permit of these inconveniences being reduced to a minimum. Moreover, the flood-water channels may be used for the temporary diversion of the stream during the construction of the reservoir, and during subsequent inspection, repairs, or cleaning out. They must be capable of discharging the maximum anticipated floods from their respective streams, and must, of course, be protected against scour, especially on the reservoir side.

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For the roof of the deposit reservoir house and the service reservoir of the Canterbury Water-works (Plates 44, 45, and 47) Mr. Homersham used concrete and cast-iron girders and columns. The concrete was temporarily supported between the girders by timbering, which was removed after the concrete had been allowed sufficient time to set. The upper surface of the concrete is sloped and coated with asphalte, in order to carry off rain water. Above this, in the case of the service reservoir, is a layer of earth, and in that of the depositing reservoirs a layer of gravel. The service reservoir is divided by a low wall into two portions, either of which may be used while the other is being cleaned or repaired.

Covered reservoirs should be provided with manholes for convenient access, and should, moreover, be well ventilated ; indeed, apart from the question of the ill-effect of stagnant air, there would in some cases be danger of the roof blowing up were not means provided for the escape of the air pent up in the crowns of the arches.

In all reservoirs into which water is pumped, it is advisable that, in addition to the ordinary overflow as a protection against over-filling, there should be some provision against wasteful pumping—some tell-tale by which the engine-attendant will know when the reservoir is full. One of the simplest telegraphs for this purpose is formed by running a small pipe by the side of the rising main from the engine-house to the top water-line of the reservoir. When the reservoir is full, water will flow down this pipe, and may easily be made to warn the man in charge of the engine, as, for instance, by blowing a whistle.

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The pipe leading from the supplying reservoir terminates in a cylinder *a*, situated in a chamber A communicating with the reservoir or filter bed to be supplied. The cylinder is bored true, and fitted with a double piston *b*, *b*, actuated by a float. The action of the apparatus is not hindered by any excessive pressure in the supply pipe, as the two pistons are practically in equilibrium. When the apparatus is in the position shown in the figure the passage of the water is stopped; but as soon as the water in the chamber falls, the float and piston fall with it, and the water flows out through the slots *c* in the bottom of the cylinder. When the water in the chamber rises again the communication is once more stopped.

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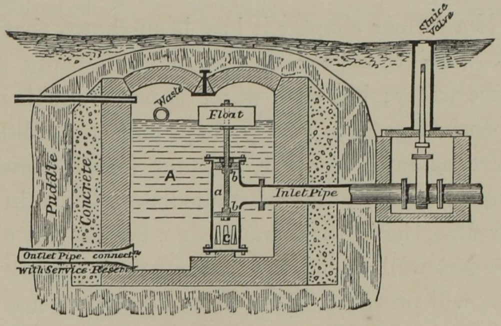

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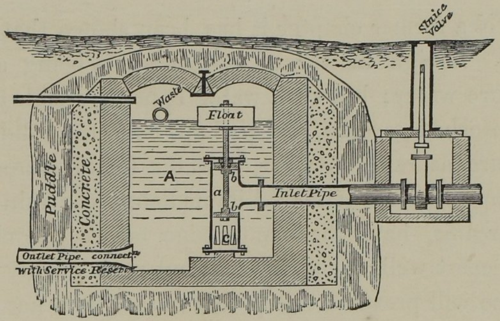

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CHAPTER IX.

THE PURIFICATION OF WATER.

INTRODUCTION—Various methods of purification: distillation, aeration, precipitation, straining, filtration—Theories of the action of sand filters, charcoal filters, and 'carbide' filters—Filtration through natural strata: filtering galleries at Genoa, Toulouse, Lyons, Perth—Filtration through artificial strata of sand and gravel: early failures at Glasgow; first filters of the Chelsea Waterworks Company; rate of filtration; filtering media of the Metropolitan Companies—Construction of filter beds: head and depth of water; inlet arrangements; drains and culverts: air pipes, overflows, and wash-outs—Cleansing filter beds—Sand washing appliances—Cleansing by back-flow: Greenock Waterworks; Dunkerque Waterworks—Leghorn Waterworks—Wakefield Waterworks—Cost of filtration.

IN a former chapter it has been shown that water in any of its natural states is never found chemically pure, foreign matter of various kinds being always associated with it. It is true that newly-formed clouds are pure water; but such water is not available until it is precipitated in the form of rain, by which time it will have absorbed gaseous, and perhaps collected solid, impurities, which a chemist would be able to detect. Not even as pure as rain, however, is water found stored by nature, for under the most favourable circumstances further impurities are gathered immediately the rain reaches the earth; while the most crystal lakes, fed by the daintiest streams, have to acknowledge before the chemist's tests. Or if you will select the brightest liquid from the deepest well, chemistry will but most readily show that still more extraneous matter has been taken up. Yet no one will presume to say that nature does not furnish, and even store, water fit and beneficial for human consumption. In our attempt at the so-called purification of water, therefore, we must be satisfied with something short of the purity understood by the chemist; but the question then arises: What other standard of purity shall be adopted? The diversities of opinion—some of which have been in a former chapter referred to—as to the fitness of certain waters for human consumption, and similar diversities which exist as to the efficiency or inefficiency of certain methods of purification, illustrate the fact that we are yet without any such recognised standard. As the purity of potable water, therefore, has to be regarded relatively rather than absolutely, so, also, must be the methods by which the artificial purification is attempted.

The only known methods of purifying water are—distillation, oxidation (aeration), subsidence, precipitation, straining, and filtration; all which—except, perhaps, the precipitation of impurities by the addition of chemical agents—are practised by nature as well as by man.

Distillation, consisting of the evaporation of water by the heat of the sun, and the condensation by atmospheric influences of the vapour thus formed, is a process which is being incessantly conducted on a most gigantic scale, and to which solely we are indebted for a mechanical restoration, and also chiefly for a thorough defecation, of the element that has already done us service again and again. Artificial evaporation, although constantly employed by the chemist and in the manufacturing arts, and now very generally relied on as a means of obtaining potable water at sea, has always been considered far too expensive to be used on land in the preparation of water, even for drinking purposes.

Oxidation is another process carried on by nature for the purification of fouled water, as noticed in a former chapter. It operates upon the class of impurities which, with one exception, have most to be feared, namely, organic matters liable to decomposition or already partially decomposed. The oxygen which is always dissolved in water exposed to the air, and the free atmospheric oxygen with which the organic matter is brought into contact by the motion of the water, combine with that organic matter, thereby converting it into harmless nitrates, nitrites, and carbonic acid. The more violent the agitation and more complete the aeration of the water, the more thoroughly will the organic matter be broken up and changed into these innocuous inorganic forms. In this way advantage may be derived from the introduction of cascades, weirs, and the like along the course of a conduit, or wherever else it may be convenient. The purifying agent is always at hand, and in superabundance; it is only necessary to utilise it by bringing it into contact with the substances upon which it has to act. This essentiaal contact may be encouraged by other means than the exposure and agitation just mentioned, but as they are associated with other methods of treatment, further reference to them will be deferred.

The class of impurities of which, in the foregoing paragraph, exception was made as being that most to be feared, is unfortunately the class upon which the action of simple oxygen is of the most doubtful efficiency. The microscopic organisms known as germs would seem to defy the action of the oxygen by that very element of vitality which renders them so persistently dangerous. While, however, the opinions of scientific men on this point are still so conflicting, it would be unwise here to do more than recommend the strictest caution. Outlines of the arguments used on both sides have already been given, and to these the reader is referred.

The subsidence of suspended matter has already been considered, in the preceding chapter, in relation to the form and dimensions to be given to reservoirs wherein this action is to be specially permitted. It is a simple process: the rate of descent will increase with the specific gravity of the matter, and will also vary inversely with its fineness of division. The reason for the latter is that, as a particle becomes diminished in size, its weight diminishes more rapidly than its area of resistance. From this cause certain substances are found to have the power of precipitating, or rather hastening the subsidence of, suspended matter; the mixed particles either aggregate or agglutinate into larger particles, and their rate of descent is immediately increased in consequence.

Water may be freed from certain dissolved impurities by the addition of a precipitant. Notably under this head comes Clarke's beautiful softening process already described in Chapter II. The analyses there given of water before and after the process show that not only is the carbonate of lime precipitated, but with the precipitate are carried down more than half the silica, all the iron oxide, and small percentages of the other impurities. In Wanklyn and Chapman's able little treatise before quoted, results are given of the analysis of four samples of water before and after undergoing Clarke's process, which show, more pointedly than those just referred to, the effects of the process in reducing the albumenoid organic matter,* which is the most suspicious, if not the most dangerous, form of organic impurity.

PARTS PER MILLION.

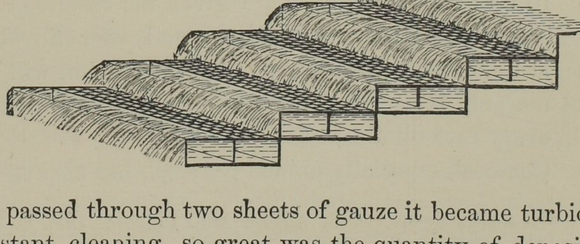
	Before		After	
	Free Ammonia	Albumenoid Ammonia	Free Ammonia	Albumenoid Ammonia
Sample I.	0·010	0·05	0·01	0·02
„ II.	0·025	0·22	0·03	0·08
„ III.	0·015	0·22	0·02	0·07
„ IV.	0·195	0·12	0·15	0·06

'It is to be observed that the organic matter removed can be proved to be present in the chalk precipitated.'†

Purification by straining through screens or wire gauze of various degrees of fineness is a process to which impounded and river waters are very generally subjected. Illustrations of this may be found on Plate 4 (Figs. 5 and 6), Plate 23, Plate 27 (Figs. 3 and 4), Plate 30 (Figs. 8 to 10), and Plate 38 (Figs. 6 and 8). Ordinarily, the process is nothing more than a mechanical one, floating or suspended matters too large to pass through the interstices or meshes of the screen or strainer being arrested. It would appear, however, that the agitation caused by the rapid passage of water through a fine screen will sometimes act in a manner other than mechanical, perhaps by assisting the contact and combination of the oxygen—atmospheric and dissolved—with the organic impurities.

For the purpose of rendering the waters of the Neva sufficiently clear for the manufacture of bank paper, Mr. Donkin constructed an apparatus which is illustrated by the accompanying figure. It consisted of a series of steps formed of troughs, rising one above the other, each of them divided longitudinally into two compartments, and a space being left between the partition and the bottom of the trough. The inner divisions were covered with wire gauze of 50 strands to the inch. The outer divisions had lipped orifices, through which the water flowed, falling, in sheets about $\frac{3}{4}$-inch in thickness, a distance of 2 feet, with a velocity, therefore, of about 11 feet per second, to the steps below. In this way it passed through all the five steps. 'The water entered the first step in a perfectly pellucid state, but before it had passed through two sheets of gauze it became turbid, and deposited a black scum on the wires, which required constant cleaning, so great was the quantity of deposit.

Fig. 95.



* Ante, p. 24. † Practical Treatise on the Examination of Potable Water by Wanklyn and Chapman, 2nd Edition, p. 92.

In the first tank the water was partially covered with a black scum of froth, sometimes more than an inch in thickness, and a thin scum having a metallic lustre appeared on the surface of the water in the second reservoir. To all appearance the deposit was similar to that thrown to the surface of foul water in general during its natural process of purification, which was in this instance accelerated partly by continued exposure to the atmosphere, and partly by the impediment to the grosser particles caused by the repeated passage through the gauze.' *

One of the most efficient kinds of strainers is that formed by a layer of fine sand ; it may be made of almost any degree of fineness, and has the advantage, moreover, of being very easily cleaned—namely, by scraping off the film of impurities from the surface. In proportion to the fineness of the sand, and its consequent efficiency as a strainer, is the rapidity with which it becomes choked by the accumulation of the arrested particles. But in this the disadvantage is only one of labour and cost, while the advantage of efficiency can hardly be valued.

The process of straining is one of the functions of the sand filters now in almost universal use for the purification of river and impounded water; and it was originally supposed to be the only function of a filter. But a strainer, acting solely as such—that is, by arresting all particles larger than its interstices or pores—could not easily be imagined varying as greatly in efficiency with different velocities of the strained water as sand filters are found to do, not even while acknowledging a certain amount of elasticity in the arrested particles, and regarding the almost inappreciable elasticity of the particles of sand. A difference of from 6 inches to 12 inches of descent per hour makes a very considerable difference in the efficiency of the filtration. Suppose that, by the restriction of waterway through the sand, and the increase of the length due to the several contortions, the actual velocity is ten times the nominal velocity. We shall then find that this considerable decrease of efficiency is brought by an increase in the velocity of from one sixtieth to one thirtieth of an inch per second. Such additional velocity could not make any sensible difference in the operation of a strainer, whereas it has a very marked effect on the efficiency of a sand filter.

Now there are other ways in which a filter operates in purifying water. If turbid water be allowed to stand in a glass vessel having vertical sides, the suspended matter will be found not only at the bottom, but also adhering to the sides of the vessel. An action similar to this, no doubt, goes on within the body of a sand filter: not only do the upper surfaces of the particles of sand afford area for subsidence, but the lateral, and no doubt even the under surfaces, serve more or less to attract and retain solid matter brought within range of the force of adhesion. And it must be remembered that the total combined area of the surfaces of the particles of sand upon which this action may take place is relatively very large. In a cubic inch of sand, which, let it be supposed, consists of little spheres 1-20th of an inch each in diameter, this area would be more than 60 superficial inches; while within the limits of a cubic yard of such sand there would be an area of 2,262 square yards. If only 1-100th part of this were available, there would still be more than 20 square yards of attractive surface for each square yard of filter-bed three feet deep. The action of this force of adhesion may not be very powerful, but its operation is extensive; and as far as matter in suspension is concerned, this function of sand filters is universally admitted. There is much contention, however, as to whether the efficiency of sand as a filtering medium is confined within the limits thus described. The older notion is that such a filter acts only mechanically; that is, as already seen, by permitting subsidence on its upper surface and on the upper surfaces of the several particles beneath, by straining the particles of suspended matter which are too large to pass through the interstices of the sand, and by attracting suspended matter which would perhaps otherwise escape the two former operations. That it is possible for a sand filter to remove matter in solution is evident from the following: 'When vinegar is filtered through quartz sand, the first portion of the liquid that runs through is robbed of almost all its acid, and the vinegar does not pass through unchanged until the sand has become well charged with acid. Potato-brandy, diluted with water and filtered through quartz sand, yields at first pure water, then a mixture of water and alcohol deprived of its fusil oil, and lastly the original mixture unaltered." †

It has been shown ‡ that water containing 1·42 grains of chloride of sodium per gallon (70,000 grains) may be deprived of 22 per cent. of that substance by filtration through a depth of 1 foot 9 inches of sand.

In the following table § are given the results of a series of analyses by Messrs. Letheby, Odling and Abel, of Thames and Lee waters, before and after filtration by the London companies. The construction of the several filters, and the manner of working them, will be presently given in detail. It is shown by the table, that not only is the small quantity of suspended matter reduced to a smaller, but the dissolved solid matter also is in every case diminished.

Charcoal, especially animal charcoal, has always been popularly regarded as a very powerful medium for the

* Remarks by Mr. C. E. Austin, Min. Proceed. Inst. C. E., vol. xvii. p. 47.

† Wagenmann Poggendorff's Annalen, xxiv—600.

‡ Phil. Mag., 4th Series, vol. xii. p. 30.

§ R. Com. Water Supply of Metropolis (1869) Report, p. ci.

removal of organic impurities from water filtered through it; but amongst chemists there is great diversity of opinion as to its efficiency in this respect. Some maintain that the impurities are retained and accumulated in the pores of the charcoal until the latter becomes saturated with them. Others, again, support the theory that the organic matter becomes thoroughly *oxidized* in its passage; the activity of the filter for further purification of

General Results	Thames Companies		New River		East London	
	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
	Grains	Grains	Grains	Grains	Grains	Grains
Dissolved matter, per gallon . . .	20·325	19·479	22·402	21·550	24·940	24·360
Of which organic and other volatile matter .	1·261	0·976	0·702	0·567	0·915	0·300
Suspended matter, per gallon . . .	0·830	0·034	0·241	0·095	0·561	0·047
Of which organic and other volatile matter .	0·173	0·005	0·033	0·014	0·045	0·023
Hardness before boiling (degrees)	14·4	13·3	15·5	13·5	14·4	14·0
Hardness after boiling (degrees)	5·3	4·6	4·2	4·0	5·0	5·0
Dissolved gases, per gallon (cub. in.)	13·77	13·85	13·95	12·75	12·51	13·75
Dissolved oxygen, per gallon (grains)	0·796	0·825	0·906	0·906	0·891	0·752
Oxygen required to oxydise organic and other matter (grains)	0·146	0·134	0·115	0·069	0·090	0·095
Ammonia, per gallon (grains)	0·003	0·002	0·001	0·001	0·004	0·003

water being in no way impaired thereby. Analyses could be quoted in support of both these theories, but on the whole the weight of evidence would seem to be more in favour of the latter. The following extract from a communication by Dr. Letheby to the Institute of Civil Engineers is of particular interest:—

'Thinking that an examination of charcoal, which had been in use for some time as a filtering agent, might throw some light on its real function as a purifier of water, he obtained from the London Purifying Company samples of charcoal from a No. 4 filter, which had been in continual use at a house in St. George's Square, Pimlico, from the month of November 1865 to the time when the samples were taken out of it for his enquiries—that was for a period of exactly two years; so that about 292,000 gallons of water had passed through it. Now it appeared to be a matter of great importance to ascertain whether the filter still had the power of purifying water, and whether it contained any notable quantity of organic impurity locked up in the pores of the charcoal. He therefore examined the capabilities of the charcoal as a purifying agent; and he found that when water supplied by the East London Water Company was filtered through the charcoal at such a rate that there was about three minutes' contact, the water was not merely deprived of its colour, as shown by examination of it in a two-foot tube, but it was also deprived in the usual way of organic matter. This he ascertained by the permanganate test, and by distillation with caustic potash. It was evident that the charcoal still acted as a purifying agent. He next examined the charcoal for organic impurity; for if it had been removing organic matter from water at the rate of only a tenth of a grain per gallon, it ought to have contained within its pores a very considerable quantity—not less than 4 lbs. of organic matter. Three examples of the charcoal were therefore submitted to distillation with a large excess of caustic potash, and the amount of ammonia obtained from 4 ounces of each of the samples was:—

Charcoal from	Top of the filter	0·321 grain ammonia
Ditto	Middle of ditto	0·162 „ „
Ditto	Bottom of ditto	0·240 „ „

thus showing that the quantity of nitrogenous organic matter in the charcoal was very inconsiderable. What then had become of the organic matter which the charcoal had for two years removed from the water? It had evidently not accumulated in the filter, and there was no proof of its having been first absorbed and then set free. To determine this question he put a known quantity of decaying organic matter into East London water, and filtered it through the old charcoal. In three minutes the organic matter had almost disappeared, and the filtered water contained a notable quantity of nitrite, which must have been produced by the oxidation of the nitrogenous matter which he had put into the water. This effect was tested still further by adding a drop of ammonia to a large volume of water, and then testing for ammonia, and for nitrate after filtration. As in the last case, the ammonia had nearly disappeared, and nitrate had taken its place. These results showed beyond question that the purifying power of charcoal was not merely dependent on the fixation or physical absorption of organic matter but also on its power of oxidation,* or, as Dr. Letheby had previously described it, a power of bringing the oxygen dissolved in the water into chemical union with organic matter, and so of destroying it.'†

Reference must here be made to the filtering medium discovered and introduced by Mr. Thomas Spencer, F.C.S., and usually associated with his name. It consists of a material called Magnetic Carbide, which is used in a layer of from 3 to 12 inches in thickness (according to the degree of impurity of the water to be filtered) below a stratum of about 18 inches of sand. The magnetic carbide consists of protoxide of iron in chemical combination with carbon. It is obtained by roasting hæmatite iron ore along with granulated charcoal for twelve to sixteen hours, at a dull red heat, so as to drive off an atom of its oxygen, from the absence of which the value of the material is supposed to be derived.

Mr. Spencer was first led to make trial of protoxide of iron by itself, because he had found in the course of a series of experiments that the most favourable results with impure water were obtained by using as filtering media those natural substances in which it formed one of the constituents. It is the opinion of Mr. Spencer that the purifying property of the oxide is due to its power of attracting oxygen to its surface, and, what is of still greater importance, without its surface being acted upon. The oxygen thus attracted is said to become changed into ozone. It may be as well to remark here that oxide of iron is found naturally in two states of oxidation, viz. the per-oxide, or ordinary rust, which exists plentifully everywhere; and the magnetic, or protoxide, which is far less plentiful and widespread, and is therefore more difficult to procure in sufficient quantity for practical use in filtration. A natural species of it is found in marketable quantities in some districts in New Zealand, where it exists in crystalline granules of the size of ordinary gunpowder.

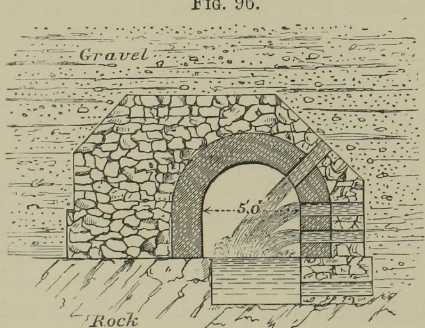
This system has been in operation on a large scale in Wakefield since 1863, where the water from the River Calder, which is contaminated with sewage, is supplied for domestic purposes, after filtration, in a degree of purity which Dr. Frankland says is 'really marvellous.'

The following table‡ gives the results of a series of analyses of water filtered through magnetic carbide, 'silicated carbon' (Dahlkes) and 'spongy iron,' a medium whose efficiency is advocated by Professor Bischof, of Glasgow. This latter material is 'a metallic iron which has been reduced from an oxide without fusion, and which is hence in a loose spongy state.' It is at present made from 'burnt ores, which are the residues of Spanish or other pyrites after extracting their sulphur in the manufacture of soda, and their copper by the wet chlorization process.'

Description of Water	Free Ammonia		Albumenoid ammonia		Organic carbon		Organic nitrogen		Total combined nitrogen	
	Parts per million	Per cent.	Parts per million	Per cent.	Parts per million	Per cent.	Parts per million	Per cent.	Parts per million	Per cent.
Unfiltered	0·0694	100	0·0225	100	0·2499	100	0·0843	100	0·1414	100
Filtered through magnetic carbide .	0·0602	87	0·0108	48	0·1045	42	0·0431	51	0·0927	65
Filtered through silicated carbon .	0·0389	56	0·0102	45	0·0558	22	0·0764	90	0·1084	76
Filtered through 'spongy iron' filters .	0·0522	75	0·0056	25	0·0216	10	0·0216	26	0·0646	46

For the supply of towns, river water, naturally filtered, is sometimes derived from galleries constructed in the sand and gravel which frequently forms the river bed and banks. These filtering galleries form a connecting link between shallow well and direct river supplies. They should be driven sufficiently below the lowest summer level of the river, that the yield may be at all times plentiful. At the same time care must be taken that the area of percolation is large enough to admit of the passage of the required quantity of water without an undue head and velocity; for where the velocity is extreme, the sand is liable to be washed in, the foundations undermined, and the stability of the structure impaired: the water itself, moreover, could not be so thoroughly filtered as with a low velocity. Fig. 96 represents the section of a filtering gallery as constructed in the bed of the river Scrivia, from which the city of Genoa derives its water supply. It is built of masonry, and the water, after passing through a bed of gravel, enters through the side of the tunnel furthest removed from the river. Fig. 97 illustrates

FIG. 96.

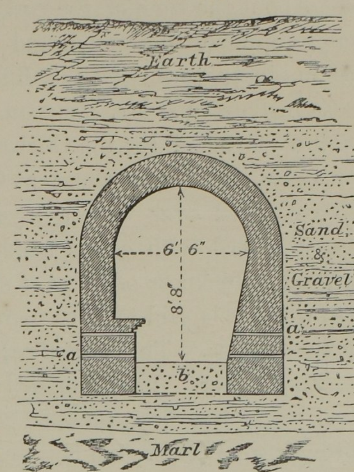


* Trans. Inst. C. E., vol. xxvii. p. 36. † Ibid. p. 6.

‡ From a paper on 'The Purification of Water' read before the Philosophical Society of Glasgow, by Professor Bischof.

a similar gallery at Toulouse, in a deposit of gravel and sand on the banks of the Garonne. The water enters at the bottom of the tunnel and through the earthenware pipes *a*, *a*, at its sides. At about every 23 feet (7 metres) the side walls of the tunnel are connected at the bottom for the width of one metre, so as to strut them against the lateral pressure of the sand and gravel. The water in the river, which is very turbid, percolates into the gallery at a very slow rate. Fig. 98 is a section of the first gallery constructed on the banks of, and about 80 feet from, the River Rhone, for the supply of the city of Lyons. It is 394 feet in length and 16 feet 6 inches in width. The bottom is entirely free to the admission of the water. The gallery is well ventilated and is also provided with man-holes.

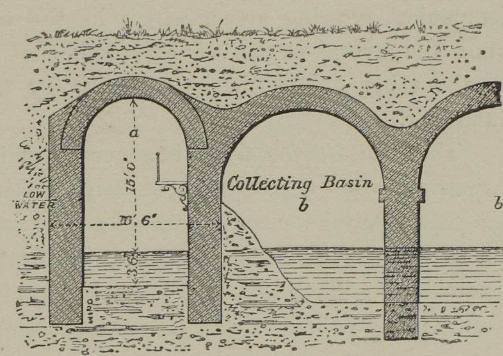
Fig. 97.



The gallery, *a*, having been found insufficient for the demand, two collecting basins were constructed, both however delivering their water into the original gallery: *b*, *b* represents a portion of one of these basins. Ultimately, as the works were still found to be unequal to their requirements, galleries of larger dimensions were driven in the bed. As regards the quality of the water, this method has been credited as a great success, the slight increase of hardness at Lyons, as compared with the water of the Rhone itself, being too small to be worthy of any consideration. Some of these galleries have been built as wide as 30 feet, but the dimensions of such structures must be entirely regulated by the circumstances of each case.

The city of Perth is partly supplied from the Tay by a process of natural filtration of a similar kind to those above described. There is a small island opposite the town, in which a deep trench, about 400 feet long and 5 feet wide, is excavated; into this the river water filters through a bed of gravel containing about 14,000 cubic yards, and is there pumped to the town: no floods make it turbid. On account of the rise and fall of the tide the filtration is to some extent intermittent. The quantity of organic matter in the water is reduced, but the hardness is increased from 1·6° to 3° by the process. The quantity of the water pumped is about 480,000 gallons a day.

Fig. 98.



The success of the system of filtration now generally adopted, like that of many other inventions and discoveries, has not been achieved without costly experience and failures of considerable magnitude.

The Glasgow Water Company and the Cranston Hill Company were rivals in the supply of water to Glasgow. The latter constructed, on Cranston Hill, reservoirs for impounding a large supply of water, together with a filter and clear water reservoir; but although the filter was said to be an improvement upon that constructed by the rival company, it was ultimately regarded as a failure, and the company entered on the construction of works of still greater magnitude. By means of an engine they forced the water over a hill 100 feet above the level of the Clyde, into a large subsiding reservoir, from which it was carried by four iron pipes into as many channels formed in an enormous artificial heap of sand. These channels, running parallel with each other, were about 13 feet in width and 10 ft. apart, and between them were constructed small paved trenches with upright sides, over which were turned arches roughly laid in dry stone, so as to leave irregular interstices. Upon these were laid small flints, and on these again a layer of fine sand. The water entering the channels percolated through the sand, flint, and stones, and entering the drains was carried thence into the reservoir. The purification effected by these measures was not, however, considered satisfactory, and, after a further failure with works at Dalmarnock, on the northern side of the Clyde, where mineral impurities were encountered, a large reservoir was formed on the bank of the river. The bottom of this reservoir, which was lower than the level of the water in the river, was traversed by thirty small cylindrical tunnels, built of wedge-shaped bricks, laid without mortar. They were about 2 feet in diameter and 20 feet apart, and were covered with coarse sand, forming as many ridges and furrows. When the reservoir was filled, the water filtered through the sand and the open brick-work of the tunnel, and found its way by means of the tunnels to the distributing reservoir. Having failed again, not so much in this case in the process, as in their efforts to keep the filter itself free from the impurities deposited in it, with unabated energy the company set about a still more expensive work.

This consisted of a series of shallow wells, 10 feet in diameter, and 6 feet deep, sunk in a stratum of sand adjacent to the river. The wells were connected by means of pipes controlled by valves, and the water yielded by them was led into the storage reservoir. The scheme, however, ultimately failed, and at last, in 1858, the rival companies amalgamated.

About the time of the earlier occurrences just narrated there was considerable agitation in reference to the water supplied to London, and Mr. Simpson was instructed by the Metropolitan Water Companies, for which he was engineer, to inspect the different processes of filtration then in use, and report upon them. In pursuance of these instructions Mr. Simpson visited Glasgow and other places in the north of England, and on his return in 1839 constructed for the Chelsea Water Company the first filters of their kind in London. They were formed somewhat similar to those at Glasgow, namely, with a series of tunnels built of brick without mortar. These were covered over with a layer of fine gravel, 2 feet in thickness, then with a stratum 2 feet deep of fine gravel mixed with coarse sand, and lastly, a layer consisting of 2 feet of fine sand ; so that the water passed through a thickness of 6 feet of sand and gravel, the matter in suspension being deposited in the top layer of sand, into which it is said to have penetrated to about the depth of 3 inches, the larger portion, however, being retained on the surface. The periodical removal of little over half an inch was sufficient to keep the filter in complete working order. The filter-bed occupied about an acre, and to it were attached two reservoirs into which the river water was first pumped and allowed to settle, and from which afterwards it flowed into the filter-bed through small pipes, the bottom of the reservoir being on a level with the top of the filter-beds. The result was highly satisfactory, and the principles and practice then adopted are, with but little variation, recognised even to this time.

It is now very generally admitted that filtration through sand, to be effective, should not proceed at a higher rate than 6 inches of descent per hour; in other words, there should be at least $1\frac{1}{2}$ square yard of filtering area for each 1,000 gallons per day. This is, of course, exclusive of reserve area, which will be necessary to permit of at least one bed being cleaned while sufficient area remains in operation in the other beds.

The table already given on page 120 shows, for the different Metropolitan Companies, the gross filtering areas—*i.e.* inclusive of spare beds—which were in operation until recently. It also shows the combined filtering and subsiding area devoted to the purification of the water. The Lambeth and Chelsea Companies' filtering areas, which in the table compare so unfavourably with the others, have lately been found the average rates of enlarged, the subsiding reservoirs having been converted into filtering beds. In the table below will be filtration by the London Companies, taken from the official returns of the Water Examiner.

The term *filtering media* is generally understood to refer to all the loose material in a filter-bed through which the water is made to pass ; but, strictly speaking, it applies only to the upper and finer strata where all the purification that does take place is effected ; the remainder is introduced merely to support the filtering medium proper, and to allow of the filtered water being drawn off without disturbing it. Fine, sharp, siliceous sand is in most general use, and the stratum is seldom made less than 2 feet, or more than 3 feet, in thickness. The finer the sand the more efficient will it be as a strainer, but the sooner will it become choked, and the more difficult will it be to cleanse. The latter considerations, however, should not be allowed to have much weight, as the prime object should undoubtedly be to ensure the greatest amount of purification. For the purpose of removing solid impurities from the water by the attraction of adhesion or aggregation, the quality of fineness will scarcely be more profitable than that of sharpness or angularity, for the 'sharper' the sand the greater will be the proportionate area of the 'facets' of the particles upon which this action will take place.

To support the fine sand is a layer of coarse sand, and this again is generally retained by successive layers of gravel of gradually increasing coarseness. Sometimes the sand is laid immediately on a bed of small shells.

The table on page 143 shows the formation of the beds of the London Companies ; and details of others will be found illustrated on Plates 2, 5, 6, 18, 23, 24, and 34.

The depth of water over the sand is sometimes referred to, though incorrectly, as the *head* under which the filter is worked. Now the head of water on a filter is properly the loss of head due to the passage of the water through the filtering medium, and is independent of the depth of water resting upon the medium. The loss of head will vary directly with the velocity of filtration and with the resistance of the medium, which resistance will increase with the depth, fineness, and closeness of the sand, and the extent to which it is choked with solid impurities arrested from the water.

The depth of water in a filter bed is sometimes made as little as one foot, and sometimes as much as seven or eight feet. The greater depths are perhaps assigned in some rare cases through erroneous notions as to the head required ; but mostly, no doubt, from a desire to keep the beds cool in hot weather. But it should be remembered that in a filter bed in operation the water is there longer exposed to the heat as the depth of water is greater ; thus if the filtration be at the rate of 6 inches per hour, the water will be exposed in the bed for twice