to the requirements of the second section of this ordinance.

"Section 4. Any persons violating sections 2 or 3 pay a penalty of $100 for every day such violation is continued.

"Section 5. For the purpose of aiding the enforcement of this ordinance the office of water-inspector is hereby created; the incumbent thereof shall be an expert chemist and bacteriologist, to be appointed and his compensation fixed annually by an ordinance of the City Council; and it shall be the duty of the water-inspector to make bi-weekly chemical and bacteriological analyses of the water supplied, and immediately report the results of the same to the Sanitary Committee and to all persons, companies, and corporations furnishing the said water, and also from time to time inspect the system or systems of filtration adopted in obedience to this ordinance, and whenever the same are not kept and operated as herein specified, make report thereof to the parties aforesaid."

CHAPTER VIII.

PURIFICATION ON A LARGE SCALE.

Notwithstanding the fact that the necessity and, in most cases, the perfect possibility of obtaining a pure water supply has been insisted upon by hygienists for a great number of years, it is still a common practice to attempt the purification of polluted waters by cumbrous and expensive systems of filter-beds and reservoirs. Such systems, however, as notably in the case of Hamburg, are liable to accidental breakdowns, which then not only cause widespread inconvenience, but in many cases serious outbreaks of disease. Although such systems are wrong in theory and commercially wasteful, after they have once been started, the value of the plant and vested interests usually provoke such determined opposition to any natural scheme, that large populations are still persuaded to endure as their drinking water what has been described as "diluted and purified sewage." As compared with an artificial conduit for bringing water from an unpolluted collecting ground, a river is at once condemned on account of the certainty that it is open to drainage of all kinds, and that the so-called self-purification of a river in flow is of doubtful efficacy, and is in most cases overbalanced by the constant accession of impurities with which its action is not rapid enough to cope.

Since, in districts distant from a supply, the rivers of the district may be the only source at present available, it is necessary to shortly describe the processes by which water originally unfit to drink can be altered to a state which is ordinarily harmless to the consumer.

Many vegetable juices containing tannin are capable of coagulating the organic matter in very bad waters and rendering them comparatively potable. This property of barks and woods containing tannin was known in very early times, and is referred to in Exod. xv. 23, in which passage the word "bitter" probably means disagreeable. The Indians in South America are similarly in the habit of purifying foul ponds by logs of the Peruvian bark (*cinchona*), and in this case the tannins act as a precipitant and the quinine as a febrifuge. The latter has been recommended to be added to marshy waters in Italy and in other places. *Strychnos potatorum* has also been used in India for the same purpose.

The common process of *subsidence* effected in settling tanks and reservoirs accomplishes the almost complete removal of suspended solid mineral matters, and with them a large proportion of the living organisms. Thus, Dr. Percy Frankland, in an examination of the intake waters of the West Middlesex Company, found 1,437 bacteria per cubic centimetre, whilst

after passing through one storage reservoir the number was reduced to 318, and after traversing a second reservoir there remained only 177 per cubic centimetre. During the process of settling, oxidation of the dissolved organic matter also takes place; but, unfortunately, the deposited bacteria are not killed, and continuing to multiply in the muddy sediment, unless this is removed at frequent intervals, necessitate periodic stoppages for cleansing, and additional reservoirs for the maintenance of the service.

Purification by *mechanical precipitation* is sometimes adopted, and consists in the addition of a finely divided solid, such as clay, chalk, charcoal, coke, spongy iron, or porcelain earth, which in its subsidence is capable of carrying down with it all solid matters, including the germs, so as to leave the water clear and almost sterile. Many of these precipitants, however, convey to the treated water an unpleasant earthy taste, and the same objection as to the settling process remains, that the deposit becomes a nidus for the further development of the microbes, which may rise and render the water at any time unfit for use. When waters have a marked colour, alum, in the proportion of about five grains per gallon, generally with the subsequent addition of an equal weight of lime, effects clarification and decoloration, the flocculent precipitate of alumina, by its well-known mordant action, absorbing the colouring matter and also entangling all the solid matters in suspension.

The mixing of the precipitant should be effected without splashing, in order to avoid the gelatinous alumina entangling air, which would retard the rate of settling. After alum precipitation, the sulphates of potash or ammonia, and those of the lime and magnesia formed, remain in the water, so that after such treatment these may be present in such quantities as to render the water undesirable for potable purposes or for use in boilers. Sulphate of alumina, free from excess of acid and iron, is better and cheaper than ordinary alum, and seven-tenths of the quantity need only be used. "Alumino-ferric" may even sometimes be employed, and ferric sulphate ("persulphate of iron"), which has lately been highly recommended, is of especial value for purifying foul river waters, as it throws down sulphides as well as the matters removed by alum. Ferric chloride (perchloride of iron) was formerly much used: it leaves in solution chlorides instead of sulphates, and has been objected to because it commonly contains arsenic. In any case, when such precipitants are employed, it is necessary to carefully determine from time to time by analysis the requisite quantity to employ, as excess may be most prejudicial.

Several chemical reagents have been proposed and used in the hope of killing the bacteria, or at least destroying their food. Manganate and permanganate of potassium or Condy's green and red fluids, when added to a very foul water until a permanent colour

remains for at least fifteen minutes, are capable of oxidising the impurities but do not kill the bacteria. When these salts are used a brown precipitate of manganese peroxide is formed, and it must be removed by filtration or settling before the water is fit to drink. In fact, all methods of precipitation require that the water should be subsequently filtered; and the expense of this operation, coupled with that of the chemicals, has caused most of the precipitation processes to be abandoned, except in local and temporary cases.

The various methods used for the softening of hard waters effect a purification of the water from organic matter and organisms at the same time, and the results obtained in this way will be further alluded to in Chapter X. Agitation with air causes a certain amount of improvement, but only a slight effect is noticeable in rivers which flow over weirs or which have waterfalls in their courses. The purifying properties of light have long been recognised, and even as early as 1640, Dr. Hart cautioned his readers against the use of well-water "to which the sun hath no reflection." Westbrook has recently, at Marburg, carefully studied the influence of sunlight upon cholera cultures in water, and has demonstrated that—

1. The heat of the sun as well as the light has an important influence upon organisms in water.

2. *Insolation* in presence of a full supply of atmospheric oxygen effectually and speedily kills germs.

3. Sunlight in the absence of air has no germicidal properties.

4. Solar heat of average intensity, when air is excluded, causes the organisms to multiply at a greater rate.

Other observers have found that at a depth of six or eight feet the destructive property of sunlight ceases. It follows that all reservoirs for *surface waters* should be shallow, uncovered, and freely exposed to the air (except in the immediate neighbourhood of towns or factories, where, however, for other reasons, such reservoirs should not be placed). Deep well and spring waters, on the other hand, should, if stored at all, be kept in covered receptacles, as algæ are thereby prevented from growing (see p. 122).

The immunity obtained by boiling water before drinking is now almost universally recognised, and if regularity of such procedure could be relied on, it would perhaps be the most satisfactory method for ensuring safety.

Mr. Hankin relates a story as to an outbreak of cholera in the East Lancashire Regiment in Lucknow, where "E" Company escaped in what was considered at the time an altogether inexplicable manner. The barracks occupied by this company were almost surrounded by the barracks of companies which suffered severely, yet the disease passed over the men of "E" Company, though they were apparently living

under exactly similar conditions to the rest of the regiment. Mr. Hankin, in his book on *Cholera in Indian Cantonments*, says:—"On questioning the colour-sergeant of this company, the mystery at first appeared to deepen, for he roundly asserted that the men under his charge had exactly the same supplies of food and water as the rest of the regiment. But on his being pressed as to how he knew that the water supply was the same, he replied that he ought to know, if anybody, 'as he boiled it himself!' Needless to say, that on making inquiries it was found this simple sanitary precaution had not been taken by the other colour-sergeants."

Sterilisation by means of heat has been used on a small scale so successfully, that many inventors have turned their attention to devising apparatus which might be suitable for use in towns and villages. The smaller forms of sterilisers, as they are called, are much used in laboratories, and are nearly all based upon the fact, that prolonged heating of water to 100° C. destroys the germs contained in it. Boiled water, however, is flat and insipid, and the process is obviously inapplicable on a large scale owing to the expense involved. By heating the water under pressure a shorter time effects sterilisation, and the gases dissolved in the water are not lost. By arranging that the sterilised water shall heat the incoming water, considerable economy in fuel is effected, so that the water discharged from the apparatus has practically the temperature of the water which enters, and thus the heat required to be maintained is only that which theoretically should be attributed to losses by radiation. Amongst the many different forms of sterilisers, that entitled

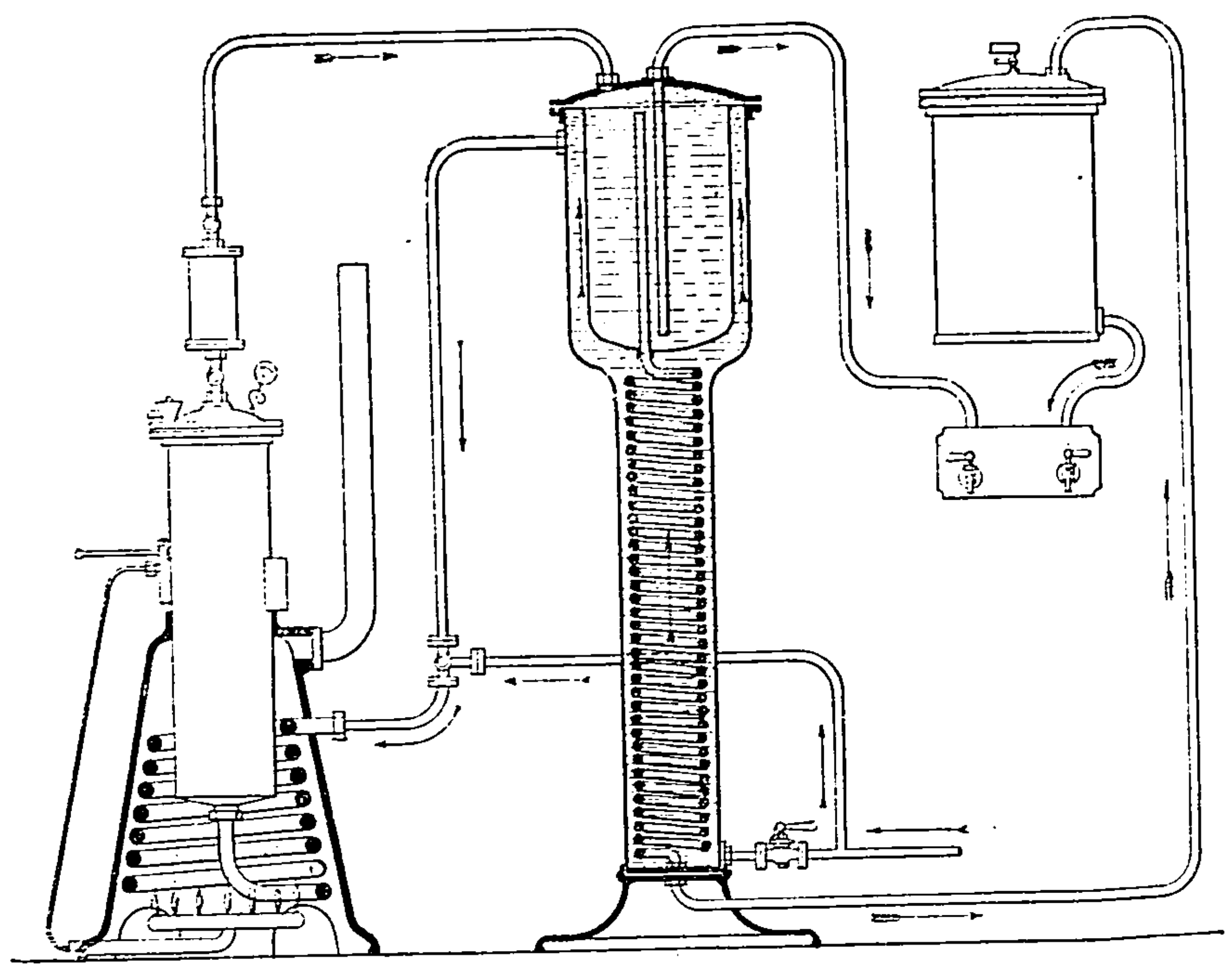

FIG. 31.—Equifex Water Heat-steriliser.

the Equifex, manufactured under the Geneste-Herscher patent, is perhaps the best known. It consists of four distinct parts: A heater, which is fired in any suitable way, and maintains the boiler at a temperature of between 120°—130° C. The heater is fitted with a pressure valve, so that the

water therein never boils while it remains within the heater for the time necessary to effect sterilisation. In connection with the heater is a serpentine tube, through which the sterilised water passes and gives up its heat to the unsterilised water entering the boiler. The sterilised water finally passes through a sand-filter, which removes any suspended matter. Such apparatus have been erected in hospitals and infirmaries, and have been used by the French fleet at Brest, and by the town of Parthenay, in France. Kühn, who has devised a similar apparatus, states that, with a steriliser of ten cubic metres capacity, 22,000 gallons of water per day, or double that quantity if worked at night, can be produced, so that a battery of these sterilisers could easily deal with the water supply of a town. Although on a small scale, the cost of heating is high, it is obvious if the regenerative principle be successfully applied, the fuel required is very small, as the only essential of a perfect apparatus is, that each unit of water shall be subjected to a high temperature for a short time, without permanently removing any of the heat required to produce that temperature.

It is important to note that cold or freezing does not render a water safe for drinking purposes. Infectious diseases have been traced to the consumption of ice-creams made from unfiltered and contaminated water. At King's Lynn, in 1892, during a frost, there was a considerable storage of the discharges of typhoid patients on land sloping to a river bank. On the snow melting, thirty-nine houses, drawing their supply from the river, were infected with typhoid fever.

Dr. Christmas, in 1892, showed that citric acid, in the proportion of eight in 10,000, was fatal to the cholera bacillus, but did not destroy that of typhoid in a less strength than one in 1,000. He accordingly proposed that in times of cholera house-supplies should be sterilised by the addition of about sixty grains per gallon per day of this acid to the water in the houses.

Anderson's process consists in subjecting the water during its passage through revolving drums to the action of a continuous shower of metallic iron. The water afterwards passes over cascades to remove dissolved iron by oxidation, is then allowed to settle in tanks, and is finally filtered through sand. The process is in use at Antwerp, Worcester, and other places, and seems to give both better chemical and bacterial results than those obtained by sand filters alone. The water of the Delaware at Philadelphia, and of the Mississippi at Memphis, have also been treated with iron; and Leffmann and Beam, who examined the process in 1890, showed that in both rivers the amount of organic matter underwent a considerable diminution, and that the action was one of oxidation. Mr. Anderson himself maintains that the effect of his machine is almost entirely a mechanical one, due to the absorbent properties of the flocculent oxide of iron.

No iron remains in the finally purified water, and the hardness, if due to carbonate of lime, is materially reduced.

The process is particularly successful with the water of the Nile, which is completely clarified by mere decantation in a very short time after shaking up with iron, while otherwise it remains turbid for weeks and opalescent for months. The most difficult waters to deal with are those derived from peaty grounds, as it is not easy afterwards to completely remove the iron. Here alum precipitation would seem to be preferable.

Iodine, chloride of lime, and other reagents have also been proposed for purifying river water, and B. Krohnke, in 1893, suggested cuprous chloride (sub-chloride of copper), especially for the Elbe water at Hamburg. One two-hundred-thousandth part—about a third of a grain per gallon—together with proto-sulphate of iron, were mixed with the water. At the end of six hours one-hundred-thousandth part of lime was added, and after deposition the liquid was filtered through sand. The water, which originally contained forty to fifty thousand germs per cubic centimetre, was thus completely sterilised, and was clear, almost colourless, and free from iron and copper. The sand filter could be used a long time without cleaning, and the copper was recoverable from the sediment. Such results would be of great importance were it not for the fact that, in working, any deviation, either by accident or carelessness, from the prescribed quantities, would lead to the water becoming poisonous. Besides, it is well known that as nothing is absolutely insoluble, precipitation never removes the last traces. It may, therefore, be laid down that no poisonous chemical reagent should be used in the purification of water for drinking. To trade purposes the same objection does not always apply.

Complete oxidation would seem to be the natural process for the destruction of organic matter, both living and dead, but it will be shown later (p. 160) that atmospheric or ordinary oxygen will not act on most varieties of organic matter without the help of microbes. Ozone, the specially active modification of oxygen, produced by electricity or by slow oxidation, such as that of phosphorus or essential oils in air, can, on the other hand, attack, bleach, and entirely oxidise organic matter. Even such resistant substances as indiarubber are corroded and destroyed by ozone. Baron Tyndal has recently proposed to the municipality of Paris to sterilise, by means of ozone, 5,000 cubic metres (1,100,000 gallons) of crude Seine water daily. Details of the process have not yet been published, but it is stated that in this way "all the microbes are immediately killed, and all organic matter rapidly oxidised, leaving only the inorganic salts." The process seems similar to the "Hermite System" of disinfecting sewage, described in the author's work on *Disinfectants* (p. 69). Dr. Coreil is at present examining the

question bacteriologically, and Dr. Schutzenberger chemically. Ordinary oxidation, assisted by microbes, is the process of purification which obtains in nature; and Pol and Dumont have lately shown that water contained in a vessel simply closed by a plug of cotton wool, which, on December 24th, 1894, contained 150,000 microbes per cubic centimetre, on December 31st had only 12,000, a loss of 94 per cent., and on January 16th 7,000, or 95·3 per cent. less.

It is almost invariably found that bacteria introduced into waters protected from further admixture thrive up to a certain point, and then undergo diminution in numbers, and finally may entirely disappear. There are three explanations of this phenomenon :—

1. They may actually feed on one another. It is known that many common and vigorous forms, which have been proved to be harmless, rapidly exterminate the bacteria of disease, such as that of typhoid.

2. They may exhaust their food supply and suffer starvation. This occurs when single isolated organisms undergo rapid multiplication.

3. They may produce products, excreta of their life, which are actually poisonous to themselves. Some of these toxines and "ptomaines" have been isolated, and have proved to be also active poisons to higher forms of life.

As will be further explained in the section on bacteriology (p. 259), several micro-organisms are distinguished by the property of liquefying the gelatine in the "culture tubes" in which they are grown, after which they break it down into simpler compounds in the ordinary course. The changes which take place in water usually follow four distinct stages under "aerobic" conditions—that is, in the presence of air, and by the influence of common water bacteria:—

1. The destruction of pathogenic organisms by non-pathogenic forms.

2. The "hydrolysis" or splitting up of the complex solids by combination with water, yielding simpler compounds in solution.

3. The conversion of these soluble organic substances into still more unstable compounds, and eventually their complete resolution by water and oxygen into carbonic acid and ammonia. This part of the process is analogous to the chemist's procedure in distilling a water with alkaline permanganate in the "albuminoid ammonia" method of water analysis (p. 243). The "free" ammonia of the chemist represents mainly what the bacteria have previously done; the "albuminoid" the bacterial work in progress. Therefore this method of analysis, although it does not give all the nitrogen, gives a valuable indication of the degree to which a water has been polluted and of the stage at which its natural purification has arrived.

4. The oxidation of ammonia by two classes of "nitrifying organisms" (p. 103) into nitrous and nitric

acids. The presence of peaty or humous matters, and of organic matters fermented as above, and of dissolved oxygen, is necessary for this final transformation. Under certain conditions, particularly the absence of oxygen, certain "denitrifying" organisms effect a retrograde change of nitrates into nitrites; and even to lower oxides of nitrogen and nitrogen itself. This action must be considered an abnormal and unhealthy change, but must frequently take place, as the loss of nitrogen from polluted waters is otherwise inexplicable. W. Adeney uses the name "bacteriolysis" for the second and third of these processes, as distinguished from the nitrification of the last stage.

Mr. Scott Moncrieff has introduced a method for the systematic cultivation of the harmless water bacteria in tanks, with the object of naturally purifying sewage before its discharge into streams. The first advantage of the process is that all solid or organic matters are liquefied by the bacteria, so that the formation of "sludge," which is such a difficulty and expense in other methods, is avoided, and the organic matters being in solution are more easily acted upon by the nitrifying organisms of the soil. Moreover, the pathogenic microbes are rapidly killed by the harmless bacteria. Mr. Cameron, the city surveyor of Exeter, has recently obtained similar satisfactory results with sewage.

Sand filtration has undergone a great change within recent years, owing to the fact that whereas it was formerly considered that a filter-bed, in order to be active, should be new and frequently changed, it is now known that clean and sterilised sand, beyond straining out suspended matter, exerts no purifying action on the water. It has also been repeatedly demonstrated that atmospheric oxygen will not act on organic matter without microbes. This was incidentally a complete settlement of the disputed question between the schools of Drs. Tidy and Frankland with reference to the natural oxidation of rivers during flow. The final result depends on the nature and number of the microbes as well as upon the aeration.

On the surface of a sand filter-bed a kind of slime, composed of finely-divided clay, the absorbent power of which is well known, is formed. A felted mass of bacilli and streptococci, entangled in a gelatinous layer of the *zooglœa colonies* of micrococci, together with a number of algæ and other solid bodies, accumulate in this cultivation bed on the surface of the sand filter, and it is here that the main purification of the water takes place. A sand filter does not, therefore, attain its maximum efficiency until this jelly layer has been produced, but when once formed the purification proceeds by the action of the nitrifying organisms immediately below this film for an indefinite period. When such a filter becomes clogged, and the flow of water too scanty, it is necessary to skim off the surface layer and prepare a fresh coating of sand, which

requires several days before it again regains its activity. If a filter be allowed to act for too long a period a gradual growth of the surface bacteria through the filter-bed takes place, and the effluent water is then found to contain these organisms, and it becomes necessary for the whole filter-bed to be renewed. The upper layer of a filter-bed thus acts mechanically, by straining off the solids and rendering the water clear, as well as chemically and bacteriologically, in the way already explained. In order to save time, it is customary in some places—in Berlin, for example—to hasten the formation of the upper active layer by spreading over the surface of the filter some of the top sand which has been scraped off at a previous cleaning, and such sand is known as "ripe" sand.

M. Piefke has shown that, to obtain less than 100 colonies of microbes per cubic centimetre, it is necessary for the filter to have been at work for at least eight days, during which the water must be run to waste, whereas, he states, the iron or Anderson process gives the same result in two or three days. The essential features of a good sand filter have been worked out at Lawrence by the Massachusetts State Board of Health.

The new filtration works at Hamburg comprise :—

1. The use of sedimentary basins.

2. Dividing the filtering area into numerous small surfaces, each of which can be readily disconnected without interfering with the others.

3. Systematic and constant bacteriological supervision, as it is only in this way that any proof of the efficiency of a filter at any given time is assured. Occasional chemical analysis of the water in order to ascertain whether the oxidation into nitrates is regularly maintained.

At Hamburg and Berlin Koch's limits are adopted, and the conditions which he has laid down may be summarised as follows:—

(*a*) No water is allowed to pass through a filter at a speed of more than 100 millimetres (about four inches) per hour.

(*b*) Each filter must have a contrivance by which the movement of the water in the filter can be restricted to a certain pace and continually regulated, and must further be provided with an arrangement by which samples of the filtered water may be taken at any time.

(*c*) A bacteriological examination by cultures must be made daily.

(*d*) Water containing more than 100 germs per cubic centimetre must not be allowed to pass into consumption. Although this is an arbitrary rule, it is one which may be regarded as tolerably safe, although, of course, even when such a small number is permitted in the filtrate, pathogenic organisms may be present.

Intermittent Filtration.—Another advantage of having a larger number of filter-beds of smaller size

is that short periods of rest can be arranged wherein the layers may become aerated. The purifying organisms are mostly *aerobic*, or require oxygen, and no filter can work satisfactorily if continuously water-logged. For this reason the Massachusetts Board prefer intermittent filtration. They say (Report, Part 2, 1890): "If we apply one day to the surface of an open body of sand one inch of water and next day another, we shall find that the water will go down each day about nine inches; in this space nearly two-thirds is sand, one-ninth water, and one-quarter air. The water is in an extremely fine layer over particles of sand, and intimately mingled with about twice its volume of air. It is pushed down each day, and the same amount issues at the bottom. Fresh air is brought in with the incoming water, so that if the sand be five feet thick, the water of any day will be slowly moving for a week over sand with two volumes of air." Sand which is too fine may remain saturated with water the whole depth, hence the advantage of using coarse sand and gravel. In London and in large towns where the demand is very great, it is difficult to afford periods of rest with the present large area filters; but with smaller ones, used in rotation, it could be more easily managed.

At Hamburg there are four settling tanks, each holding water enough for a day's supply, and having an area of about twenty acres. Each of these in turn is allowed to fill, and then rest for twenty-four hours, when the clear water is pumped off and the sediment removed.

About thirty filters are alternately in use. The medium employed consists of an eight-inch layer of small stones, then eight inches of gravel, and the same depth of coarse sand, followed by three feet of fine sand. The water is admitted with special care so as not to disturb the surface, and a depth of three feet is maintained above the sand. With this head of water the proper rate of filtration is secured. As the bed becomes choked, the head of water has to be increased, but there soon arrives a limit when the filter has to be thrown out of rotation and cleaned. Each filter has a separate outlet, where samples for analysis can be taken, and arrangements are provided for aeration. The total cost of the works was less than £500,000, and the supply will be ample for many years to come.

At Warsaw the water is kept under cover, but in other respects the arrangements are similar to those at Hamburg. At Lawrence, Mass., the impure water of the Merrimac is passed through four and a half feet of sand, and the bacteria reduced from 9,000 to 150 per cubic centimetre. The average speed of filtration is from five to eight feet per twenty-four hours. At all these places the death-rate from zymotic diseases has been very markedly reduced.

At Zurich four inches of garden soil are introduced into the filter-bed to promote nitrification.

The filters are of gravel and about four feet of sand, and are run at four times the rate recommended above, but the lake water which forms the supply is of exceptional purity. At certain periods of warm weather, chiefly from July to September, a slimy layer called "waterbloom," consisting of microscopic algæ, makes its appearance on the surface, which requires removal, as it rapidly blocks the filter and gives the water a bad taste, variously described as "fishy," "marshy," or "mouldy." The same difficulty has often occurred in the United States.

The filter-beds of the London companies average about an acre in extent. As already mentioned, a greater number of beds of less area should be substituted. Smaller filter-beds also can be more readily protected and covered from frost. An epidemic of cholera at Altona arose from one of the beds being frozen, and in London water-famines have often occurred from this cause, and the water at other times has been indifferently filtered. The London filter-beds usually consist of a layer of sand two to four and a half feet in thickness, with gravel and stones below. The reservoirs contain from two to fourteen days' supply. The daily rate of filtration should not be more than 2,000,000 gallons per acre, but in times of great demand this is often exceeded.

Dr. Shirley Murphy, in his report to the London County Council for 1894, draws attention to the coincidence which existed between abnormal cases of typhoid in the last weeks of the year throughout the whole of the metropolitan area (with the exception of that supplied by water from the East London and Kent Water Companies) with the insufficiency of filtration, due to the floods in the Thames and Lea, which prevailed at that season. This relation between increase of enteric fever and insufficient filtration on the part of the London Water Companies was confirmed by an examination of the outbreaks of this disease in suburban areas, where a similar coincidence was noticed. In provincial towns supplied with adequately filtered water, during the same period the number of cases of enteric fever notified was normal.

Sediment reservoirs occupy an immense amount of ground and are expensive. The water is also apt to deteriorate by standing in them, while in warm climates they cannot be prevented from becoming foul through the rapid growth of vegetation and animal life. The Riddell filter is extensively used in America, and lately in India, for rapidly removing the coarser impurities. It is a closed iron vessel fitted with fine sand, through which water can be forced under pressure at almost any required rate. The inlet is through a gridiron with fine jets, which is forced down into the sand as the latter become clogged. The apparatus can be cleansed by reversing the valves and injecting a strong upward current of water. Subsequent removal of the bacteria by finer filtration is afterwards necessary.

Mechanical Filtration.—The sand filter cannot be relied upon in America to remain unfrozen during winter. Hence many systems of rapid filtration under cover and aided by pressure are in use in the United States, chiefly for the waters of muddy rivers. Alum or sulphate of alumina, in the proportion of one-half to two grains per gallon, is first added, and the water then passed through filters of small area, of which the "Hyatt" and "National" are the best known. The filtering material is usually sand or coke, and is cleaned at short intervals by reversing the current, as in the Riddell filter.

The Morison-Jewell Filter Company, of New York, introduced in 1887 a system of purification on a large scale, which substituted a film of gelatinous alumina for the slimy organic film of ordinary sand filters. The "coagulant" is a "basic sulphate of alumina," formed by mixing sulphate of alumina (containing 17 per cent. of Al_2O_3) with caustic soda, which yields, when dissolved, sodium sulphate in solution and aluminium hydrate as a suspended gelatinous precipitate. This, when run on to the filter-bed, forms a layer which very rapidly removes the colour and suspended matter of the water, and also 98 to 99 per cent. of the bacteria. The medium is quartz, crushed by machinery to a diameter of 0·38 millimetres (·0142 inch) and screened. Steam is also used for cleansing and sterilising, with a solution of soda-ash at intervals. The beds are supported by perforated screens of aluminium bronze. The filter is readily washed by reversing the current and removing the top surface by a mechanical rake, then introducing fresh quartz sand and alumina, the process taking about eleven minutes. Washing is done once every twenty-four hours, and oftener in flood-times. The rate of filtration adopted at Providence, Rhode Island, is 100,000,000 gallons per acre per day with a head of three and a half to six feet. The amount of aluminium sulphate used is 0·5 to 0·75 grains per gallon of water filtered. Prof. Doremus, of New York, has reported favourably on this process.

The objection made to these filters is that the constant addition of chemicals to the water may exercise an injurious influence on the public health. At the Providence waterworks, Mr. Weston found by the logwood test finely divided alumina in the filtered water. Prof. Drown records a decrease of oxide of iron by 0·023 grain per gallon, an increase of alumina by 0·0292, and of sulphuric acid (SO_3) by 0·205 in the filtered water, when about half a grain of aluminium sulphate was stated to have been added. It must be mentioned that officers of health in some forty or fifty towns using alum-treated water attribute no ill effects to its use, and the water has had no injurious action on boilers. The rate of filtration through sand of the London Water Companies is 540 gallons per square yard per twenty-four hours, equal to 2,600,000 gallons per acre. The Morison filter is said to pass in the same time 102,000,000 gallons.

At Yeovil there is no attempt at chemical or bacteriological purification, but floating and visible suspended matter is removed by copper wire strainers of 132 meshes to the inch.

The Atkins process of filtration will be noticed in a subsequent chapter, in connection with the softening plant of the same inventor.

Although sand is commonly employed as a filtering medium, Dr. Frankland has shown that coke has a far greater efficiency than sand, and Mr. Dibdin has obtained the best results in filtering sewage from the use of coke "breeze." In all filters the nitrifying action is, of course, increased by intermittent working, so as to ensure a full aeration of the filtering material from time to time.

Filtering galleries consist of underground waterways, which are run at a low level parallel to the banks of a river to receive the naturally filtered river water; but the greater portion of the water which collects in such galleries is subsoil water derived from neighbouring higher land, as the bottom of a river is usually almost impervious to water, from the fine deposit of silt and clay. At Toulouse there are long filtering galleries excavated in the alluvium, which yield 2,800 cubic metres of clear water at a uniform temperature daily. A similar gallery at Lyons has deteriorated both in quality and quantity. On the whole, the experience gained from the existing galleries is not favourable, but when the water is derived wholly from the subsoil at sufficient depth, and the surface is kept free from habitation or contamination, as at Frankfort, the water collected in this way is of great organic purity and nearly germless.

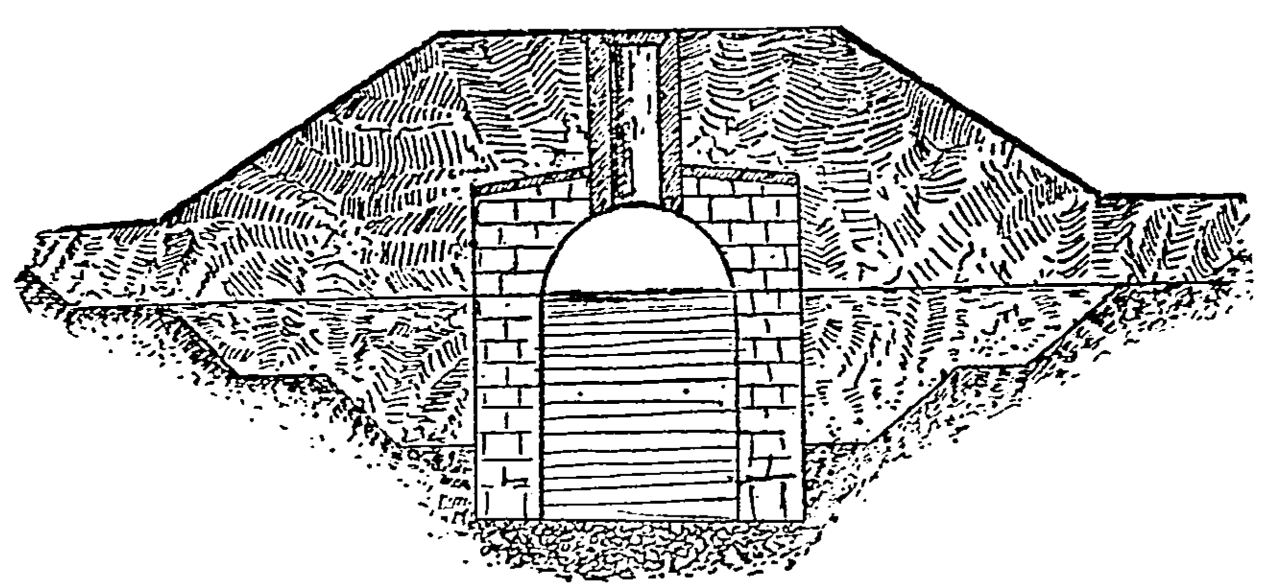

FIG. 32. Filtering gallery at Lyons.

Filtering cribs are large boxes of iron or wood sunk in an excavation in the bed of the river or lake, then surrounded and covered with gravel and sand. The water is pumped through pipes to the shore. To them, still more than to filtering galleries, applies the objection that, being submerged, they are beyond daily inspection, while control and repair may be almost impossible.

CHAPTER IX.

HOUSEHOLD FILTRATION.

THE original idea of a filter was simply a strainer, which, by keeping back the solid particles, could render a water clear and bright. For this purpose, sponge, sand, and linen were found to be sufficient, and water that had passed through them was supposed to be wholesome. Sponge was convenient, as it could be so easily washed and squeezed out. Sand can be taken out and washed, but a layer of gravel, followed by coarse sand, must be introduced below the fine sand which does the main work of clarifying, and finally a layer of gravel again, to prevent the fine sand from washing up. Such filters were furnished with a perforated plate, or sometimes with a small sponge, to protect the bed and to retain the grosser impurities. All this was so complicated that the arrangement was sealed up when purchased, and was used till it became stopped by the dirt from the water. On such an occasion, which perhaps happened every two years, the filter required to be cleaned and refitted, and this process was frequently delayed by the user owing to its cost.

Charcoal, with or without the use of the sponge, was then introduced as a medium. Vegetable charcoal