through, the sponge substance favors the increase of the bacteria to a greater extent than is the case with sand. The sponge, within twenty-four hours after sterilization may, under these conditions, cause the water first running through after the intermitting of the flow to have five hundred times as many bacteria in each cubic centimetre as are found in the water supplied for filtration.

The only way really to cleanse such a filter is to remove the sponge and boil it. Then the process repeats itself. In a few hours after unsterilized water moistens it, the mass of sponge is again teeming with bacteria. Sponge filters are, so far as I have seen, becoming less popular. It is easily recognized, even by an untrained observer, that the organic matter in sponge can undergo decomposition under the conditions obtaining in ordinary filters. Several of the large filter systems used in manufactories, hotels, and other places where large amounts of strained water are used, employ sponge and the filtered water abounds in bacteria.

Filter paper, as used in laboratories, is useful in separating precipitates and sedimental particles from water, but at least from fifty to seventy per cent. of the bacteria in Croton hydrant water go through with the water filtered, even if the pressure be exceedingly slight. The paper which I employed in the trials was, of course, carefully selected, and the folding was cautiously done, so as to prevent any break in the substance. Only single sheets were tested.

"Prepared cotton," cleansed as for surgical dressings, and so made absorbent, removes considerably fewer of the impurities of the water than does the filter paper. Two-thirds of the bacteria pass through when the cotton is at its best, freshly sterilized and carefully packed. If enough be used, it will usually render the water clear; but, as it has been lauded as a filter, I ought to add the statement of my observation that, when left moistened with water, as in the intervals of filtering through it, the bacteria of the original water can multiply over one hundred and fifty times, and all kinds can pass through it.

Combinations of the various substances mentioned have hardly any enhanced merit as strainers, and, as far as the bacteria are concerned, the combination seems to add no safeguard. Sand with carbon (bone charcoal) and sponge or cotton, hold back at first a larger percentage than sand would, by itself. Yet bacteria pass through in any case, and the increase afterward is greater than in simple sand. This I have seen in various filters.

In a well-known bottling establishment of New York, where immense quantities of artificial waters are prepared every week, all the water used in their preparation flows through a layer of fine sand in the bottom of an enormous vat and, from the receptacle into which it then flows, it passes through a layer of charcoal. These layers are each less than a foot in thickness, and water passes rapidly through. The sediment is thereby removed, but in the single examination which I was enabled to make I found that each cubic centimetre of the filtered water had over

3200 bacteria on each of the two plates made, while the Croton taken from the hydrant in the immediate neighborhood on the day before averaged a few over one-eighth as many (432).

Asbestos of the best quality, new, freshly sterilized and tightly packed, I have found capable of holding back all bacteria when the pressure of the water was low, and the few that were forced through when the substance was defective did not seem to multiply so rapidly as in other filter-masses. While it, when of the best finish and most tightly compressed, deserves to rank next to the principle employed in porcelain filters, these latter are superior in that they can be regularly furnished of a uniform and definite quality which produces the best results, while I have found it difficult to keep the best asbestos boards up to their original standard of excellence, and if the surface be large enough to insure an abundant flow of water, flaws are liable to arise, and these let various bacteria through. With asbestos it is the fineness of the surface which the original water encounters that is important more than the thickness of the layer.[1]

Although wire cloth strains out the coarser particles, its structure does not cause the removal of any of the bacteria from water passing through. Still it has the positive merit of being easily cleaned, and can be heated in an oven or boiled to sterilize it. Furthermore, it does not furnish a filter-mass for the bacteria to multiply in, although harmful bac-

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[1] Hesse; Deutsche med. Wochenschrift, 1885, No. 5.

teria can adhere to it and become dangerous if it be left uncleaned.

Closely woven cloth, such as thick, dense flannel, when only a slight pressure is exerted by the water, may stop ten per cent. of the bacteria in the water poured upon it. It is easily cleansed and, if very often changed, and boiled before using, it serves excellently as a simple strainer without the disadvantage, in this respect, of ordinary filters, in whose substance the increase of bacteria may be enormous.

Like porcelain, filters of porous stone, if of the best quality, prevent the passage of bacteria with the water filtered through them just after they have been sterilized. To test porous stone I employed selected perfect specimens of a popular filter which very satisfactorily clears all turbidity from as bad a water as that of the Hudson River at its worst. In these, the stone layer was cemented into a porcelain cylinder and was about three-eighths of an inch in thickness. The pressure was never more than that of ten or eleven inches of water, and, at the fastest, less than three-fourths of a litre passed through in an hour. As the sediment of the water settled upon the surface of the stone, the flow became much slower. During twenty-six trials of this kind of filter, it had previously been sterilized ten times by exposure to moist or dry heat, or to both, for several hours. In every one of these ten cases the various waters poured into the receptacle above the porous stone for the first time after sterilization, flowed through germ-free; that is, the stone was permeable for water, but at first allowed no bacteria to pass through, and the plates of gelatine developed not a single colony from the usual cubic centimetre of the filtered water. After some hours of use, a few bacteria had insinuated themselves into the stone or were drawn through with the water. Within twenty-four hours the water flowing through and collected in sterilized receptacles contained many bacteria, which numbered regularly from seven to fourteen times as many as were in the original hydrant water supplied during these trials. After several days, the number of bacteria had so multiplied in the stone, that the first water running through after the stone had remained for several hours without any flow through it (as happens constantly over-night in domestic use), showed in each cubic centimetre of this filtered water over one hundred times as many as the average water poured in for filtration. To test further these filters, I have used artificial waters made by adding bacteria of all shapes and characters, from pure cultures to Croton water sterilized by boiling. These various kinds can get through, but the disease-producing and spiral forms usually died out in large numbers before any could pass. From Croton water, the most marked by its predominance in the filtered product was a short, mobile bacillus which was unlike the two varieties first forced through the porcelain in my experiments.

Allied to the porous stone filters are those of porous porcelain prepared in this country. Porcelain baked at the same low temperature as the porous cups used in electric batteries is, in its efficacy, very much like the stone just described. Under a low pressure, water passing through this substance during one or two days can become completely sterilized, which is a result superior to that got from the stone filters. Before much water has passed, the bacteria make their way through and multiply somewhat on the passage. This material, as I have thus far found it, of American manufacture, is therefore imperfect, yet is superior to rebaked porcelain in the single important respect that it is not brittle, while the rebaked porcelain cylinders of the Chamberland-Pasteur filters are quite fragile.[1]

Recognizing the defects of other substances, Pasteur and Chamberland[2] called attention to their filtering cylinders, in which the important element is unglazed, rebaked porcelain. Originally employed to facilitate "cold sterilization" of fluid culture media, the fact that water went through the porcelain without carrying any bacteria with it has caused attempts to popularize its use. Inasmuch as some bacteriologists on both sides of the Atlantic had reported that this filter prevented the passage of bacteria, I was careful to use only selected cylinders without flaws,

[1] It has for some time been known that fluids can be rendered germ-free for laboratory use by being passed through solidified plaster-of-Paris (best prepared with incorporation of asbestos shreds). These filters, however, lack permanency and cause the objectionable sulphate of lime to be present in the filtrate.

[2] Bouley (for Chamberland): Comptes Rendus de l'Acad. des Sciences, 4 aout, 1884.

Chamberland: Comptes Rendus Hebd. (etc.) de la Société de Biologie, 1885, p. 117.

Immediately following this (*idem.*, p. 120) were reiterations of adverse criticisms by Galippe and Bourquelot.

and did not omit any precaution to prevent the introduction of contaminations.

The most satisfactory way of using this for testing was to employ the single porcelain cylinder, within the usual casing, attached to a hydrant system and with a pressure of water varying from six to fifteen pounds.[1] Even with the highest New York hydrant pressure the flow is only drop by drop. It can be used to siphon water out of a jar, and in this way it works nearly as rapidly as when attached to the hydrant in the basement of a house in the centre of this city. By a porcelain cross-tube sold in Paris, two or more cylinders can be siphoning at the same time into the same tube. To avoid risk of contamination, I used for siphoning a single cylinder, to which a bent glass tube was attached by a tightly-fitting piece of rubber pipe, all parts having been sterilized as well as the water by which the flow of the siphon was started. I got germ-free results regularly by this means in seven trials with two cylinders used separately;[2] but, in order to insure this, all the precautions mentioned are necessary as, in the water siphoned in domestic use of these cylinders, bacteria of various sorts are

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[1] This highest pressure was only at night, and once on Sunday night the pressure for a short time was three pounds greater. During the daytime the pressure was rarely more than ten or eleven pounds, but occasionally the gauge vibrated a little higher on account of the concussion of the water while a neighboring pump was working. The pressure was tested by an expert, and was only half of that indicated on the French circular of the agents of this filter in Paris as yielding 200 litres (50 gallons) per day.

[2] One cylinder being used three times, and another four times, each being carefully sterilized before each trial.

found, yet they are possibly contaminations due to the inherent defects of all such joints as are used. So I have devoted more time to testing these when directly connecting with the hydrant, as very slight precautions are needed, in their use with faucets, to eliminate all chances of contamination.

My first thirteen trials of this filter used in this way were under less satisfactory conditions than the fourteenth and those following, as the former were in a laboratory where the available water came under not much more than twenty feet pressure from a tank, and I was not able so well to control the constancy of this pressure as I was during the later trials. My first sixteen tests of various ones of these cylinders gave sterile water. Then, attached to a basement faucet, with a direct flow from the hydrant under a pressure never exceeding fifteen pounds (except that on Sunday nights it was for a few hours three pounds higher), the filter, after several days of intermitting use, gave over 3500 bacteria in each cubic centimetre and all the water examined (two samples per day) for four days showed an increasing number of bacteria.[1]

On the third and fourth days after the first passage of bacteria through the porcelain wall of the cylinder, the number in each cubic centimetre varied above and below 400,000. The filter was then sterilized by steaming for five hours, as was also done between

[1] The varieties first passing through were:

1. Colonies liquefying gelatine, and composed of medium-sized very mobile bacilli.

2. Superficially-spreading colonies of short, mobile bacilli.

the second and third series of tests. These tests bore out the results of the former observation.

That these results show that average specimens of this substance have the inherent defect of all filtering material, though in a much less degree than all others, seems to me unquestionable. That the bacteria did not get through owing to some defect in the particular filters which I used is evident from the fact that the cylinders employed (and which were selected by me in Paris as perfect), through which the bacteria passed, are still free from any appearance of a flaw which could explain the passage of these microorganisms. The same filter which (first of those used in my tests) allowed bacteria to pass through, has repeatedly filtered water free from all bacteria for a few days after each of the several sterilizations which it has since undergone.

In three following series of trials of this identical cylinder, bacteria have gone through its walls in from three to four days after each sterilization. They have also gone through a second perfect cylinder with which I experimented. That the bacteria were not introduced by careless manipulation is evident by reason of their number, and because of the fact that, after the filter was sterilized, they were found in each case at a particular phase of each series of tests with the intermittent pressure which only for a few hours once a week was as high as eighteen pounds, and was usually as low as eleven. At the beginning of each series of tests the filter was sterilized.

The bacteria were not splashed in from the sink below, for, in the first place, all splashing failed to carry in any as revealed by testing the water filtered after such experimental attempts to throw water in, and none had ever multiplied inside or even remained there during my first thirteen tests, when there was much splashing in the common sink. During my later trials there was no chance of such contamination.

To answer fully in advance any such objection, I will state that after I got the enormous number of over 400,000 in each c. c. flowing through the porcelain, and had sterilized the cylinder, water was allowed to flow through it and plated, but was sterile in that no bacterial colonies developed. Then, while the filter was in action, I introduced, with a sterile needle (from below through the aperture into the inside of the cylinder), and, touching the needle to various parts of the surface, deposited over it peculiar bacteria from a pure culture derived this winter from the water of one of the northern lakes which I examined during my investigations as biologist for the Syracuse Water Commission. The colonies of this bacillus, when growing on gelatine plates, have a peculiar odor, a distinctive green color, and other characteristics which clearly differentiate them from any bacteria ever found in the Croton water. The water flowing out all the while, or rather dropping out, was, three minutes after the introduction of these, collected in sterilized test-tubes and was found to contain 175,000 of these peculiar bacilli in each c. c. After seventy-five minutes there were only 14 bacilli in each c. c. of the water then flowing through the porcelain and two hours later, and during the next day, there were no bacteria of any kind in the water which again later in the series showed that the Croton bacteria had passed through with it. This proves that the increase in the number of the bacteria was not after the water had passed through the substance of the filter.

These facts, together with the extreme fragility of this rebaked porcelain, and the exasperating slowness of the flow, which does not improve on long trial, have caused me to modify the recommendations which I gave among my colleagues and others after my first tests of these filters.

As regards rapidity of flow and non-fragility, a notable improvement over the cylinder form (which I have just spoken of) is afforded by a series of two or more flat plates of porcelain similarly prepared. In the Varrall-Brisse pattern these porcelain plates are backed by carbon plates of the same shape and size and the filter yields sterile water for a long time under gentle pressure, although I do not consider the carbon an advantage. The further such filters vary from the simplest type, the greater is the likelihood of the introduction of contaminating bacteria into the filtered water.[1]

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[1] As out of twenty-seven kinds of filters that I have been able to test, this seems, on the whole, the best substance yet produced for the purpose, it is to be hoped that American ingenuity make further improvements upon the models now existing. The cost need not be great even if all be carefully tested before being sold, as suggested by Fol and Dunant (Rev. d'Hygiène, 21 mars, 1885, p. 183).

The "Pasteur Filter Co." requests me to state that it now furnishes a slightly different style of cylinder in which the porcelain is invariably of fine quality and claimed to be "germ-proof."

Of the various forms of filters used upon faucets, I feel bound to warn against those rotating within an outer shell. Whether packed with charcoal, sand, or any other material, and even if the water go through the filtering mass and not around it, the filter has the great drawback of various irregularities and depressions on the interior which retain organic matter and allow bacteria, both harmful and harmless, to increase in it and maintain their vitality for a longer time than in ordinary filters. This conclusion I am led to by the results of various experiments and observations. In a recent epidemic in a large New England city this form of filter appeared to play an active part in continuing the infection, for cultures, in every respect like those of the germs of typhoid fever, were derived from several of these suspected filters by Dr. Prudden and others. I have found that the typhoid bacillus lives much longer in the sediment collected from filters than in pure water.[1] At its best, this filter cannot remove the

[1] I have removed the slimy sediment from the outside of a porcelain filter, and without sterilizing this, put it into sterile test-tubes, and then added water in which the germs of typhoid were found living. After these had stood together for four weeks, several plates of the water were prepared and, making several cultures from the various colonies which appeared like typhoid, a bacillus identical in all its features with that of typhoid was isolated, and considered as typhoid by those to whom it was shown. This is longer than I have been able to keep this bacillus alive in pure Croton which had been sterilized. All waters tested were in tubes of the same size and at the same temperature. In laboratory experiments we are not able to reproduce the conditions existing in the large bodies of water, where these harmful bacteria can probably live longer still under the evener temperature there prevailing.

bacteria from water, and they multiply in the charcoal or sand so that, even after several minutes of washing out by the stream flowing from the hydrant, the water coming through this filter may show several times as many as are in the water directly from the hydrant. To avoid waste of time in repetition, I will refer to the facts observed with the sand filter, as the mechanical action of the filtering mass is identical in both.

The sand filter, for attaching to faucets, is perhaps the simplest and most popular used. It consists of a cylinder of like breadth and length, being not quite three inches long. It screws by either end upon ordinary faucets, and its interior is filled with crushed silica or fine sand, kept in place by wire-gauze at either end. I have adapted several much larger without securing more satisfactory results. Taking a new one, sterilized throughout, allowing a fair stream of water to flow through it when attached to a faucet and at the same time taking water directly from the same supply-pipe from the hydrant by means of another faucet by its side, and under the same conditions of pressure and outlet, except that there is no filter upon the second faucet, the water is seen to flow in a free stream nearly as large as from the unobstructed faucet, while the Pasteur filter, attached to the same supply-pipe and with the same pressure, allows the water to come at the rate of only a few drops each minute. Even with a gentle stream through the freshly sterilized sand filter, very few of the bacteria are arrested. With very fine sand in a cylinder holding three times as much as the ordinary one, and a very small stream flowing, I have observed more than fifty per cent. to be retained. This result is seen only in the first use of an absolutely sterilized filter.

Speaking of the tank variety of sand filters, it was shown that moistened sand favored the increase of bacteria brought into it by Croton water which had flowed through. In the sand or other granular contents of these filters attached to hydrants the same multiplication takes place when the water has for some time ceased flowing, and this increase is at a more rapid rate than in water standing in a clean vessel by the side of the filter. The first flow in the morning, for instance, after the filter has remained unused over night, shows a much larger number of bacteria than the hydrant water then contains. Even after the water has flowed for several minutes for the purpose of washing out the filter, the bacteria are in excess over the number in the original water. After such a filter has had the hydrant stream running through it long enough to wash out all the germs that have resulted from the increase (which complete cleansing is not always producible), the bacteria in the water may appear nearly the same in number as in the hydrant water, varying slightly either above or below. While such filters are worse than useless from a bacteriological point of view, they are good strainers when not clogged by too long use without cleansing. As strainers they are less troublesome than flannel bags (which are as safe as these sand filters for use with suspected water, provided that they are removed at least once a day to be disinfected by boiling). The act of reversing this popular sand filter does not cause the removal of the organic matter upon which the bacteria can be nourished. Only the loose outer portion is thereby removed. Such a sand filter is a safer strainer when never reversible and it should be cleansed at least once a day when needed at all.

Powdered magnesia and other granular substances used instead of sand in the style of filter just described, have no superiority over the easily cleansed sand.

Asbestos-board I have not been able to procure of sufficiently firm, strong, and fine surface to resist the passage of bacteria under any considerable pressure from the hydrant brought to bear upon such a surface. The quality of the surface seems the important point. To yield a flow of any degree of rapidity, this surface must be large and that creates a tendency to break and necessitates a bulky filter, which most people shun. Packed asbestos shreds allow a few bacteria to pass through when the sterilized filtering mass is so dense as to cause the flow to be very slow. In this substance I have, as already mentioned, not observed so marked multiplication of bacteria as in the sand, porous and other filters.

Although large bodies of sand fail to prevent the passage of bacteria with the water which percolates through, it is noticed that certain natural filters of this sort render water much freer from bacteria when the water has first to make its way through a layer of silt and minute particles which have been arrested by fine sand. It is from the application of this principle that the large filter-beds are built which purify the water distributed by hydrants throughout various cities. Taking as a model the very carefully managed filter-beds of Berlin, it is seen that above the base of the filtering tanks is a layer of a foot of stones, gradually becoming smaller in size toward the upper surface, upon which is coarse gravel to the height of a foot more, then upon this a little more than two feet of sand, which at the top is as fine as can be procured. When the filter-bed has been freshly cleaned, as is found necessary for it after being constantly used for a week or so (occasionally several weeks), purified water is slowly backed into the filtering-mass from below until this water, carrying up all the air with it, has reached the top of the upper layer. Then the ordinary river (or lake) water is made to flow very gently in, to the depth of one metre. This is then allowed to stand for at least twenty-four hours. The nitrogenous or other particles, confervoid vegetation, and whatever else the water contains as sediment, have then settled upon the upper portion of the fine sand without sinking deeper, and a delicate film is formed which, with careful inlet and gentle pressure (never to exceed two metres of water), retains nearly all the bacteria of the water supplied, and prevents their passage, provided that the flow through is very regular and slow (never more than three metres in a day). Nearly all this separation of the bacteria is produced by the sedimental matter retained on the surface of the sand, so that, when the filter slows from clogging, it is found that less than half an inch of the upper layer of sand need be removed.

From the statistics of Wolffhügel[1], and of Plagge and Proskauer,[2] we learn that the number of bacteria, originally very large in the river Spree, is reduced to a very small percentage in the filtered water, oftentimes a fraction of one per cent. I may add that the organic constituents are also decidedly lessened, and that the oxidibility, as tested by the reduction of a standard solution of permanganate of potash, is seen to be regularly lowered one-fourth and often one-third of the amount shown prior to the filtering. The long arrays of figures given in the reports of the action of these filter-beds show that, with hardly an exception, the ammonia is constantly removed by the process.

In this country the filter-beds, all of which are built upon the same plan as those in Berlin, are less perfect in their action, as the people in charge do not devote sufficient care to sedimentation in the case of those which I am familiar with. Thus, a very carefully planned filter-bed, which filters river-water for one of our cities, allowed, at the time when I examined it, nearly half of the large number of bacteria in the water pumped from the river to pass through. This unsatisfactory result seemed to be due to the fact that too much water was required from the small filter-beds and hence not enough care could be bestowed upon the thoroughness of the filtration.

Of the various large filter systems which I have tested while they were in use in various manufactories

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[1] G. Wolffhügel: Arb. aus d. Gsdamt., ii. 1 und 2, p. 109.

[2] Plagge u. Proskauer. Zeitschrift f. Hygiene, 1887, ii. p. 401.

and institutions, for which these filters were straining large quantities of water, the only kinds which reduced materially the number of bacteria as found in the hydrant-water were those in which, by the addition of a minute proportion of a suitable salt, usually alum (as approved by the general experience of years in many districts), the suspended particles with the organic matter are caused to settle more rapidly, and then these form a deposit upon very fine sand, through which water is forced. From several examinations of a filter of this type, which in every case rendered the water much freer from germs than the original (unfiltered) water, I once found the filtered water wholly sterile, while the (Brooklyn) hydrant water of the neighborhood at the same time showed 397 germs developing from each c. c. This particular filter was constructed on the principle of Prof. A. R. Leeds, who informs me that the alum was present in the proportion of only 1 part in 100,000 of water. I could not, by the ordinary tests, detect the presence of this salt, and such a small amount can cause no appreciable harm. The alum used is probably decomposed, and its elements taken up by the organic matter and bases present. As previously stated, the sterilization of the water is here caused by mechanical and not by chemical action. In my tests the typhoid bacillus of the first agar culture from a recent spleen was not destroyed by standing for forty-eight hours in a solution of ten times the strength of that employed in these filters, while many other bacteria were alive after standing for forty-eight hours in an alum solution of 1 part to 1000 of water, which sufficed to destroy the typhoid bacillus in that time.

In the present stage of chemical knowledge there seems no sufficient evidence that in water these microörganisms evolve the organic alkaloids which are considered to be produced when harmful bacteria are introduced into the system and by their action there cause disease. What the exact nature of the volatile organic constituents carried over in distillation may be, and whether they be deleterious or not, rests for the science of the future to determine. The process of boiling previous to vaporization in the still must kill all harmful bacteria, and all other bacteria that I have ever encountered in the original hydrant water from which such water as the well-known "Hygeia" is prepared. The bacteria which I have found in specimens of this excellent distilled water that I examined must have been introduced from without after the water was condensed from the still and before the bottling process was completed, and in this I have never found any other than harmless varieties. Water condensed from various stills of approved patterns I have found sterile. The relatively large amount of free ammonia found in such distilled waters (it being several times greater than any detected in the Croton hydrant water) does not seem to me to be objectionable. The condensed steam produced in distilling, and which constitutes the Hygeia water, represents a much larger original amount of water than results after the process of vaporization and condensation is completed, and the ammonia may besides come from the air and from other sources.

To those who desire a water freer from alkaline earths than the ordinary "hard" water which they may have to drink, it should be mentioned that the process of heating, in the sterilization by boiling which I so urgently recommend when it is necessary to drink suspected water, drives off free carbonic acid and so causes the deposition as an insoluble sediment of the carbonate of lime and other objectionable salts which form the so-called "temporary hardness." The water is thus rendered "softer."

When boiling is resorted to because of actual infection of the water, it should be carefully done. It is best to have the water, perhaps after a preliminary boiling and straining, decanted into bottles, each holding say a quart, and these covered with a suitable glass cap or plugged with cotton or provided with a clean stopper loosely dropped in, and then the bottles placed in a kettle or cauldron in the absence of a steaming apparatus. This is heated and kept near the boiling point[1] for an hour. Then the whole is allowed to cool, and the bottles may be placed near ice; but into the water thus carefully prepared it is not advisable to put ordinary ice, for harmful bacteria may retain their vitality in ice

[1] Although Miquel and others have called attention to micro-organisms retaining their vitality at a temperature above 71° C. (160° F.), these seem to have no harmful character. See Globig (*Ztschr. für Hygiene*, iii., 2, pages 322 and 331). The spores of the "red potato bacillus," which he reports as very resistant even to steam heat, have never appeared in waters that I have seen; and the time limits for boiling which I have elsewhere given, after careful observation, hold true as regards all known disease-producing bacteria.

longer than in water. Pure water loses all its excellence when unwholesome ice is melted in it. For those to whom the taste of boiled water is unpleasant, weak teas, wine, or other savor may be added to mask the absence of the more agreeable taste imparted by the process of aërification (which under ordinary conditions may itself be a means of adding bacteria to the water).[1]

There are ingenious hypotheses as to the utility of nitrifying bacteria in overwhelming other varieties and conjectures that, if recognized and planted upon filters, these nitrifying ones would safely destroy the pernicious ones; but among these theories I know of none to be seriously recommended. The recent results in America and various parts of Europe are so inconclusive and diverse that the brief limits and practical aim of this paper will hardly permit any further consideration of them.

SUMMARY.—Boiling sterilizes water, and within thirty minutes will have killed harmful bacteria.

Drugs and other agents acting chemically, if used

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[1] Berckholtz (Arb. aus d. K. Gesundheitsamte, 1889, p. 14) (employing exsiccator and four days of agar culture, dried on silk thread) found that the cholera spirillum, contrary to earlier results, retained its vitality in air for over two weeks.

In connection with my experiments I have found the typhoid bacillus to live dried on the glass of a test-tube, for a week and longer. I have made no special attempt to determine how long it will live in a dry state.

Tommasi-Crudeli, Dr. Bern. Schiavuzzi in Pola (Rendi Conti della R. Accademia dei Lincei, Dicembre, 1886) say with others that the malaria bacillus, which they, like Klebs, found in soil and air, may be carried by and live in water. The same is true of many other bacteria introduced into water.

in amounts which are commonly safe, do not sterilize water.

The prolonged heat which water undergoes in the usual process of distillation destroys all germs which may be in the water undergoing the process.

Ordinary filters, even if satisfactory as strainers, fail to remove all bacteria from drinking-water. So far from lessening the number in the original water, the filtering substance may allow a more rapid multiplication than these microörganisms would ordinarily undergo in the unfiltered water on standing, and the germs of disease, even if held back by the filtering substance, may be harbored in all filters.

The finer the substance through which the water passes, and the lower the pressure, the more perfect is the action of the filter in holding back the bacteria.

Of all substances thus far furnished for domestic filters, porous rebaked porcelain, carefully selected, I have found to be the best. If thick and strong enough to allow the use of a large surface, and the substance remain perfect (without flaw or break), this may yield a fair flow of clear water, free from all bacteria; yet under our ordinary Croton pressure of one atmosphere or less, this yield is only in rapid drops, unless the apparatus be complex.

To insure the permanency of this action, the filter should be occasionally sterilized throughout, by steaming or by other means; for, under prolonged pressure, various kinds of bacteria can go through, and in the copious organic matter collected on the filter some harmful microörganisms can retain a high degree of vitality for weeks longer than I have ever found them to live in pure water.

Where filtering is really necessary, it is in general best for the community that it be done carefully on a large scale through sand-beds upon which a fine layer of organic and inorganic matter is expressly produced by sedimentation, because of its valuable action in holding back the great majority of the bacteria.

A bad water filtered is less desirable than a pure water in its natural state. When, therefore, filtration is employed because of real danger of infection, the filtered water should, as a rule, be furthermore boiled, as the entire absence of sediment and cloudiness does not insure that the bacteria of disease may not have made their way through the filter.