CHAPTER IX

Multiple Filtration: Seventeenth to Twentieth Centuries

Multiple filters were installed in a few places abroad in the nineteenth century. Since then they have come into extensive use in France and have been used less commonly in the United States, Great Britain and other countries. The number of successive filtrations has ranged from two to six. A roughing and a final filter is the general rule, outside of France. Long before there were any permanent installations, small-scale experiments with multiple filters were made and plans for such filters were published.

Francis Bacon, in his *Sylva Sylvarum* of 1627 (1), mentions two sets of experiments on freshening sea water by passing it through ten vessels in one case and twenty in another, the first being a failure, the second a success (see Chap. II). In 1711, Marsigli (2) reported that sea water was not made drinkable by filtering it fifteen times through superimposed vessels filled with clay and sand (see Chap. II).

Porzio, in his book on military camp sanitation, published in 1685 (3), described at length and illustrated a series of multiple filters, the first of each pair working downwards, the second upward. One scheme was for three pairs of filters in a boat, floating in the water to be purified, the other for treating well water on land (Chap. II).

Patents of Three Centuries

As in other fields, so in this one—few of the many patents granted got beyond the patent stage. For the first time, their number and variety is here exhibited.

Joseph Amy, leader of the procession, outdid most of those who followed, in that he made and sold hundreds of filters. In 1745 he applied for a French patent on passing water through sponges inserted in the side of a boat, supplemented, if need be, by filtration through sponges inserted in cross-partitions in a second boat. Sponge having been disapproved, a patent was granted to Amy in 1749 for a filter of sponge and sand placed in a lead, pewter or earthenware container. Among various types of filters described and illustrated by

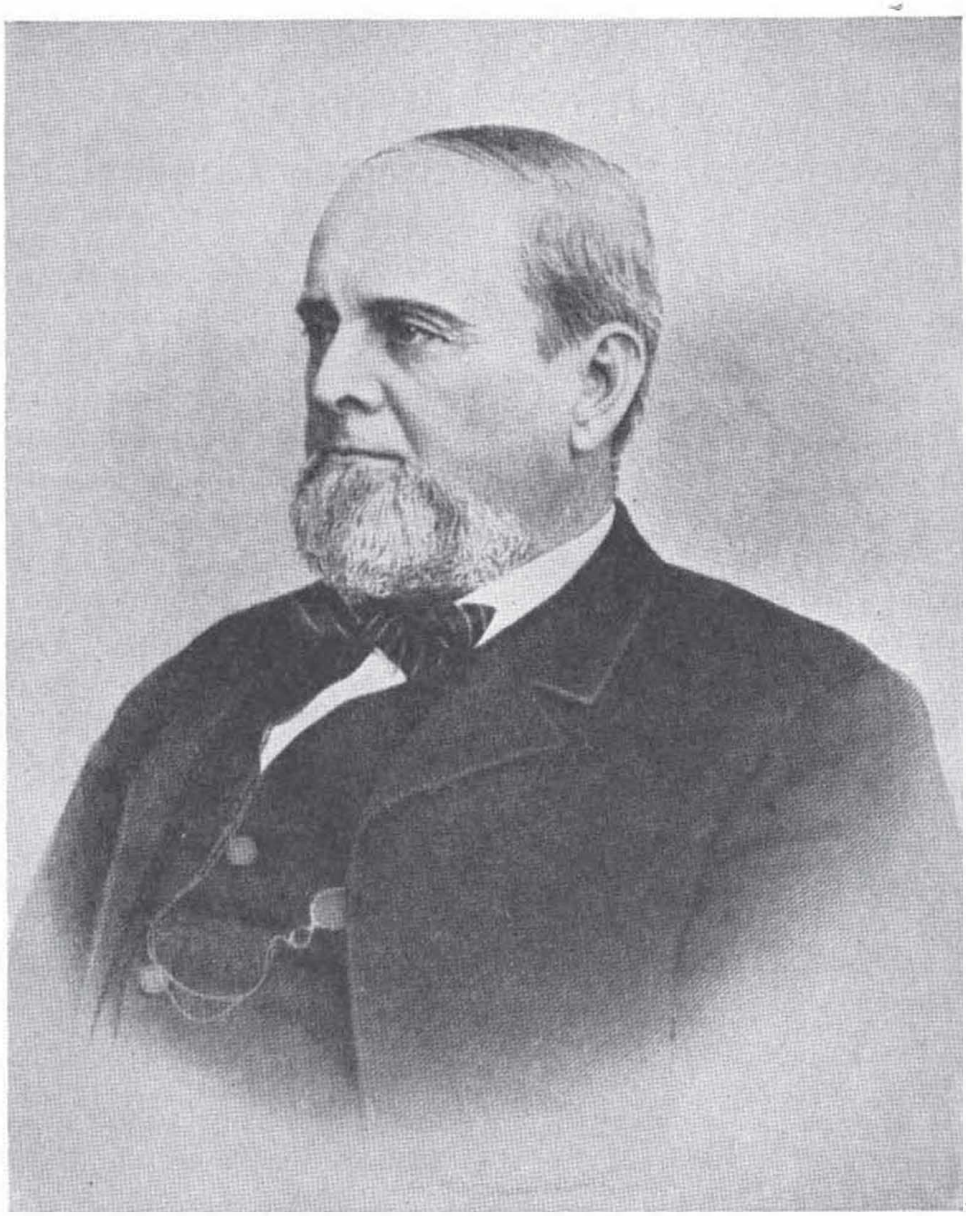

FIG. 50. J. D. COOK (1830–1902)

Chief Engineer, Toledo, Ohio, Water Works during construction in 1873–74; designed settling reservoirs and filters for original works, but city authorities eliminated reservoirs and reduced filter area, thereby rendering filtration unsuccessful; Cook then designed multiple filters which city did not build; latter design patented in 1879

(From portrait in *Cyclopedia of National Biography*)

Amy in a book published in 1754 was a large one designed for a military garrison. It included three pairs of filters working in series. In each pair the water passed downward, then upward, through 3 ft. of sand, making 18 ft. in all (see Chap. IV). The basic design closely resembles that of Porzio.

The first of a long series of British patents on multiple filters was granted in 1798 to Joseph Collier for an upward-flow filter working under hydrostatic pressure. After passing upward through a settling chamber and a leather diaphragm for clarification the water continued upward through charcoal to "sweeten" it or free it from any "putrid or noxious particles."

Triple filtration, preferably in a watertight chest, was patented in 1810 by Joseph Stephenson. The sequence was downward through sponge compressed by the weight of the water, then downward through sand and charcoal and sand, and then upward through charcoal topped with sand.

Henry, Count de Crouy, took out a patent December 12, 1839, for a "filtering machine" consisting of two or more sets of filters, working under head provided by a cistern.

Double lateral filtration through (a) sand and (b) artificial slabs of coke or coal cinders and coal tar was one of several elements in a patent granted February 14, 1873, to F. H. Atkins.

Caesar Gerson, M.D., of Hamburg, Germany, took out a British patent August 27, 1877, for double filtration: (a) upward through layers of sponge and powdered pumice stone or gravel, each impregnated with insoluble iron salts; and (b) downward through a mass of Swedish iron ore and layers of sand, powdered glass and wool shearings, all impregnated with iron salts. (An American patent was granted to Gerson on March 19, 1878.) A modified form of Gerson's filter was described in 1887 (4), with a statement that it was designed for industrial plants and town water works, requiring for the latter only a ninth of the space needed for sand filters. Several industrial installations in England and on the Continent were mentioned.

Elaborate multiple pressure filters were proposed for construction at Toledo, Ohio, by J. D. Cook, engineer and superintendent of the water works of that city, but the plan was not adopted. He was granted an American patent on a slightly different system of multiple filters on March 6, 1877. The design called for several pairs of narrow settling chambers and filters, as many as might be thought necessary. The

flow was downward in the first and upward in the other filters. Any filter could be washed while the others were in use. Broken stone, gravel, sand, charcoal, sponge or other filtering material could be used. No filters of this kind were built.

To remove micro-organisms from liquid which preferably had been passed through an ordinary filter to free it from mechanical impurities, K. Möller proposed, in a British patent of January 14, 1885, secondary filtration through compressed asbestos, amianth, stagwool or other fibrous material.

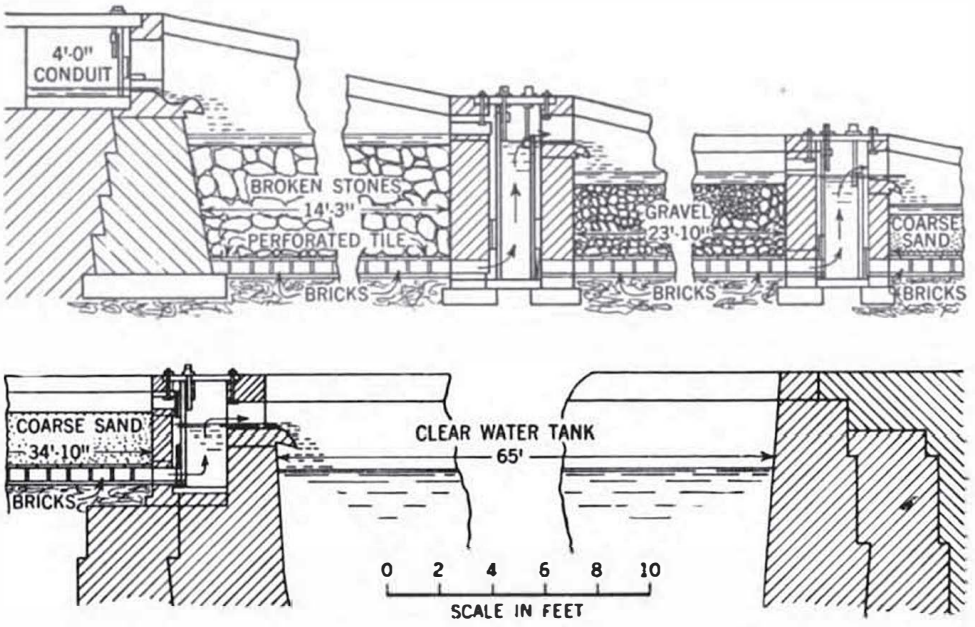

FIG. 51. MULTIPLE FILTERS AND AERATORS AT GLASGOW
Designed and built in 1846–48 by William Gale Sr., Chief Engr., Gorbal's Gravitation Water Co.
(From copy of Gale's drawing supplied by John Cochrane, Chief Engr., Glasgow Corp. Water Works)

Andrew James Bell, of Manchester, England, was granted a British patent March 2, 1885, for a combination of a downward-flow filter to remove grosser impurities and, below it, lateral-flow filters in vertical tubes for additional purification. The filters were cleaned by a reverse-flow current of water or steam. Double filtration following the underlying principle of the Möller and Bell patents was patented in England October 24, 1888 by G. D. Gerson. His primary filter, to remove suspended matter, was composed of sponge, placed at the bottom, and pumice stone at the top, both treated with tannate of iron.

His secondary filter was of pumice stone. Filtration was upward in both filters.

Alexander T. Walker, water works engineer of Reading, England, was granted a British patent on multiple filters February 8, 1893. His design called for a filter of coke or other material followed by a series of polarite filters, all working by upward flow. He had already built multiple filters on the same general principle at Reading, as noted below.

The Reeves Patent Filters Co. and W. Reeves were granted a British patent November 4, 1897, on a combination of presedimentation, upward-flow filtration through coarse material placed above, and downward-flow filtration through a rapid filter cleaned by reverse flow aided by a horizontal revolving rake working in the surface of the filter.

Armand Puech, of Mazemet, France, took out a British patent on May 14, 1898, on multiple filters. The filters were a result of experiments made at his cloth factory in southern France, where he put in a working filter, apparently in or before 1897. With later improvements designed by H. Chabal, this became the Puech-Chabal system, mentioned below.

Installations in the Eighteenth and Nineteenth Centuries

Europe.—The first working multiple filters, which were also the first known filters for municipal supply, were completed in 1804, at Paisley, Scotland. Water was taken from a river through a filter trench of stone to a settling basin, then passed laterally through two filters, the first of gravel, the second of sand. Triple filtration was begun in 1848 by a company supplying a suburb of Glasgow, Scotland.

At Glasgow, Scotland, in the ill-fated filters designed by Thomas Telford and put into use in 1807, water was passed in succession "through a series of cells, filled with sand" (see Chap. V).

In 1812, "Paul found in Geneva" a series of twelve, fifteen or twenty filters working in tandem. The containers had a diameter of 6 in., were 2 ft. high, filled nearly to the top with sand and hermetically sealed. If ten or twelve of these filters were in use, says Delbrück (5), the water would pass through 16 to 20 ft. of sand. No further information on these filters has been found.

John Williams, in a book designed to promote his patented scheme for "Sub-ways," published in London in 1828 (6), suggested that water taken from the Thames above London might be passed downward

through a succession of filters, located at lower and lower levels, "until sufficiently pure to enter the pipes."

While at Leghorn, Italy, in 1866, James P. Kirkwood (7) saw a sextuple filtration plant consisting of three pairs of filters. The first filter of each pair worked by downward and the second by upward flow. The filter media in the first five filters were, from top to bottom, fine gravel, coarse gravel, wood charcoal, coarse gravel. In the sixth filter, gravel only was used. As the source of supply was springs, normally clear and bypassed when turbid, the filters and monumental filter house seem to have been more ornamental than needful. This may have been due to the fact that Paschal Poccianti, who designed the water works, was a Florentine architect of "high reputation." Kirkwood does not say when the works were built but as the architect had been "some time dead" it may be assumed that these multiple filters were installed in the 1850's. It may also be assumed that Poccianti got his ideas for multiple filters from Porzio's book of 1685.

Two of the London water companies employed double filtration in the latter part of the nineteenth century, beginning in 1866 (7) and 1891 (12), respectively.

In Belgium, in 1881, after experiments made in 1879–80 by Professor Gustav Bischof, the Antwerp Water Works Co. put in prefilters to treat settled water. They were composed, from the top down, of 2 ft. of river sand, 3 in. of gravel and a 3-ft. mixture of spongy iron and gravel. The final filters were of sand. Provision was made for aeration between the prefilters and final filters. The layer of spongy iron and gravel matted together and clogged. As there were 27 in. of sand and gravel above it, renovation was no easy task (see Chap. XIII).

At Stamford, England, double filtration, first upward then downward, was adopted early in 1882. The media were spongy iron, sand and gravel. A 6-in. layer of spongy iron was separated from the other material by perforated brick, laid dry. Both units were washed by reverse flow. Whether the spongy iron was at the bottom of the filter, as at Antwerp, is not stated in a contemporary description of it (8).

In Holland, double filtration, first through coarse sand and gravel, then through fine sand, was put into use at Zutphen, in 1889, and at Schiedam in 1890. At Zutphen the object was to remove iron and manganese from well water. Before prefiltration, the water was aerated by passing it over weirs. In 1923 a new but similar plant was built for Schiedam, except that sprays were used for aeration.

The double filters at Schiedam were also of coarse and fine material. They treated river water after sedimentation. These filters were used from 1890 to 1921, when a supply, also twice filtered, was obtained from Rotterdam.

Eugen Goetz (9), engineer of the water works of Bremen, Germany, introduced there an unusual system of double filtration in 1895 or earlier and at Altona, Germany, in or about 1896. The water of a newly cleaned filter was siphoned onto an adjacent filter that was "ripe" or in good working order. Siphonage made it possible to have all the filters on the same level. According to Carriére (10), Jewell rapid or mechanical filters, supplied with water settled for ten hours, were installed in 1913 and 1917 to treat water before its delivery to slow sand filters.

Amazing as it will appear to those who have seen the clear water of Lake Zurich, the supply of Zurich, Switzerland, taken from that source, has been twice filtered for four decades. This is largely on account of plankton in the water, two-thirds of which are removed by the secondary filters. Bacteria are reduced one-half by the prefilters and up to 50 per ml. by the final filters. Slow sand filters had been used for many years before prefiltration was introduced. In 1898–99, Water Engineer Peters built prefilters of coarse sand under the roof of the filter house and above the slow sand filters, and substituted finer sand than that previously used. In 1912–14, a new double-filtration plant, higher up the lake, was built. When the author visited the plant in 1904 the prefilters were cleaned by reverse-flow wash, aided by compressed air once in 3 to 4 days; once in five years, the entire bed was removed, washed and replaced. Four prefilters, of fine sand, were added in 1928. [The preceding statements were revised in November 1939 and March 1940, by O. Lüscher, Director of the Zurich water works. He stated that the final filters were cleaned once a year and the sand renewed once in ten to twenty years (11).]

At Reading, England, Borough Water Engineer Alexander T. Walker experimented with multiple filtration in 1889, installed a plant in 1890 and in 1893 took out the British patent already mentioned. Each unit of the plant of 1890 included five prefilters with media progressively diminishing in size, and a final slow sand filter. Somewhat remodeled by Leslie G. Walker, son and official successor of Alexander, these filters were still in use late in 1941. Complete "modernization," planned by the second Walker, was deferred by the

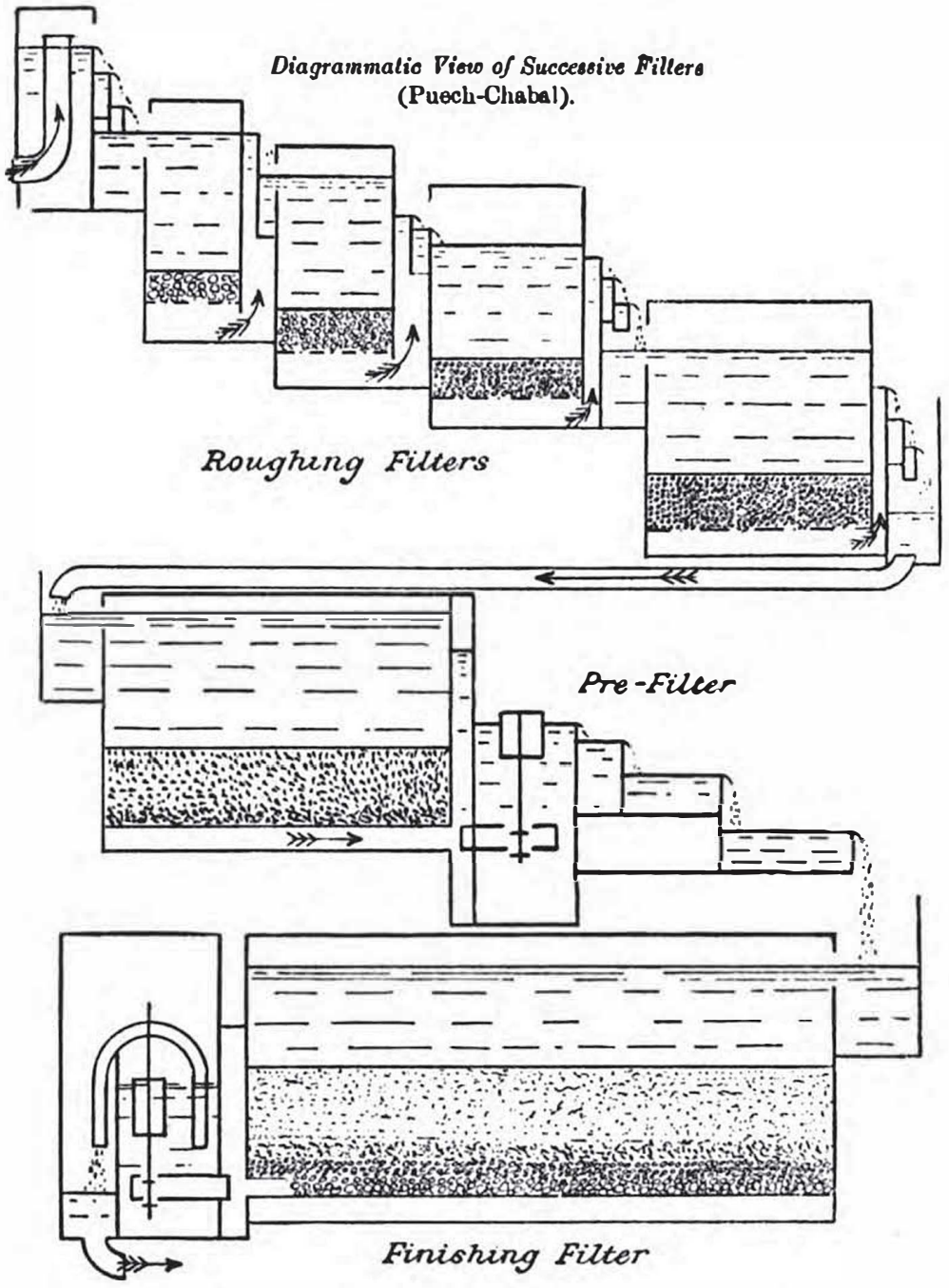

FIG. 52. PUECH-CHABAL MULTIPLE FILTERS AND AERATORS

Flow is through four *degrossisseurs*, a prefilter and a final filter with five cascade aerators

(From John Don's "Purification of Water for Public Supply," *Proc. Inst. M.E.*, January 1909)

second world war. Walker prefilters on another site of the Reading water works deliver water, strange as it may seem, to rapid pressure filters. Postchlorination was begun at Reading in 1910.

Under the leadership of Armand Puech, whose patent of 1898 has been mentioned, and his engineer-lieutenant and successor, H. Chabal, many Puech and Puech-Chabal filters have been constructed. The first of these for municipal supply was completed in 1899 to treat a part of the water supply of Paris. Information supplied in 1935 by H. Chabal et Cie, Paris, showed that about 125 municipal Puech-Chabal plants had been built in France, nearly 20 in Italy, a number in other countries to the south or east and two in England. Each unit includes three or four *dégrossisseurs* or roughing filters, a so-called prefilter and a final filter, the whole working in series or tandem. The filtering material decreases successively in size and the unit-area rate of filtration also decreases from filter to filter. As a rule, there was in the early days no presedimentation, no coagulation, no disinfection. In the passage of time, the roughing filters and the intermediate prefilters have been virtually converted into rapid or mechanical filters, but not so called by the promoters.

The Paris filters of 1899 were installed by Puech before he was joined by Chabal. They were located at Ivry on the Seine and treated water from a settling reservoir. There were three *dégrossisseurs* of gravel and a final slow sand filter. The rated capacity of the plant was 20,000 cu.m. or 5.25 mgd. By 1935, the capacity of the plant had been increased to 300,000 cu.m. or 82 mgd. Meanwhile, the settling reservoir had been converted into roughing filters; prefilters had been inserted ahead of slow sand filters; and air-and-water wash had been provided—at least for all but the final filter.

Of the two Puech-Chabal installations in England, one was completed in 1902 by the East London Water Co. shortly before the Metropolitan Water Board acquired the works of all the water companies in the Metropolitan District. Water taken directly from the Thames at Hamworth was passed through three roughing and one slow sand filter. These filters were abandoned in May 1914, when use of the intake supplying them was discontinued (12). William B. Bryan was engineer of the East London Water Co. when it adopted the Puech system on his recommendation. He journeyed to Paris to see the Puech system there when, by an hour's journey to Reading, he could have seen the Walker sextuple filters that had been in use for a decade.

The second and only other installation of Puech-Chabal filters in England was completed in 1912 for part of the water supplied in bulk by the Derwent Valley Water Board to Derby, Leicester, Nottingham and Sheffield. There are three sets of roughing filters and one of slow sand filters. Before the second world war, R. W. S. Thompson, engineer of the board, began changing the slow sand to rapid gravity filters. Up to December 1941, the work had progressed slowly, due mostly to labor shortage. The Puech-Chabal filters were still in use. Ultimately, it is expected that the roughing filters, which have limestone media, will be used to harden the water before rapid filtration. Another part of the water supplied by the board is treated by rapid pressure filters.

Filters at each end of its gravity aqueduct from Wales were put into use by Birmingham, England, on July 21, 1904. They are notable for being the first large and apparently still the largest installation of double filters in Great Britain. The primary filter is unique because its object, states Chief Engineer A. A. Barnes (13), is to remove "fine solids of a peaty nature, together with *Crenothrix* and kindred iron bacteria" which, says a booklet of 1908, would be deposited in the aqueduct and reduce its carrying capacity (14). Following is Barnes' description of the filters as they were on May 18, 1942:

> The primary or roughing filters are of coarse sand. Their area is 13,500 sq.yd. and their maximum capacity, at a rate of 4,500 gpd. [Imp.] per sq.yd., is 60 mgd. [Imp.]. The filtrate is hardened by lime treatment at the rate of 60 lb. per mil.gal. [Imp.].*
>
> The water thus filtered and hardened passes for 73.5 miles through cast-iron and steel aqueducts to open storage reservoirs with a total capacity of 700 mil.gal. [Imp.]. The final filters are of sand, 2.75 ft. deep and 68,500 sq.yd. in area. Their capacity at a maximum filtration rate of 560 gpd. [Imp.] per sq.yd., with a final head of 3.75 ft., is 38 mgd. [Imp.]. Each filter is hand scraped once in ten weeks.
>
> [In U.S. units the roughing filters, working at a rate of 26.1 mgd. per acre, have a capacity of 75 mgd., and the final filters, at a rate of 3.25 mgd. an acre, a 45.6-mgd. capacity.]
>
> Two rapid filters, originally intended for primary filtration, were put into use for Birmingham August 2, 1938. Each unit is 15 x 60 ft. in plan, with sand 2 ft. deep. Working at a rate of 20,000 gal. [Imp.] per sq.yd. per day [about 106 mgd. (U.S.)] per acre, their joint capacity is 4 mgd. [Imp.]. They are backwashed for 10 min. once in 48 hr., with filtered water under pressure

* This was advised, at the start, by the medical officer of health, to prevent action of the soft water on lead service pipes of the distribution system (13).

at three times the rate of filtration. The normal filtering head after backwashing is 2.33 ft., running in 48 hr. to 4.25 and 4.75 ft. The water is so clarified by these filters that no secondary filtration is found necessary. The filtrate is chlorinated at a rate of 0.3 ppm. [Imp.].

To sum up Great Britain's story, where multiple filtration has been adopted the general custom has been to put rapid or mechanical filters ahead of slow sand filters, and not to use a coagulant. This was done at York, in 1900, when an American make of filter was installed under the direction of W. E. Humphrey, Engineer of the York Waterworks Co., who became British agent for the Jewell Export Filter Co.

More than two score years later, after a number of similar adoptions in Great Britain, the London Metropolitan Water Board cautiously began tests of rapid prefilters. In 1925 a small plant was installed. Since then rapid prefilters have been constructed at several of the board's filtration works. The main object has been to increase the capacity of slow sand filters. It should be noted that ample storage and presedimentation of river water has long been provided at London, with pump shutdowns when the water is highly turbid; also that during the first World War, coagulation was introduced to reduce the cost of pumping to storage reservoirs.

United States.—In the United States, multiple filtration came late. Atlantic Highlands and Asbury Park, N.J., included double filtration in iron-removal plants completed in 1893 and 1895 (see Chap. XXI). At Wayne, Pa., double filtration was used in 1895–96, then abandoned.

Maignen scrubbers or roughing filters, generally consisting of sponge above stone, were installed at five Pennsylvania water works in 1900–09. In partly modified form, they were installed at Wilmington, Del., in 1910. All have since been abandoned. The first of these plants was put into use by the Huntingdon Water Supply Co. in 1900. Maignen scrubbers were completed at two of the Philadelphia filtration plants: Lower Roxborough in 1902 and Belmont in 1909. The scrubbers were introduced at South Bethlehem in 1904; Kittaning in 1905; and Lancaster in 1906.

Philadelphia has the largest double filtration plant in the world, at Torresdale, on the Delaware. To lessen the burden on slow sand filters having a nominal capacity of 220 mgd., rapid filters using air-and-water wash, were completed in 1909. In 1920, a presedimentation reservoir, with a detention capacity of twelve hours, was added to supply the rapid filters. Subsequently, coagulation by means of sulfate of alu-

mina was introduced for use at times of high turbidity. At the Queen Lane reservoir, Philadelphia, a 60-mgd. double filtration plant was completed in 1911. In 1922, half of the prefilters were converted into rapid sand filters, with air-and-water wash, raising the capacity of the plant to 100 mgd. (15). Continuation of double filtration at Philadelphia, with probable extension of the use of rapid prefilters, was projected in 1940. Plans were being made in 1942 (15).

At only a few other cities in the United States has double filtration been employed. At Steelton, Pa., prefilters of the rapid type, but using anthracite coal screenings, were completed in 1908, to treat water laden with coal dust and dirt, plus the sewage of Harrisburg.

At South Norwalk, Conn., also in 1908, a double filtration plant with double aeration was put into use to cope with algae causing tastes and odors. Slow sand filters were used, with fine-grained primary filters working at a low rate and a single coarse-grained bed working at a high rate, thus reversing the usual practice. This plan was adopted on the advice of Harry W. Clark. Associated with him in its design was William S. Johnson (16). In 1936, states Engineer Elmer F. Bracken (17), the secondary filter was converted into a clear-water basin (see Chap. XVI).

The only other known prefilters in the United States were installed to reduce the burdens on existing slow sand filters treating highly polluted water. There were three of these: Albany and Poughkeepsie, N.Y., and Lawrence, Mass. At Albany, scrubbers were installed in 1908. They were converted into rapid filters, put in operation January 1, 1928, and used until the abandonment of the Hudson River supply in 1932. At Poughkeepsie, after the slow sand filters of 1872 had been used for nearly 40 years, rapid prefilters were completed in 1920. At Lawrence, rapid filters were completed late in 1938 and put in use ahead of the slow sand filters (see Chap. VI).

Canada.—In Canada, double filtration was put into use at Montreal in 1918. It was practiced intermittently until given up in 1935. Since that time single filtration, through mechanical filters, has been employed. Coagulation was never used at Montreal (18).

The almost complete absence of multiple filtration in the United States today and its complete absence in Canada is due to confidence in single filtration, generally of the mechanical type, supplemented, in nearly all cases, by disinfection with chlorine. The reliability of single filtration and chlorination is backed by public supervision of the hygienic qualities of public water supplies.

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