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.

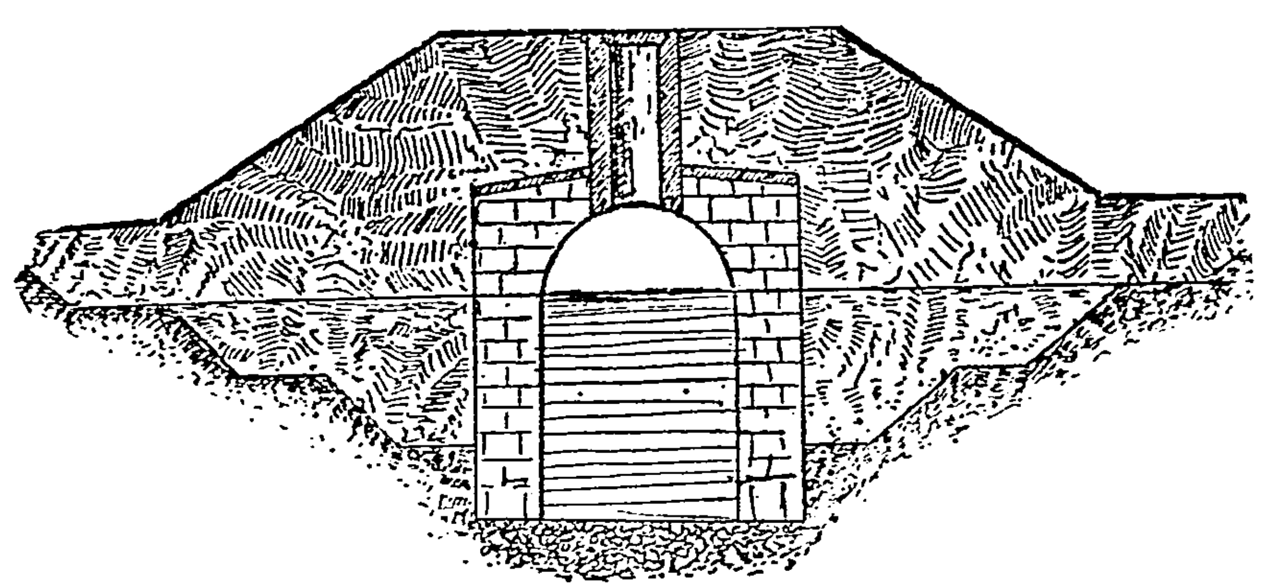

FIG. 32. Filtering gallery at Lyons.

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 was known to remove odours, animal charcoal to take away colour; the latter became the favourite, and a great variety of forms of charcoal filters were placed on the market and received "testimonials." The action of the charcoal was not merely mechanical: it also for a time softened the water by absorbing some of the lime; metals like lead and iron were removed, and it was supposed to be even capable of purifying from "sewage." By compressing the charcoal with some binding material, like resin, oils, silicates, &c., and then charring again in close vessels, the once popular blocks were formed; they had the advantage that they could be cleaned by scrubbing and blowing water through in the reverse way. Only a few years ago the tests which were considered valid as applied to these filters consisted in adding water containing finely divided carbon or ultramarine, and noticing whether a clear filtrate was produced. In the same way, claret was poured in and came out colourless, solutions of lead and iron were added, tests applied after filtration, and none of the metal found. It need hardly be said that the filter must be fairly *new* for such tests to succeed.

But the progress of bacteriological knowledge prompted a further question as to charcoal filters—Do they remove disease germs? In 1876, the Royal Commission on Rivers Pollution pointed out that when the filtered water was allowed to stand, even excluded from the air, minute organisms, animal and vegetable,

appeared, and made it unfit to drink and actually offensive; whilst, if the charcoal had not been burnt at a sufficiently high temperature—which is rarely done, as it involves a loss of carbon—some nitrogenous matter remained and became a breeding ground for organisms. They also found that fresh organic matter, like white of egg, was almost unacted upon. The large quantity, about 70 per cent., of calcium phosphate that animal charcoal contains, was also shown to favour the growth of life.

It was common for the objectionable sealed-up filters of certain firms to be found, on being sent back for renewal, to be excessively foul internally, being green with confervæ and containing small worms and swarms of bacteria.

Dr. Drown, in a recent report to the Massachusetts State Board of Health, laid it down that one of the chief objects of water filtration was, in most cases, the removal of the disease germs. However bright and sparkling a water may be, it has been repeatedly proved during cholera outbreaks that it may frequently convey germs. Such water is apt to be preferred by unthinking people when a water slightly turbid might be perfectly harmless. In 1888, typhoid bacilli were actually found by Prudden and Ernst in the domestic filters of houses at Providence, Rhode Island.

In view of this essential point, Dr. Sims Woodhead and Dr. Wood subjected existing types of filters to a bacteriological test by passing through them yeast cells and various pathogenic organisms (*Staphylococcus pyogenes aureus*, typhoid and cholera bacilli; see p. 253). They examined the filters of twenty-one manufacturers, including all the best known types, and found that the only forms that did not admit the passage of disease germs were the candle filters known as the Pasteur-Chamberland, Berkefeld, and Aéri-Filtre-Mallié. They condemn all others as increasing the risk of acquiring infectious diseases, and as "giving rise to a sense of false security, which prevents the precaution of boiling the water being taken where necessary" (*British Medical Journal*, Nov. and Dec., 1894).

A report by Dr. Plagge, which has been issued by the Prussian War Office, mentions that in 1885 he tested all the then known filters, and found that the carbon, natural stone, gravel, sand, cloth, sponge, paper, and asbestos forms extant in Germany were entirely useless. In the few cases where he examined filters from England, made with spongy iron or some form of carbon, he obtained the same result. In a renewed investigation of modern forms of filters, conducted within the last few years, he came to a similar conclusion. With reference to a number of carbon filters, he found that they were all incapable of preventing the passage of disease germs, and he severely characterised the false claims put forward by the makers. The different forms of filter composed of a carbon preparation and asbestos, were also found to

fail, as well as the well-known Austrian filter of Breyer, composed of "micro-membranes" of an exceedingly close felt of very finely-divided asbestos. With regard to this filter, Dr. Guinochet also says (*Eaux Potables*, J. B. Baillière, Paris, 1894): "It is not a perfect filter, as it allows microbes to pass; it proves, in fact, that the fineness of the filaments used in the construction of a filter does not play such an important part as has been said, since here is a membrane whose particles are not more than $\frac{1}{1000}$ millimetre (0·0004 inch) in diameter, while porcelain would be formed of grains much more bulky, besides leaving between them spaces larger than those of asbestos. It is not so necessary to obtain spaces smaller than the microbes, which is practically impossible, as to secure that the microbes arriving in the interior may be retained by molecular attraction." Dr. Guinochet concludes that the Breyer form does not filter so well as the Chamberland, that it is delicate, difficult to clean, and liable to leakage.

Dr. Plagge also condemned all filters made of paper, cellulose, and asbestos, whilst the Pasteur-Chamberland was described as satisfying all sanitary requirements. He then examined some of its imitations, which, while yielding water much more rapidly, are stated by the makers to be equally efficient. The Berkefeld filters were successively under observation during three years, thirty-seven specimens being used; of these, twenty-nine passed microbes almost immediately, within twenty-four hours, or before the end of the trials, which lasted three to eight months. Dr. Plagge is of opinion that it is indispensable for the Berkefeld filter to be boiled either once or twice in twenty-four hours, according to the extent of its use. He further draws attention to the fragility of the Berkefeld filter as compared with the Pasteur-Chamberland form.

Dr. Johnston, in a bacteriological examination of representative filters in 1894, obtained similar results, and states that "the Pasteur-Chamberland filter is the best and the only one on which reliance can be placed for permanently sterilising water." The results were obtained with the cylinders marked "B," which are intended for slow filtration, worked from a main tap at a pressure of from twelve to forty-six pounds to the square inch.

Guinochet, using the rapid Pasteur filters marked "F," working continuously under pressure for several weeks, found in the filtrate only a few bacterial colonies and moulds, which he considers were due to accidental contamination while making the cultures.

Unfortunately, therefore, the majority of household filters are worse than useless, since they do not remove the contaminating bacteria, and actually, by forming a nidus for their growth, contribute to their formation and multiplication in the water sought to be purified by their means. The extent to which the danger of

a bad filter may go was calamitously shown at Lucknow, in 1894, when a particularly virulent epidemic of cholera among the East Lancashire regiment was traced to the pollution of the barrack-room filters. Out of a total of 646 officers and men there were 145 cases, of which 93 terminated fatally.

Mr. Hankin, official chemist and bacteriologist to the North-West Provinces of India, maintains, in his report of 1895, that all the domestic filters, with the exception of the Pasteur-Chamberland, are quite incapable of keeping back the cholera bacillus. Dr. Percy Frankland, in his report to the Royal Society, obtained some unexpected results with filters made of porcelain (Pasteur) and of infusorial earth (Berkefeld). Thames water sterilised by filtration was infected with the bacillus of typhoid fever. The organisms refused to grow, and in five days had disappeared entirely. To ascertain whether any antiseptic substance had been communicated by the filter, it was washed with a large volume of pure water and tried again, when the same result occurred. Moreover, in the same water in which the typhoid bacilli had been destroyed with such remarkable rapidity, ordinary water bacilli were found to multiply with ease.

The only explanation seems to be that the filtration deprives the water of a food-substance which is necessary for the growth of the germs of typhoid. The report of M. de Freycinet, Minister of War, to the French Government in 1892, states that wherever the Pasteur-Chamberland filter has been introduced, typhoid fever has disappeared, even in the garrisons which were most often and the most cruelly attacked. General Zurlinden, Minister of War in 1895, strongly corroborates this statement, but gives the caution that "soldiers who have in their barracks a pure water are none the less exposed to typhoid fever in inns, restaurants, and other public places."

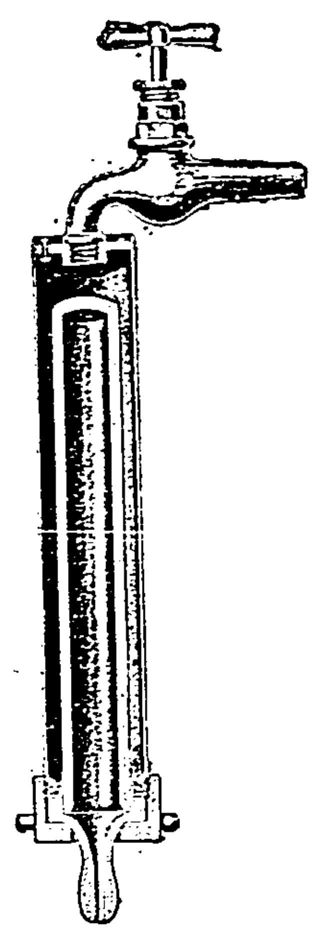

FIG. 33. Standard Pasteur-Chamberland filter (pressure form).

The candle filter is the outcome of experiments made by Pasteur, who found that plates of plaster of Paris were inefficient in sterilising bacteriological fluids. Chamberland afterwards suggested the application to drinking water of the tubes which Pasteur had found efficient for bacteriological work. Such filters do not merely strain off suspended matter, as many of the organisms are smaller than the pores. The action must therefore be due to some molecular attraction dependent on the material of the tube and its manufacture. Many other forms of porous porcelain have been tried, but none of them seem at present to give the same efficiency. Candle filters are manufactured by the Sanitats Porzellan Fabrik at Charlottenberg, and in this country several English-made candle filters have made their appearance.

The standard "Filtre Chamberland système Pasteur" is manufactured at Choisy-le-Roi, in France, and is rapidly finding favour in this country.

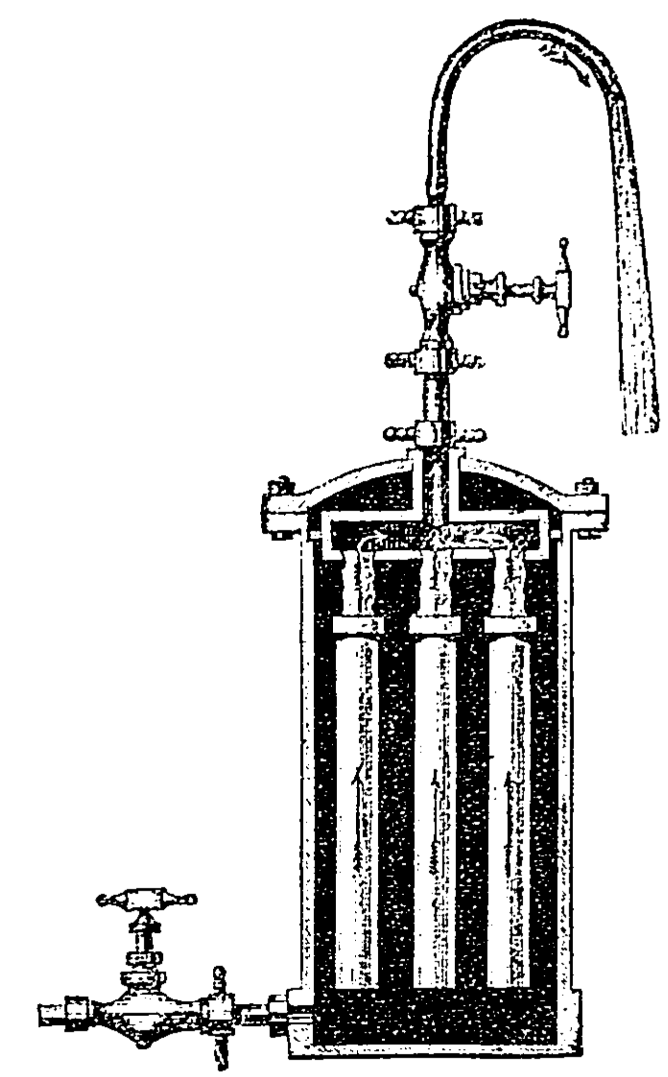

FIG. 34. Battery of pressure filters (English form).

In use the unfiltered water passes through the filter tube or tubes from outside inwards. This may take place under the pressure of a water main (Figs. 33, 34, 39) or of a pump, under suction of a siphon tube which may deliver into a separate filtered water

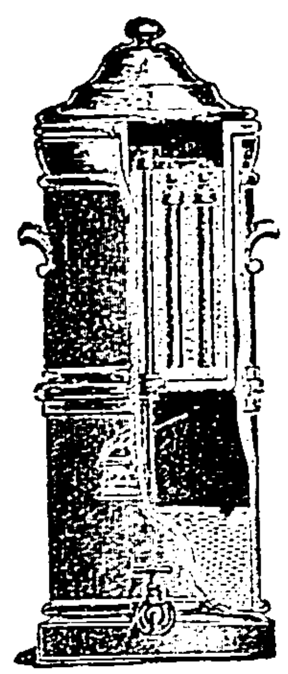

FIG. 35. Pasteur-Chamberland filter for table use (without pressure).

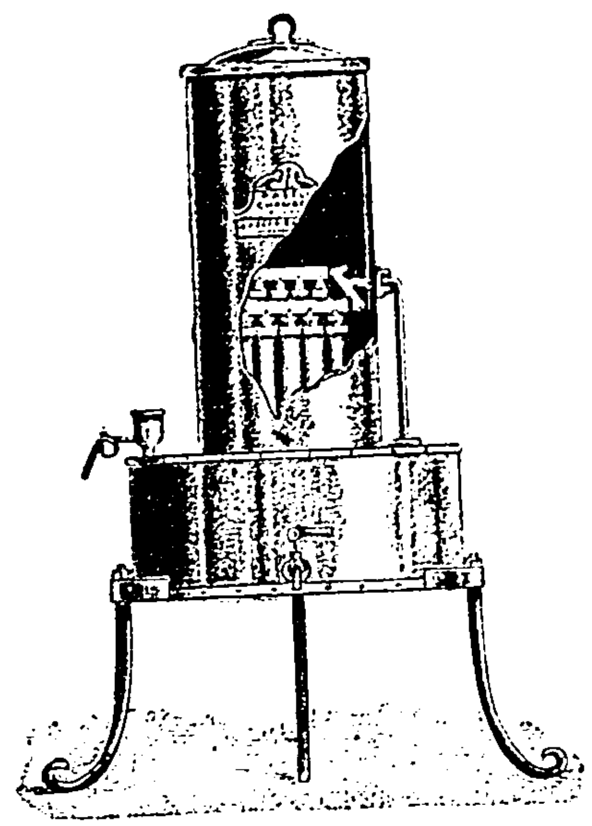

FIG. 35A. Battery of candle filters for schools.

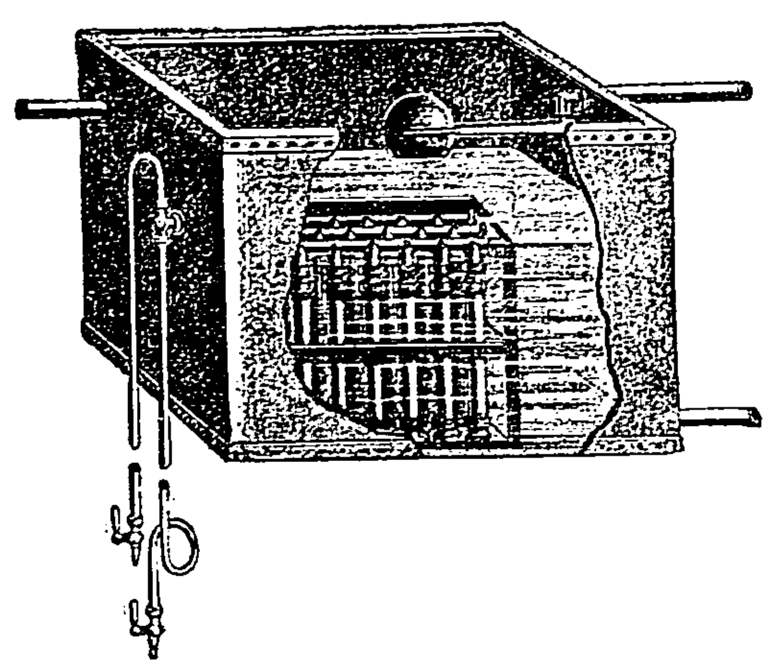

FIG. 35B. Cistern form of filters with siphon tube.

chamber, as shown in Figs. 35 and 35A, or from the

cistern by a long siphon tube to a lower room, as shown in Fig. 35B. Under some circumstances the head of water in the filter chamber above the candle can be used, but the yield is then slow. In Fig. 36, the candles are fitted into a closed reservoir, from which the filtered water is removed by a hand-pump, which creates a partial vacuum in the filtered water chamber and thus augments the rate of filtration. The filter may consist of one or any number of tubes delivering into a common reservoir made either in one with the filter or separate from it. In the latter case, care should be taken that the receptacle is dust-proof. The water can obviously be led by pipes and distributed over the house instead of unfiltered water. The average yield per tube is about half a gallon per day without pressure and eight gallons per day with pressure.

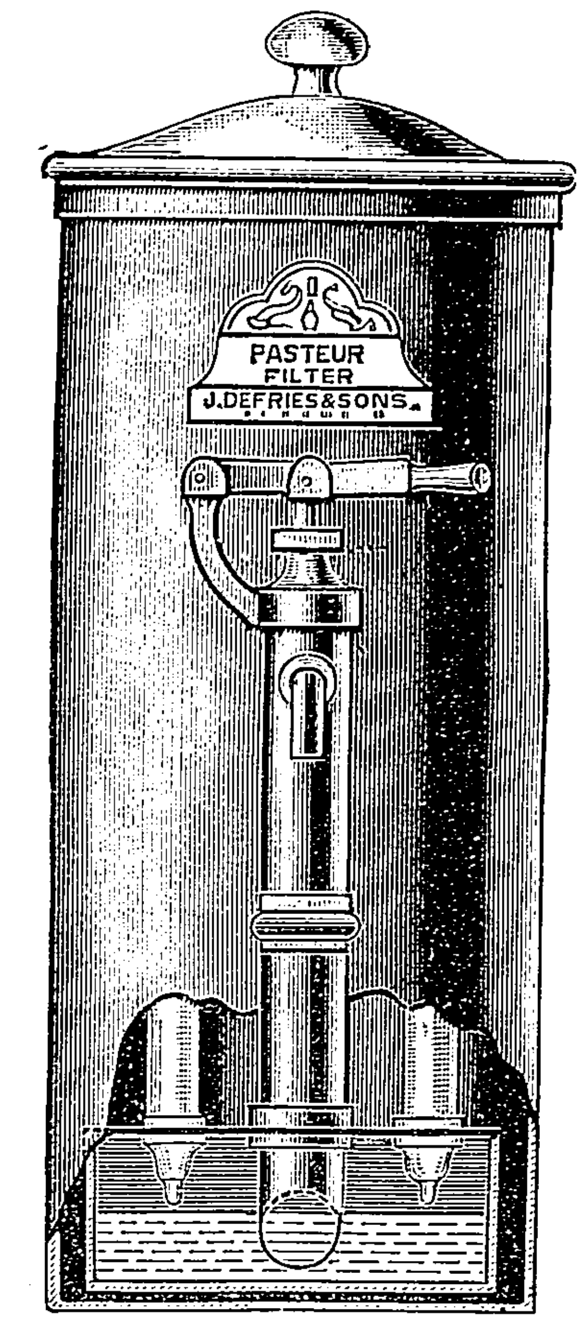

FIG. 36. Cistern filter with hand-pump (Pasteur-Chamberland).

The Nordmeyer-Berkefeld filter (Fig. 37) is made of kieselguhr, or infusorial earth, in the same form as the Pasteur, but of much greater thickness. This material consists of the minute siliceous skeletons of fossil animalcules called infusoria, much broken by the pressure and mixing to which they have been subjected. It is much more porous than the porcelain of the Pasteur-Chamberland, and allows the water to pass with about five times the rapidity, which would be a great advantage if it were not for the fact, as shown by the experiments mentioned above, that it is also more permeable to microbes, and allows them to grow through in a shorter though variable time, and therefore does not present an equal safety. The filters are also considerably more fragile. Dr. Plagge advocates that the directions for use ought to insist, that for domestic filtration at least two cylinders should be purchased, and that these must be changed every day. The outside of the filtering cylinder can be

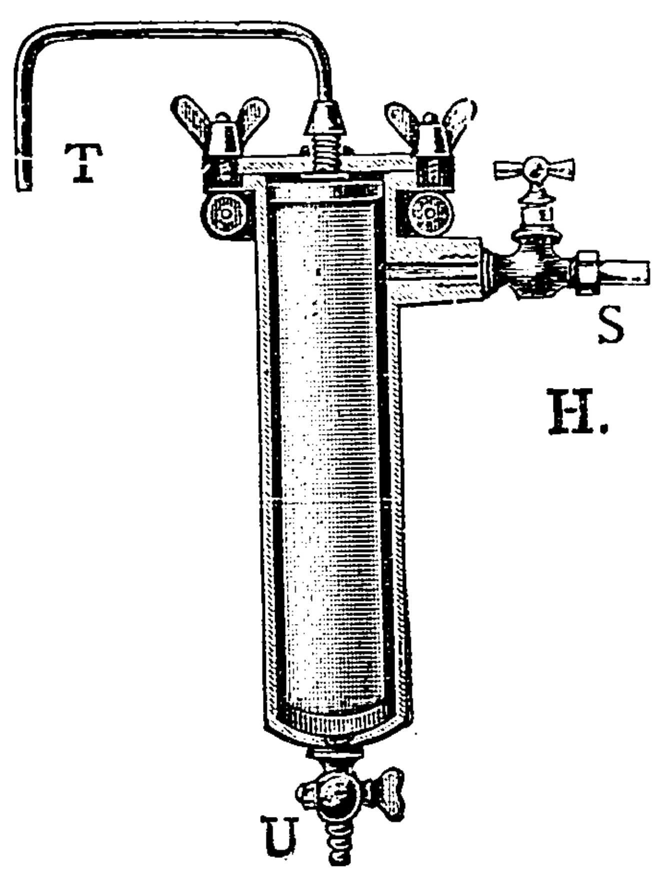

FIG. 37. Nordmeyer-Berkefeld filter (pressure form).

cleaned under the tap with a piece of "loofah" (Dr. Plagge recommends brushing: it is more effectual, but wears away the surface); the cylinder should then be sterilised by placing in warm water and raising the temperature to boiling, continuing the boiling for one hour and allowing it to cool in the water under cover, so that it will be ready to replace the other cylinder on the next day. The proprietors mention that it will greatly facilitate the cleansing if a handful of finely-divided kieselguhr, which is supplied at 6*d*. a pound, is put into the filter casing when replacing the cylinder. The rush of water will cause it to spread evenly over the surface, and the dirt will be more easily detached.

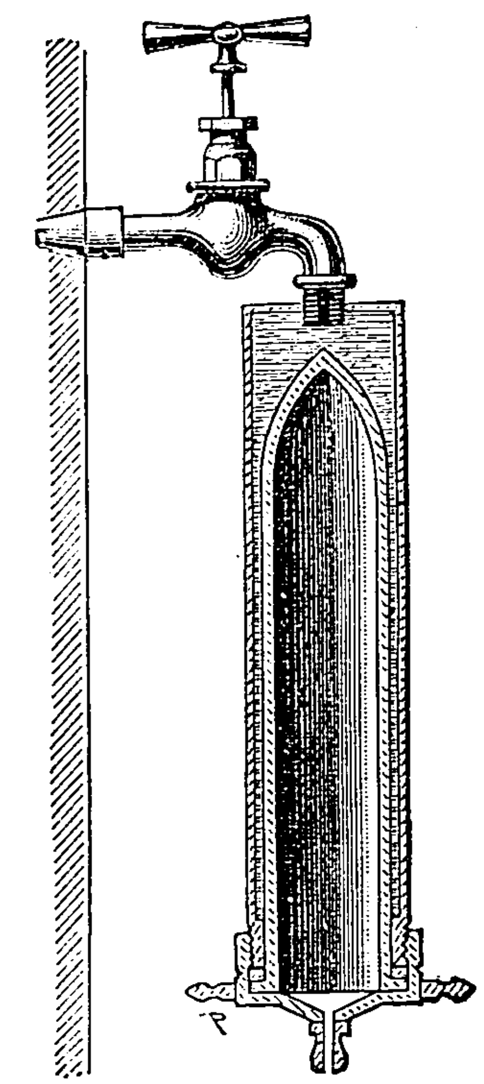
FIG. 38. Filtre Mallié (pressure form).

As to the rapidity of filtration or output of the Berkefeld filter, Dr. P. Frankland, who reported very favourably on this form, but tried it after too short a time (twenty minutes), using Loch Katrine water, found that the rate, which was at first about seven gallons an hour, had in one hour diminished to about half that amount, and in twenty-four hours' continuous running had come almost to a standstill. The matter removed was a dark brown layer of slime of a vegetable or peaty nature, containing also all the bacteria. He publishes no trial of the filtrate after the first twenty minutes mentioned above. The Manchester town supply also gives a coating of thick black mud one-eighth of an inch in thickness, swarming with bacteria and other organisms. The Pasteur filter with the same water required cleaning once a week, which seems the ordinary time for the Pasteur form.

Under the conditions then of daily sterilisation, a sound Berkefeld filter seems to be as safe to use as the Pasteur-Chamberland form, and the question would resolve itself into a choice between a battery of Pasteur-Chamberland filters, involving only a weekly cleaning and somewhat larger initial cost, and that of a couple of Berkefeld filters purchasable at a more moderate cost, but necessitating a daily sterilisation as recommended by Dr. Plagge. Both the pressure and non-pressure filters supplied by the Berkefeld Company, when previously sterilised, yield water free from germs when first put into action. The kieselguhr filters have to be handled with considerable care, as they are far more fragile than those made of porcelain, and the slightest flaw would render them quite useless; and in this way the renewal of tubes, which are more expensive than Pasteur tubes, is a larger item of upkeep. There is, however, no

certainty that the Berkefeld tubes are always initially sound, owing to the absence of any trustworthy test other than bacteriological examination; and the process of cleaning inevitably destroys their soundness and renders the filtration illusory sooner or later. Pasteur tubes, on the other hand, are not sensibly affected by cleaning or sterilisation, however often repeated; and their bacterial and mechanical soundness is readily tested by air pressure.

The "Aéri-Filtre Mallié" is constructed in a similar way to the Pasteur form, but is made of a porcelain paste of exceedingly finely-divided asbestos (Fig. 38). It can be used in conjunction with a preliminary purifier of charcoal or glass wool, by which the larger suspended matters are retained, and the fine pores of the porcelain prevented from becoming so rapidly clogged. At present, however, the Filtre Mallié has been only a short time before the public, and requires further experiments to demonstrate its efficiency. It seems likely to rank as a safe filter, and the inventor is at present endeavouring to render it a little less fragile by introducing an admixture of kaolin, or porcelain clay, which brings it nearer to the composition of the Pasteur-Chamberland.

It must be remembered that the difficulty with all the filters yet invented is that bacteria gradually penetrate or grow through any material, and then multiply in the filtered water. So that even the Pasteur-Chamberland, though at present the most perfect, will allow this growth in time if not periodically cleansed. Any filter not attended to and thoroughly sterilised at proper intervals constitutes a source of danger, *and actually pollutes the water instead of purifying it.* In case of a suspicion of failure, or the occurrence of an epidemic, a sample of the filtered water carefully collected in a stoppered bottle, as described on p. 17, should be submitted to an expert for bacteriological examination. Whatever form of filter be adopted, the filtered water must of course be carefully guarded from subsequent pollution.

Batteries of the Pasteur-Chamberland filters are now being fitted up in various places in India for water supply on a large scale. The new filters made for the Darjiling municipal waterworks (Fig. 39) are of the pressure type, and consist of thirty-eight cells of tough cast iron, served with an acid-resisting composition, and arranged in four rows. Each cell contains 250 Pasteur filter tubes fixed into solid elastic bushes, and is connected by wrought-iron pipes to cast-iron mains, which deliver into cast-iron collecting mains, all protected by the acid-resisting composition. The cells are fitted with gun-metal valves, enabling any one cell or group of cells to be cut out for cleaning or other reason. The inlet and outlet pipes are controlled by sluice valves in the ordinary way. Cleaning of the tubes and cells is effected by means of a circulating pump, which

forces through the tubes of any cell or group of cells a solvent—usually a diluted acid—by which the deposit in the pores of the filter tubes is removed; and it is claimed that at the same time the whole of the filtering system is sterilised. This process only entails the passage of an inappreciable quantity of acid per gallon of filtered water during the day; and as the acid can be used again and again, it is accordingly both economical and free from objection. All the parts of the installation are interchangeable, and its nominal output is 150,000 gallons per day.

For military or travelling purposes exhaust filters are found by experience more suitable than the pressure forms, as they involve no joints which have to be broken for cleaning. During the late Ashanti expedition, a number of portable pressure filters were used in the field and caused trouble in this way. These were specially made, and were constructed of aluminium alloy, with gun-metal fittings, so as to reduce the weight to the utmost extent consistent with serviceable strength. The station where they were used was the only one which was free from dysentery, so that the efficiency of the filtration was thus again verified.

Exhaust filters are made with single tubes for personal use, or with batteries for the use of bodies of men. In view of the temptations offered by casual streams to men on the march, small pocket filters in a case, which could be used with or without a small hand force-pump, can be supplied to the men. Mouth suction filters are always objectionable, as it is hardly possible to prevent the saliva passing down the tube. The siphon form is useful if a suitable vessel is at hand. The portable form with hand pump is much to be preferred.

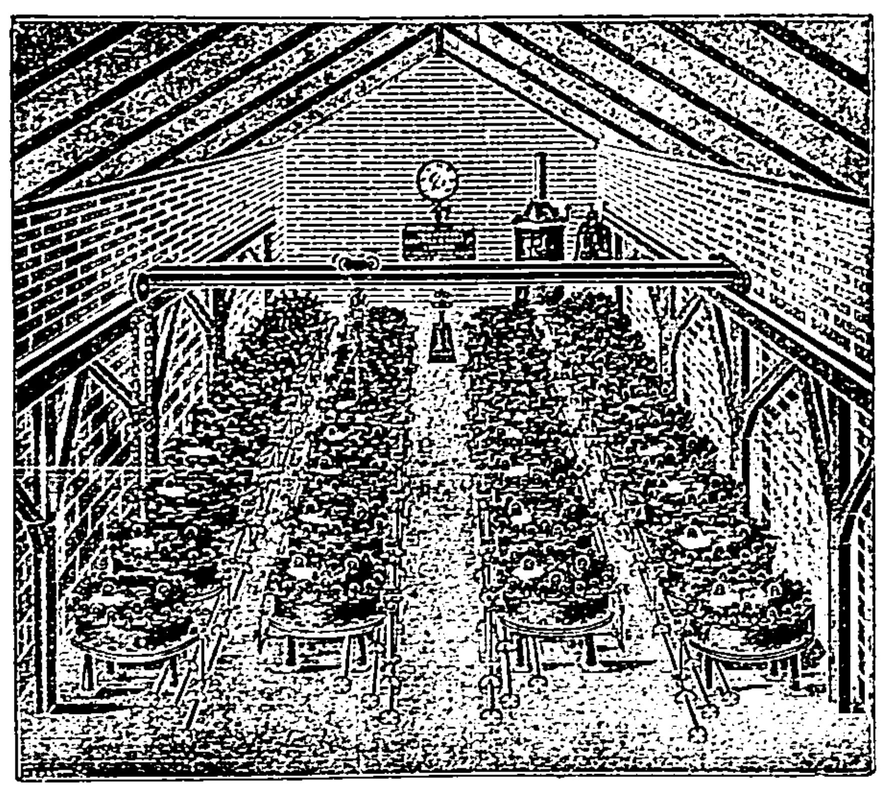

FIG. 39. Pasteur-Chamberland filters at Darjiling.

In conclusion, although a town supply may be of good chemical quality, comparatively free from bacteria, and well filtered, yet in its passage from the works to the consumer it may become contaminated with the bacillus of typhoid or cholera, or some other pathogenic organisms, brought in by leakage from the drains in the neighbourhood of the supply pipes or by infection of cisterns. There may also be a

breakdown in the filter-beds, as occurred in 1894 at Altona, when a fresh outbreak of cholera occurred through one of the sand filters becoming frozen and refusing to act, though in the previous year the filter had successfully resisted the epidemic. In the same way Dr. Klein has recently shown the liability of the London supply to pollution by sewage organisms, and Dr. Shirley Murphy attributes sporadic cases of enteric fever in London to the same cause. It is on these grounds chiefly that at the present time the sterilisation of water at the supply works is not advocated, and only the partial bacterial filtration aimed at. The possibility of subsequent pollution from some such causes renders it highly important that some adequate system of domestic filtration should be adopted by every householder. In many conditions, as on board ship and in country places, filtration on a smaller scale is the only purification practicable.

That such a system is attainable by simple means we have attempted to show. It would be a hygienic ideal, and probably will become a necessity, that the required apparatus be furnished as an integral portion of the ordinary water fittings, and that the duty of keeping it cleansed and in order be enforced by official inspection. The expense would bear no comparison with the outlay that is periodically occasioned in combating with diseases which are conveyed through the medium of impure water.

The reports of the French Minister of War in 1889 and 1892, on the mortality from typhoid fever in the French army, demonstrated in the clearest manner that a conspicuous diminution in the number of deaths had followed the substitution of spring or filtered water for the water of rivers or wells which had been previously used. A striking instance of the connection between typhoid and water occurred in the barracks of Melun. In 1889, the deaths from this disease had been 122; after the introduction of the Pasteur-Chamberland filter, the mortality of subsequent years fell to fifteen, six, two, seven, and seven. In one case the attacks were absolutely confined to soldiers lodged in the better rooms of the barracks, who, contrary to strict orders, had made use of water from troughs fed from the Seine, on account of the filters being frozen. The other battalions, who had drunk nothing but the regimental tea, had not a single case. Similar and quite as conclusive examples occur throughout the report in reference to typhoid and cholera, and still more striking results to the same effect are given in the report for 1894.

CHAPTER X.

SOFTENING OF WATER.

Among the gases dissolved by water from the atmosphere, carbonic acid, being the most soluble (at ordinary temperatures water dissolves its own volume of this gas), occurs in the largest proportion. Although the carbonates of lime and magnesia are almost insoluble in water, in presence of carbonic acid they dissolve to an appreciable extent, forming the unstable bicarbonates. As rainwater and other natural waters contain free carbonic acid, they exert a solvent action upon any carbonates present in the soil or rocks with which they come in contact, and thus most natural waters contain these bicarbonates in solution. Such waters are said to be *hard*, and, as a rule, the hardness is due to lime salts. Formations containing magnesium carbonate, such as the new Red Sandstone and the Permian, usually yield waters in which the hardness is due to magnesium bicarbonate.

The word *hardness*, implying the hard or harsh feeling to the hands in washing, is thus used in a purely technical and commercial sense. In very hard waters the curds which are formed before a permanent lather is produced by the soap are often