CHAPTER V

British Contributions to Filtration

England and Scotland divide the honors for pioneer work in filtration. The Lancashire filter appears to have been a crude forerunner of the slow sand filter. Its earliest development is uncertain but may have been before 1790. Two centuries before, the British patent office had started issuing patents on distillation, chiefly of salt water for use on shipboard. Not until 1790 was a patent relating to filtration granted, the first being one for the composition and manufacture of household filters of earthenware.

In 1791, James Peacock was granted the most remarkable filter patent issued in England (1). Two years later he published an expository pamphlet (2) which deserves a high and lasting place in the annals of filtration.

The first filter to supply water to a whole town was completed at Paisley, Scotland, in 1804, but the water it supplied was carted to consumers. At Glasgow, in 1807, filtered water was piped to consumers by one water company and immediately after by a rival. In 1810, the first of these companies built the earliest recorded filter gallery. Altogether the two companies built a half dozen filter plants within fifteen or twenty years; none of them was a success.

In 1827, slow sand filters designed by Robert Thom were put into use at Greenock, Scotland, and similar filters designed by James Simpson were completed at London in 1829. Both were slow sand filters. Thom's were cleaned by reverse-flow wash; Simpson's by surface scraping. The Simpson design became the model for English slow sand filters throughout the world, and it still is the model wherever that type of filter is continued in use.

Thom's filter design was followed in only a few places, most of them in Scotland; however, two of its main elements—false bottom and reverse-flow wash—were and are principal features of the rapid filter, developed in the United States during the 1880's. The rapid filter has largely supplanted the slow sand filter in most countries of the world.

British workers contributed little to filter design after the days of Simpson, but added much to the knowledge of the reduction of bacteria by slow sand filtration. They also demonstrated the importance of presedimentation, although they were slow to accept coagulation as an aid to sedimentation and rapid filtration.

The Lancashire Filter

References to the "Lancashire Filter" are numerous but vague in publications of the second quarter of the nineteenth century. Apparently the earliest of these filters were used for industrial water supplies, and some may have been installed before 1790. In the light of meager evidence that has been found they may be considered as primitive slow sand filters.

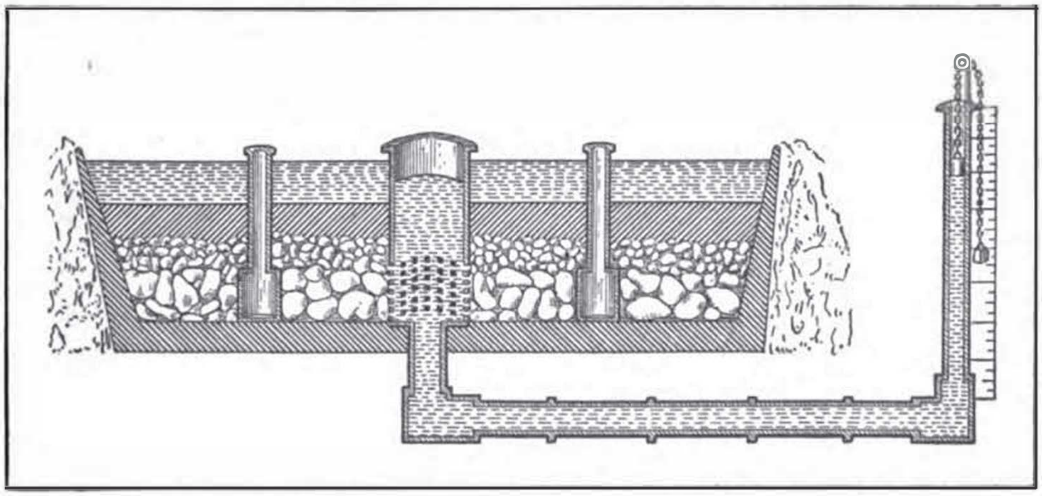


FIG. 14. CROSS SECTION OF LANCASHIRE FILTER
(From Thomas Graham's *Elements of Chemistry*, 1850 edition)

In the second edition of *Elements of Chemistry*, Thomas Graham (3) describes and illustrates a water filter, "as it is usually constructed for public works in Lancashire." It was placed in an excavation about 6 ft. deep, lined with well-puddled clay. On the bottom was a layer of large stones, while above this were smaller stones, then coarse sand and gravel. From the bottom layer of stones the filtrate found its way to a central iron cylinder, the lower part of which was perforated. Two air-vent pipes and a water-level gage were provided. The central collecting well and absence of underdrains suggest a primitive design.

Graham did not mention any of the municipal filters in Great Britain, some of which had been in use twenty years. But in both editions of his book (1842 and 1850) he describes large-scale filters as being composed of gravelly sand, for which there might be substituted

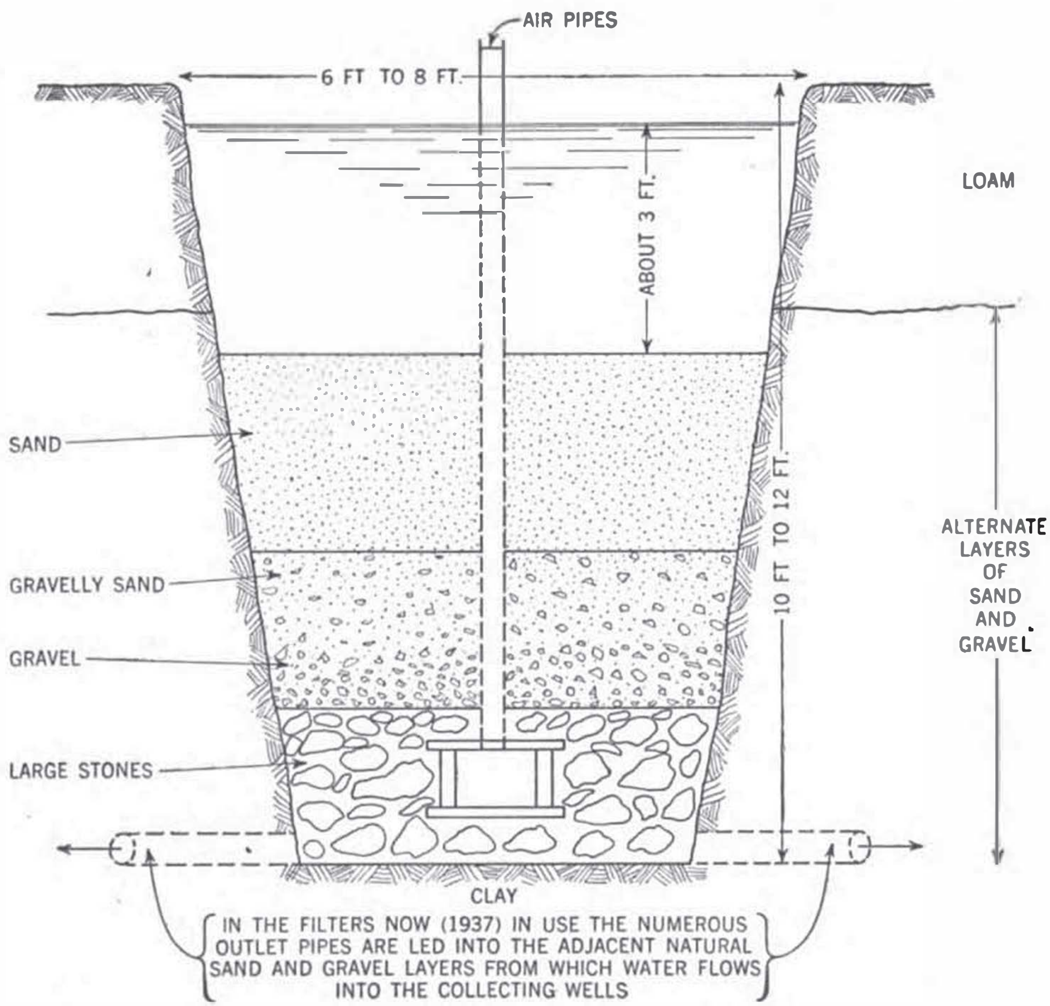


FIG. 15. OLD FILTER AT CLOSE BLEACHWORKS, RADCLIFFE, ENGLAND
James Simpson visited a filter at "calico works" near Manchester on his 2,000-mile inspection trip in 1827
(From sketch by W. F. Creber, Chief Engr., Manchester Corporation Waterworks)

crushed cinders or furnace clinkers. The function of any of these media, he said, was to support "finer particles of mud or precipitate where first deposited" on the surface, and "form the bed that really filters the water." When the sand became clogged, an inch or two of the surface was removed by scraping.

An appeal for information made in 1937 to W. F. H. Creber (4), then chief engineer of the city water works of Manchester, Lancashire, brought a hypothetical sketch of one of several very old filters at bleach works at Radcliffe near Manchester. These were 6 to 8 ft. wide, 50 to 150 ft. long and 10 to 12 ft. deep. On the natural clay base a collecting drain of brick or stone ran the length of the unit. This was surrounded by a layer of stone. Six air-vent pipes were provided for each unit. Turbid water was brought from the river to one end of each filter. The collecting drains led to circular brick pump wells. Although the earliest record of filters at the bleachery dates from 1878, Creber states that "there is little doubt that the filters have been in use for upwards of 150 years."

Johanna Hempel's Domestic Filter

The first evidence found of the manufacture of household filters in England is the grant of a British patent, on October 16, 1790, to Mrs. Johanna Hempel, a potter of Chelsea. The patent was for a composition of materials and for a means of manufacturing it into vessels "having the power of filtering water and other liquids in a more cheap, easy and convenient manner" than they could before be filtered. The principal materials were tobacco-pipe clay and sand in ratios varying with the size of the vessels. Mrs. Hempel is the only woman inventor and manufacturer of filters whose name has been found in the annals of filtration.

Peacock's Upward-Flow Filter With Reverse-Flow Wash

James Peacock, a London architect of note in his day, was granted the first British patent on a process and apparatus for water filtration (December 23, 1791, No. 1,844) (1). In 1793, Peacock published a promotion pamphlet (2) setting forth the need for filtration and the principles that should guide the choice, preparation and placing of filtering media, showing sketches of filters of different sizes and design. It includes a diagram showing superimposed spheres of diminishing size, illustrating a mathematical exposition of the reasons why coarse filtering material should be placed at the bottom of a filter with layers of material of regularly decreasing size above it. Peacock's exposition brings to mind the Wheeler filter bottom designed more than a cen-

XXXIII. ***Specification of the Patent granted to Mr.* JAMES PEACOCK, *of Finſbury-ſquare, in the Pariſh of St. Luke, in the County of Middleſex, Architect; for his Invention of a new Method for the Filtration of Water and other Fluids, which would be of great public and private Utility.***

Dated December 23, 1791.

TO all to whom theſe preſents ſhall come, &c. NOW KNOW YE, that in compliance with the ſaid proviſo, I the ſaid James Peacock do hereby declare, that the nature of my ſaid invention for filtration of water and other fluids, applicable to heads of water, of various magnitudes or extents, for public ſervice, reſervoirs, or ciſterns, for private uſe, and for other purpoſes of filtration, and in what manner the ſame is to be performed, is deſcribed as follows; that is to ſay: My method for the filtration of water and other fluids, is by impelling the aſcent of the fluid through the filtering medium, inſtead of the common method by deſcent.

* * * * * * *

The filters will be cleanſed, by drawing out the head or body of water or fluid; by which the water or fluid will deſcend in the filter, and carry with it all foul and extraneous ſubſtances. In witneſs whereof, &c.

FIG. 16. FIRST BRITISH WATER FILTER PATENT

Issued on December 23, 1791, to James Peacock; opening and closing paragraphs are shown

(From *Repertory of Arts* (London), pp. 221, 226 (1799)) tury afterwards (5). No such thesis had appeared before Peacock's day and none surpassing it has appeared since.*

Peacock opens his pamphlet by declaring: "The Poet's maxim, that 'God never made his works for man to mend,' if not generally false, is however pretty glaringly so, in many important particulars upon this atom of a universe." † Peacock continued:

> Among the various subjects evidently designed by Providence to ask amendment at the hands of men, there is one of immense importance, which has not yet received it in the degree it is capable of, and that is WATER.
>
> This element, necessarily of such universal use, and particularly in food and medicine, is suffered to remain laden with a great diversity of impurities, and is taken into the stomach, by the majority of mankind, without the least hesitation, not only in its fluid state, however turbid it may happen to be; but also in the forms of bread, pastry, soups, tea, medicines, and innumerable other particulars.
>
> Medical gentlemen can readily point out the probable advantages towards the preservation of health, and extending the period of human life, which would result from the use of soft water, cleared from the earthy, and the living, dead and putrid animal and vegetable substances, with which it is always, more or less, defiled and vitiated. (2)

Because of the "indelicacies of turbid soft water," many are "driven to the use of hard water, although they are not unapprized of the probable danger to their health, from its petrifying quality, or from the metallic, or other mineral, taints, too frequently suspended or concealed therein."

Peacock deprecates the use of natural "filtering stones," which may "contain copper, or other metallic, or mineral substances, dissoluble

* Through the kind aid of Sir William Paterson of the Paterson Engineering Co., London, a photostatic copy of Peacock's pamphlet has been supplied for use in this book by the British Museum (see Fig. 16). The only known copy of the pamphlet in the United States is in the Library of Congress. Extensive inquiries by the author failed to locate any other copies in the United States, England or Scotland, although appeals were made to many dealers in rare books.

† Like many other detached quotations this one has a different significance when considered in context. Dryden, whom Peacock did not name as the author, wrote:

> Better to hunt in field for health unbought
> Than fee a doctor for a nauseous draught
> The wise for cure on exercise depend;
> God never made his works for man to mend. (6)

The entire passage, applied to water supply today, would mean: search the fields and mountains for pure water rather than attempt purification of what is unfit; or in latter-day parlance, "innocence is better than repentance."

A

SHORT ACCOUNT

OF A

NEW METHOD

OF

FILTRATION BY ASCENT;

WITH

EXPLANATORY SKETCHES, UPON SIX PLATES;

BY JAMES PEACOCK,

OF FINSBURY-SQUARE, ARCHITECT;
Author of OIKIDIA; or NUTSHELLS, SUPERIOR POLITICS, &c.

Adde quod e parvis ac levibus est elementis
Nec facile est tali naturæ obsistere quicquam
Inter enim fugit ac penetrat per rara viarum.

LUCRETIUS.

LONDON:

PRINTED FOR THE AUTHOR;

AND

SOLD BY LACKINGTON AND Co. CHISWELL-STREET,

1793.

FIG. 17. TITLE PAGE OF PEACOCK'S PROMOTIONAL PAMPHLET
(From a photostat of the copy in the British Museum; obtained for use here by William Paterson, Paterson Engineering Co., London)

by water" and render the filtrate "somewhat suspicious." As to "artificial productions" made of clay in which combustible material has been placed to be burned out in firing, rendering "the mass porous," Peacock remarks that "the ingenious Mr. Wedgwood [the famous English potter] informed the writer hereof that he had caused some of this kind to be made, but that their effects were so trifling, and temporary, that he did not think proper to continue the manufacture of them."

Whether Peacock knew of Mrs. Hempel's patent of 1790 on earthenware filters is not apparent, but like all the capable promoters he disparaged the products of rivals, both stone and artificial filter vessels, as follows:

> Neither of these kinds of filters will afford clear water in any considerable quantity, and notwithstanding the repeated brushing and cleansing applied to the surfaces of their concavities, the pores, beyond the reach of the brush, will, sooner or later, clog up; and the stones become entirely useless. (2)

Having set forth the need for water treatment and the inadequacy of the filter stones and vessels then in use, Peacock remarks, with the confidence and benevolent spirit of the inventor-promoter:

> To supply, therefore, the inhabitants of this great metropolis and its environs with more than a sufficiency of perfectly clear soft water from the inexhaustible sources contained in the noble rivers in its vicinity, has been the writer's study for several years past. He has viewed the subject with much attention; and has made a very great variety of experiments, in order to arrive, as near as possible, to the simplicity and perfection of nature, in her process of percolation, by using the same medium and the same mode, taking away, by human art, her hurtful and disgusting redundances only; how far he has succeeded herein, the impartial public will best judge. (2)

Peacock's Design.—The novelty of Peacock's invention, he declared in his patent, was filtration by ascent instead of the common method of descent. This could be applied under any head, in any quantity and for public as well as private use. A further novelty, far more significant, was cleaning the filter by reverse flow, the descending water carrying with it "all foul and extraneous substances."

To put his innovation into effect, Peacock proposed either three tanks, or one tank with three compartments: one for turbid water, one for the filter and one for clear water. The filter was fed from the bottom of the raw-water vessel, which discharged into a small chamber beneath the filter, the latter being supported on a false bottom of slats with spaces between them, arranged to form a flat cone.

The raw water passed through the false bottom and up through the filter. The filtrate passed from the water space above the unit into a clear-water tank or chamber.

Filter media were sand, sandy gravel, and broken glass or other material which could be graded into various sizes. A material was prepared for use by repeated washings until the wash water ran clear, spreading it to dry, and then grading it into various sizes by means of a set of superimposed sieves actuated in unison until the remaining particles were as small as possible, after which, if necessary, trituration or pulverization was used. When washed and graded, the media

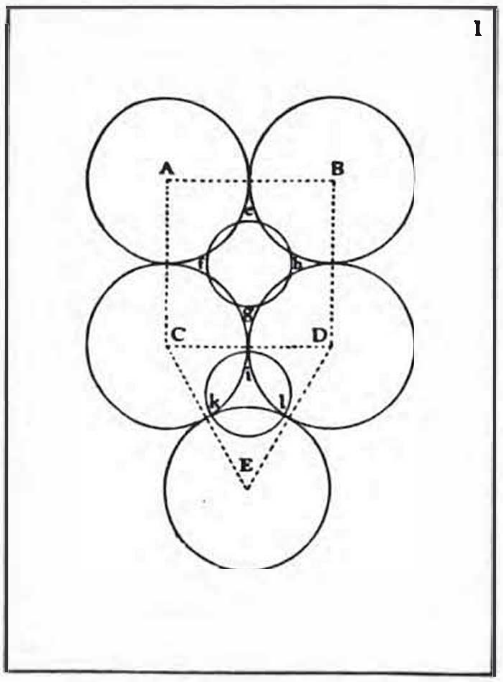


FIG. 18. PEACOCK'S DIAGRAM TO ILLUSTRATE REASONS FOR ARRANGING FILTER MEDIA IN LAYERS OF DECREASING SIZE

Superimposed spheres with diameters in each layer about double those in the layer below would increase interstitial spaces in geometric ratio: 1, 2, 4, 8, 16...

(From Peacock's promotional pamphlet (Fig. 17))

were put in place in layers of size in nearly "subduple ratio to each other," with the largest at the bottom. The finest or top layer served as "the main agent of percolation." While these filter media were being arranged, pure water was run through the strata to condense the particles.

An air-vent pipe was placed in the center of the filter unit, extending from the top of the false bottom to the level of the top of the sand. This pipe was filled with media arranged as in the filter except that the coarsest bottom layer and the finest top layer were omitted.

The theory of filtration by ascension was that gravity would cause some of the sediment to be deposited in the chamber beneath the false bottom and that the remainder would be intercepted by the increasingly fine material; also that reverse-flow wash would cleanse the filter and the settling chamber. To "counterbalance and resist any disturbance from the [upward] pressure of the column of turbid water," there was to be placed on and above the filtering material a second series of materials, arranged in reverse order, but omitting the finest material.

The raw-water vessel was kept full by a pipe-and-ball cock, discharging into a bag or strainer. The latter, particularly in summer, intercepted "innumerable green filaments" abounding in the waters of some streams, which "coalesce and form a tough mucus" giving rise to "disagreeable effects." Peacock said that this did not occur unless the water was exposed to the sun. Perhaps this is the earliest statement of the kind recorded.

Four designs for filters were illustrated in Peacock's pamphlet. The first made use of three cylindrical glass containers side by side, and was apparently for household use. The second one showed a single cylindrical tank, divided by curved vertical partitions into three compartments. The third design, for "sea, camp or garrison service," showed three wooden casks, with wooden slats for the false bottom of the filter and a wooden grating at the top to compress the filter medium and hold it in place in land transit or on shipboard. The fourth design was intended to serve filtered water to a community of any size, at a small annual charge. In such a water works, three masonry-lined wells would be made in the ground at any convenient distance from a pond, ditch or river. If the body of water were large enough, two wells would give a constant supply, one for the filter, the other for the filtrate. The drawing showed a building with open sides above the three-well purification plant.

Peacock's Influence.—Of the many published comments on Peacock's filter, from 1795 to 1929, the first was the only one containing an adverse judgment (7). It was, however, the philosophy expressed in the pamphlet that was criticized and not the filter itself, which was called ingenious. Partly in defense of unfiltered water the reviewer said:

> The petrifying quality of hard water no philosopher, we believe, now regards as connected with the origin of nephritic complaints. That the ordinary qualities of sweet and soft water are prejudicial to health has never, so far as we know, been demonstrated, nor rendered probable: . . . We shall

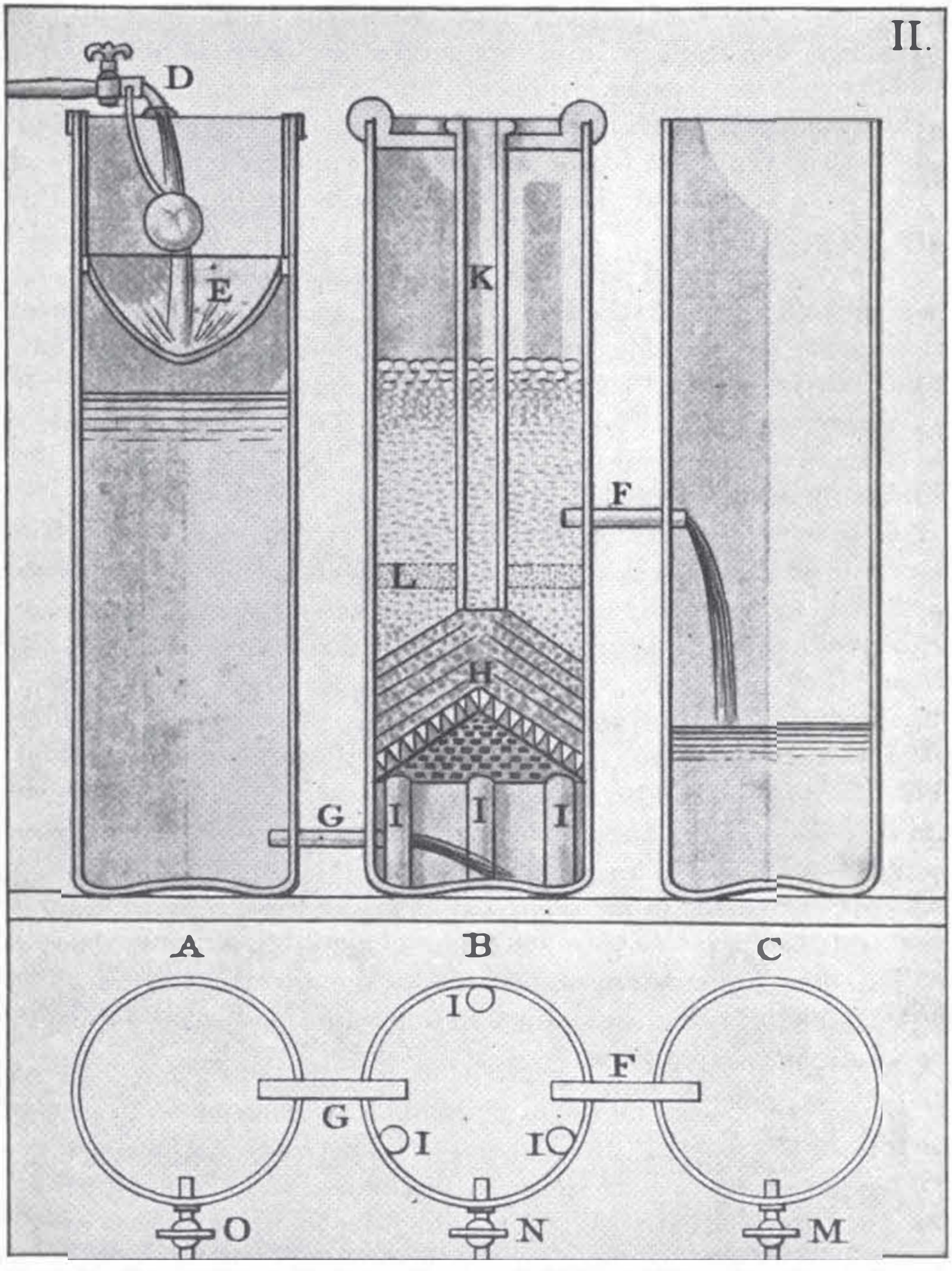


FIG. 19. THREE-TANK FORM OF PEACOCK'S UPWARD-FLOW BACKWASH FILTER
A—Raw-water tank with float valve and strainer; *B*—Filter, with media supported on inverted conical bottom composed of slats with spaces between; *C*—Clear-water tank
(From Peacock's promotional pamphlet (Fig. 17))

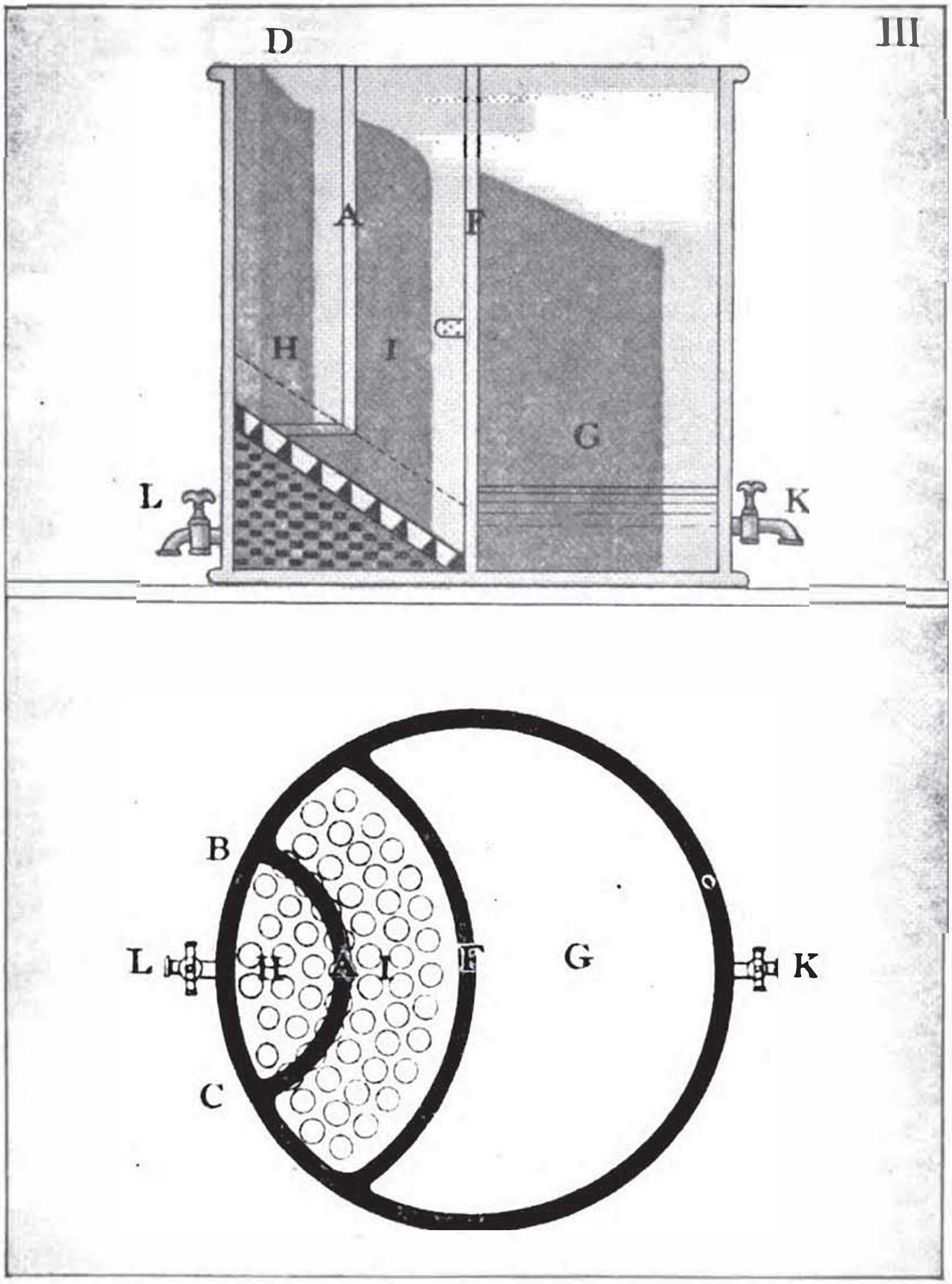


FIG. 20. SINGLE-TANK FORM OF PEACOCK'S UPWARD-FLOW BACKWASH FILTER
The same three elements as are shown in Fig. 19, combined into a single tank unit
(From Peacock's promotional pamphlet (Fig. 17))

not deny that Mr. Peacock's process is highly desirable in point of delicacy; and on this score we wish him success, because he appears to deserve it; but we need not at any time apologize for exposing what we take to be mistakes or gratuitous suppositions; in the present case, we consider it humane to prevent, as far as our influence extends, a false alarm on account of their health from spreading amongst the drinkers of unfiltered water.

Referring to the filter's deficiencies, the critic said:

Now, by this contrivance, such matters only as are diffused through the water, and not such as it holds dissolved, would be separated and left behind. Mr. Peacock tried this with brine, and found the salt still remaining in the water, as any smatterer in chemistry would have predicted. [And as to Peacock's statement, in answer to an inquirer, that he had not yet found whether his filter would "sweeten putrid water," the reviewer declared that Peacock] might have answered in the negative, for he seems not to have heard of the purifying quality of charcoal; of which, we apprehend, he might take advantage.* We rather wonder that Mr. Peacock did not think of submitting his manuscript to the inspection of some person acquainted with recent philosophical discoveries. [The reviewer, for instance?—*M.N.B.*] A very little of this kind of knowledge might have freed it from the unauthorized assertions which it contains. (7)

The only evidence that Peacock's filter was ever put into use appears in a French article of June, 1804 (8), which stated that the Peacock filter had been tried three years before by order of Admiral Parker, on board the *Vengeance, Magnificent* and *Lancaster*. On these ships, according to reports of their captains, the filters yielded 2,880 *pintes* of water in 24 hours.†

The French article describes Peacock's filter as a box filled with washed gravel or sand. A plate shows the filter as a cube-shaped box, tilted on edge, with raw water entering at the bottom and filtered water drawn from the top. An air vent and a force-and-suction pump were provided, the latter for use in washing the filter by reverse-flow.

* When Peacock published his pamphlet in 1793 he may not have heard of Lowitz's paper of 1790 on the use of charcoal to sweeten putrid water (see Chap. III). Subsequently he appears to have used charcoal in the filters installed on naval vessels, mentioned below. It was in the days of sailing ships that "putrid" water was most troublesome. Lowitz demonstrated the value of powdered charcoal added to "stinking" water rather than the use of charcoal in filters. But the passage of years showed that sand and gravel were the best filtering media, thus justifying Peacock's earliest conceptions.

† The old French *pinte* seems to have been about equal to an English quart or 0.3 U.S. gal. On that basis the yield of the filters (on each ship?) would be about 860 U.S. gal. a day.

In special cases, the filter might contain a mixture of powdered wood charcoal and limestone to disinfect the water.

Peacock lived until 1814. He had a hand in designing many buildings, some of which were important and may well have been equipped with his filters at a time when London and vicinity were being supplied with turbid and filthy water from the Thames.

Potentially, Peacock's contribution to the art of filtration was great; but there is no way of learning how many of his successors in the field profited by his patent and pamphlet. His filter cleaning by reverse-flow was one of the basic elements of the later mechanical filter. Upward filtration was a delusion and a snare that caught the fancy of many, including some engineers, during the ensuing century. The false bottom and air vent were old. Sand had been used for centuries; but Peacock's specific directions for preparing sand for use and placing it in graded layers containing particles of decreasing size were both new and thorough.

The First Filtration Plant for City-wide Supply

The quest for pure water entered a new phase when John Gibb decided to supply filtered water to his bleachery at Paisley, Scotland, and cart it to "almost every door" in town. His is the first known filter for city-wide supply installed anywhere in the world. It was probably put into use in midsummer of 1804.

Famous for its shawls and threads, Paisley was early in the field with cotton mills, bleacheries and other industries. As was the case in other manufacturing towns of Britain and America, the industries at Paisley quickly monopolized and shamelessly polluted all sources of water supply within the town.

A contemporary description of the Paisley filters, written by the Rev. Robert Boog, first minister of the Abbey Church in Paisley, is found in Sir John Sinclair's *Code of Health and Longevity* (9). It was published in 1807 to show how the inhabitants of a town of 20,000, "who were formerly in a distressed state from the unwholesomeness of the water, are now plentifully supplied with that valuable article in great perfection."

The idea of supplying filtered water to Paisley, wrote Boog, occurred to a bleacher as an accessory to plans for improving his bleaching grounds. These grounds lay along the River Cart, a little above Paisley. The water of that stream was often muddy. It brought down wastes from print fields and from lime, copperas and alum works and so it was unfit for bleaching. This suggested filtration to the bleacher, "an operation," wrote Boog, "not uncommon but perhaps nowhere so carefully executed as here." If filtration were not uncommon, what a pity, it may be interjected, that Boog did not give the location and nature of the other filters he had in mind!

Transformation of the muddy, industrial waste-laden water of the Cart was effected by a roughing filter, sedimentation and subsequent double filtration. The flow was lateral throughout. The final filtrate occupied a central circular well, surrounded concentrically by the main filters and the settling chamber—an arrangement used more than a century later in the so-called Morse filter at Burnt Mills, Md., and elsewhere. Robert Morse used steel; Gibb used masonry.

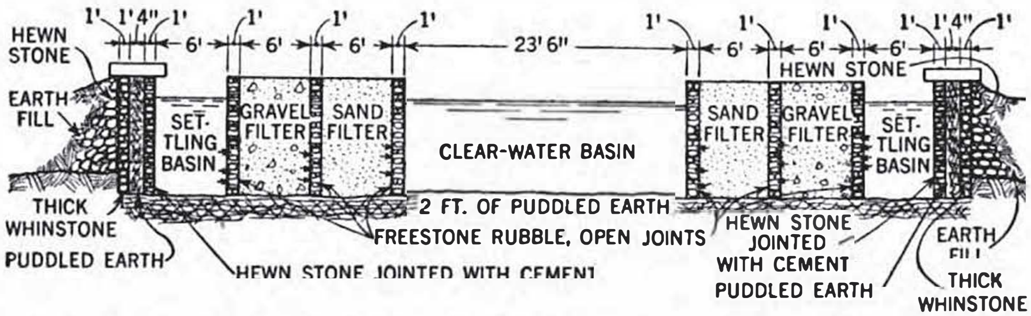


FIG. 21. FIRST KNOWN FILTER TO SUPPLY AN ENTIRE CITY WITH WATER, COMPLETED AT PAISLEY, SCOTLAND, IN 1804, BY JOHN GIBB

Water passed through stone-filled trench to ring-shaped settling chamber, then through two lateral-flow filters to central clear-water chamber; delivered to tank on a hillside from which it was carted to consumers

(From description in Sinclair's *Code of Health and Longevity*, London, 1807)

Water from the River Cart flowed to a pump well through a roughing filter about 75 ft. long, composed of "chipped" freestone, of smaller size near the well than at the upper end. This stone was placed in a trench about 8 ft. wide and 4 ft. deep, covered with "Russian matts" over which the ground was leveled.

A small steam engine placed over the well lifted the water to an "air-chest" about 16 ft. higher than the river, from which it was forced to the settling chamber through about 200 ft. of 3-in. bore wooden pipe of Scots fir. The settling basin, main filters and clear-water basin were formed by concentric masonry walls carried up 10 ft. above a puddled-earth bottom, the top of the latter being 2 ft. above the original ground surface.

The ring-shaped settling basin and the two filters nested within it were each 6 ft. wide. The outer filter was composed of coarse gravel, the inner of very fine gravel or sand. The depth of the sand is not given. The clear-water basin was 23.5 ft. in diameter. The outside wall of the settling basin was double, filled with 16 in. of puddled earth, with a coping stone over the whole. All the other walls were of open-jointed masonry, each about 1 ft. thick. Water passed laterally through the joints in the walls and through the filters into the clear-water chamber. All the stone in the roughing filters and in the walls that were in contact with the water was carefully chosen from "quarries perfectly free from any metallic tinge"—this may have been chiefly for the benefit of the bleachery.

From the clear-water basin a pipe extended about an eighth of a mile to a declivity where the filtered water could be discharged into a cask holding about 480 wine gallons. Such casks were placed on carts and two carts so loaded went seven times a day through the town—thus delivering about 6,700 gal. a day. The water was sold at first for a halfpenny (1 cent) a gallon. Later, to meet the cost, the price was increased to three farthings (1.5 cents), "but if any considerable quantity is bought," wrote Boog, "some gallons are allowed in addition." Commenting on the cost and value of the service, Boog said: "This is some addition to the family expenses; but, for pure water, all who value health will willingly pay at this rate; and, as it is brought to almost every door, to those who are at a distance from wells or river, there is considerable saving of time and labour. This plan is susceptible of improvements; but it is sufficient to demonstrate, that no town near a river, need be destitute of good water" (9).

The air-chest, wrote Boog, "is a contrivance employed for extinguishing fire. The water is driven into a receptacle, by a forcing pump, and its return prevented by a valve opening inward. A pipe is inserted into the top or side of the chest with its mouth near the bottom. The compressed air acting on the surface of the water forces it through the pipes" (9). Thus did the Paisley bleacher anticipate the apparatus widely used decades later to supply isolated buildings with water under pressure.

Boog described the Paisley filters as in use but did not say when they were put into operation nor give the name of their builder. The missing information was found in the Boulton & Watt collection preserved in the Reference Library of the city of Birmingham, England. A search made under the direction of H. M. Cashmore, City Librarian, disclosed letters showing that John Gibb, of Paisley, ordered an engine from Boulton & Watt early in 1803; and that in May, 1804, the engine "with some appendages of pumps [was] nearly done" and that settlement of the balance due on account would be made in a few days. This correspondence does not mention filters, but in a letter dated January 23, 1810, written by Boulton & Watt to the Glasgow Water Works Co., specific mention is made of "filters erected by Mr. Gibb at Paisley," which completely purified the muddy water of the River Cart (10).

How long water from Gibb's filters was carted to consumers is unknown. In 1838 a water company began to pipe water through the streets of Paisley from a reverse-flow-wash sand filter designed by Robert Thom (see below). A recent letter from James Lee, Water Engineer of Paisley (11), leads to the conclusion that the Gibb filters, with later duplications, continued to supply bleach works at least until 1861. An ordnance map of that date shows three groups of concentric circles, designated "filtering tanks," close by the "Linside Bleach Works," near the River Cart. The outside diameters of these circles, Lee says, were approximately 65, 50 and 40 ft.

Thirteen Decades of Filtration at Glasgow

Glasgow, Scotland, was the third city in the world to have a filtered water supply. Unlike its predecessors, Paisley and Paris, where filtered water was carted to consumers, Glasgow was supplied by pipes. At Glasgow, two rival companies began to introduce water from the Clyde, the Glasgow Water Works Co. in 1807 and the Cranston Hill Water Works Co. in 1808. The earliest filters of the first company were failures. They were immediately followed by others, but these were likewise unsuccessful and were supplemented by filter galleries. The Cranston Hill company, after various misfortunes, also built a filter gallery. Subsequently the second company was absorbed by the first. The galleries and at least some of the filters built by the two original companies continued in use until the city introduced a gravity supply from Loch Katrine, in 1859. Just before that, the city had acquired the property of the consolidated water company, and had also bought the property of the Gorbals Gravitation Water Co., which had completed works in 1848 to supply a suburb afterwards annexed to the city. This third company had unique filters which were remodeled by the city and were still in use in 1936 (12). Thus, for thirteen decades Glasgow has had filtered water piped to consumers—a record unparalleled.

The Glasgow Water Works Company

Thomas Telford, who later founded and served as first president of the Institution of Civil Engineers, was engineer for the Glasgow Water Works Co. Correspondence between him and Boulton & Watt (13) affords meager data regarding his plans for the earliest filter at Glasgow. In a letter dated May 25, 1806, he said that "if there is any difficulty in getting the water [from the Clyde] to subside or filtrate so as to be perfectly good—then instead of one reservoir 6 ft. in depth, it will be advisable to have two of 3 ft. in depth each—and each one acre in superficial area."

About forty years after the works were completed, Donald Mackain, engineer of the company then supplying water to Glasgow (14), described how Telford proposed that water be pumped from the Clyde at a point two miles above the city to three reservoirs each holding a day's supply. These reservoirs were to be so placed, wrote Telford, in a report no longer available, "that the water in passing from one to another shall be filtrated." Telford's plan was followed, says Mackain, but in times of flood the river brought down alluvial matter that did not soon subside, followed by water from sources higher up which had a deep brown color. Telford's filter yielded water differing little from that of the river.

Again what a pity that Telford and Mackain made only vague references to filters built so early. Neither Telford in his autobiography (15) nor Sir Alexander Gibb in his recent biography of Telford (16) mentions Telford's filters at Glasgow.

James Simpson, in a discussion (17) of Mackain's paper, describes Telford's filters as "a series of cells, filled with sand" through which the water passed in succession. When the water was at its worst it was little changed after passing through the first filter, but at times the filters worked satisfactorily.

More specific data are given by C.-F. Mallet (18) who, as chief engineer of a projected water supply for Paris, visited Glasgow in 1824. He reports that, years before, an attempt had been made "to unite sedimentation and filtration." Three ponds were built, each 120 x 30 m.

FIG. 22. THOMAS TELFORD (1757–1834)
Engineer for Glasgow Water Works Co. and designer of its first filters, 1807
(From a painting by Henry Raeburn, R.A., 1812, reproduced in Sir Alexander Gibb's *The Story of Telford*, London, 1935)

and 1.5 m. deep (394 x 98 x 4.9 ft.), on levels 1.5 m. apart. The ponds were "separated by filters in which the water circulated alternately before reaching the last reservoir; but the wind agitating the water, the sedimentation upon which they had counted" was imperfect, "and the water left the sand without having experienced a notable change from its original condition."

Dr. Ure's Unsuccessful Filters.—Immediately after the failure of Telford's settling reservoirs and filter cells the Glasgow Water Works Co. offered premiums for filter plans. Amazingly, 22 plans were submitted. The highest premium was awarded to Dr. Andrew Ure, then a lecturer at Glasgow University. Filters were built under Ure's direction, says Mackain (14). For a short time and under favorable conditions these filters "yielded a sufficient supply of pure water; but they were too small . . . became clogged with silt deposited by flood waters," and so water had to be taken directly from the river, regardless of its condition.

Doubtless this was the first filter-plan competition ever held. No description of the plans can be found. Dr. Ure does not mention even his own plan in any of the books he wrote subsequently. Apparently he, like Telford, felt that the less said about his unsuccessful filters the better.

Alterations in both the Ure and Telford filters, says Mackain (14), were "unavailing." The market price of the stock of the company fell owing to the character of its water and "other causes." A change in the source of supply was imperative. Chief among the "other causes" was the competition of the Cranston Hill company, whose filtered water seems to have been in high favor when introduced in 1808.

Pioneer Filter Gallery in 1810.—To meet these conditions the Glasgow company decided to go across the Clyde to a peninsula of sand and gravel which it believed would yield "a large quantity of water, either filtered through the sand bed from the river or from natural springs which might be obtained by sinking wells and connecting them by tunnels or culverts." Tests for yield being successful, "tunneling was commenced in 1809" (14). Contrary to tradition, James Watt did not propose the filter gallery nor design the flexible-jointed pipe laid beneath the Clyde from the filter gallery to the existing pumping station. He may have suggested the basic idea for the flexible joint, which was said to have been like the joint of a lobster. When Boulton & Watt sent the design for the submerged pipe on January 23 1810, they disclaimed approval of the filter gallery, and suggested building a third set of filters (10). The submerged pipeline, following the Boulton & Watt drawing, appears to have been put into use in midsummer of 1810, and with it the filter gallery. Each was the first of its kind.

The yield of the filter gallery, says Mackain (14), "was pure as to its origin and pure to the eye," and became almost exclusively used by the inhabitants—to the distress of the rival Cranston Hill company.

Cranston Hill Water Works Company

A calico printer named Richard Gillespie, having a "printfield" in the neighborhood of Cranston Hill, Glasgow, was the founder of the Cranston Hill Water Works Co. Like the Paisley bleacher, he wanted to supply his works, and at the same time serve private consumers with water pumped from the Clyde, below Glasgow, to a reservoir on Cranston Hill. Robertson Buchanan, author of *Mill Work,* became engineer of the company. The "prudence" of drawing water "below the drainage of the city" having been questioned, says Mackain (14), Thomas Simpson, Chief Engineer of the Chelsea Water Works Co., London, was consulted. Simpson reported that the supply of the London Bridge Water Works Co. was preferred to that of the other companies taking water from the Thames, "being by the filth" it received "materially improved." Strange doctrine! But the London companies were already on the defensive and were soon to be attacked for supplying grossly polluted water.

Although the Glasgow "doubters were silenced," Scotch skepticism led the company to install a settling basin of several days' capacity to remove the grosser particles of sediment and a filter to remove the finer. The filter was composed of several feet of sand and gravel with "tunnels" below, leading to a pure-water basin. "This being the first experience of artificial filtration on a large scale," wrote Mackain, many trials were made to determine the requisite depth of sand and also the yield of the filter under different circumstances. This suggests that the filter was built before the Telford filter cells were put into operation.

Charles Dupin, a French naval officer, wrote two descriptions of the Cranston Hill filter, apparently as seen by him during two visits to Glasgow (19, 20). Between these visits the filter seems to have been changed from upward- to downward-flow operation. Both descriptions indicate a ridge-and-valley surface. In the first, settled water discharged into pits or wells in the ridges, flowed into many conduits beneath the valleys, rose through open joints in the conduits, passed up through the stone or gravel and sand of the filter into the valley and flowed thence to the pure-water basin (19). The second description says that water from the settling reservoir was discharged through four iron pipes into four long channels in the filters. About 4 ft. beneath the bottoms of these channels was a layer of paving stone rising toward the center of the channel. Beneath the ridges were small open-jointed masonry drains. Both the drains and the pavements were covered with small pebbles, above which was sand (20). The channels were 14 ft. wide on top and 10 ft. apart. Whether or not Dupin's first description applied to the filter as completed in 1808 he does not say.

The Cranston Hill company began supplying filtered water in 1808, just at the time the Telford filter cells of the Glasgow company had proved themselves to be a failure. Immediately afterwards, the second or Ure filter of the Glasgow company met a like fate. The market value of its stock went down. The Cranston Hill company, elated by the favorable reception given to the product of its filter, put a premium on its shares in 1809. The elation was short-lived. In 1810, the Glasgow company completed its filter gallery and the market price of its shares went up. Contrariwise, the Cranston Hill company, however satisfactorily its filter seemed to work, was confronted with more and more objections to "water previously contaminated with drainage." Its revenue fell below expenditure. The use of its old intake and apparently of its filter on Cranston Hill was continued, but its consumers were chiefly industrial (14).

Cranston Hill's Unsuccessful Filter Gallery.—After some years the directors of the Cranston Hill company decided to build a filter gallery up the river near the one built by its rival ten years before. To their amazement, when this gallery was put into service in 1820, instead of yielding "brilliant" water, like that from the near-by gallery of its rival, the water was so heavily charged with iron that it was unpleasant to domestic consumers and unfit for manufacturing calico. This is the first instance found in the literature of trouble arising from iron in ground water.

William Mylne, Engineer of the New River Water Co., London, was called to Glasgow. He assumed that the trouble came from the water mains instead of the water, and spent many days, says Mackain (14), in an effort "to ascertain how the currents flowed in the pipe" but not until he got back to London was his attention "directed to the real seat of the trouble." He then furnished plans for a filter which Mackain does not describe. Instead of following Mylne's plans, however, the company started a tunnel between the filter gallery and the river on the assumption that the iron-impregnated water could be excluded from the gallery by back pressure.

Second Filter of Cranston Company.—Although this device promised to be a success, the company decided to follow the advice of its manager, a Glasgow architect named Weir. His plan was to build a filter near the unsuccessful filter gallery, similar, wrote Mackain, to the one that had done so well on Cranston Hill, except that the water, instead of being pumped to the filter, would flow from the river "into the hollows between the tunnels"—meaning underdrains.

Mallet, who saw the filter soon after it was completed, says that on the bottom of an excavation, 20-in. cylindrical "galleries" were built of wedge-shaped brick, laid dry. The galleries were 23 ft. apart. A layer of sand was placed on the bottom of the excavation and extended over the underdrains. Thirteen valleys were thus created, making a unit some 300 ft. across. Each underdrain discharged into a main drain of stone, laid dry, leading to a pump well. To clean the sand, wrote Mallet (18), "a very ingenious method was used." A cast-iron pipe was laid above the main drain, and from this pipe "branches descended to the bottom of the valleys, which were paved and on a level with the galleries." To clean the filter, wooden stoppers in the ends of the branch pipes "were removed, the pump started, and the water passed along each valley in a direction contrary to that employed when the filter was in use, thus carrying away the sediment that had been deposited." But "the water, charged with this sediment, quickly put the pump out of order; . . . it was longer out of repair than in use; they had to give up this means; the consumers diminished and the Cranston Hill company was placed in a difficult position." This implies that a pump was used to remove the wash water.

A different explanation of the failure of this filter is given by Mackain (14). Under some conditions, he says, the filter improved the quality of the water but whenever the river was swollen above mean summer level, iron-bearing water from the substratum rose into the underdrains.

When Mackain became chief engineer of the Cranston Hill company in 1829, he made alterations in the works which, he says, led to an increased demand for water (14). These changes he does not describe. Mallet, in his report of 1830 (18), says that Mackain sent him a plan of his scheme, probably executed meanwhile. The plan was to build a number of wells placed checkerboard-wise and connected by pipes. The wells were 10 ft. in diameter, 6½ ft. high, of brick laid dry and covered with plank. Matthews, in his book of 1835 (21), mentions that raw water was delivered to the wells, passed up through a thick stratum of sand and flowed to a reservoir. There is no direct evidence bearing on the success of this filter. According to Mackain, soon after he made the changes described, the two companies had a rate competition but in 1833 stopped it. In 1838, the Cranston Hill company was absorbed by the Glasgow company (14).

The Consolidated Company.—Under Mackain as engineer of the consolidated company, says J. M. Gale (22), "filters upon the Lancashire principle were constructed at both works." What that principle was, Gale, like many other writers of the period, did not think it necessary to say (see Lancashire Filter, above).

When Glasgow took over the works of the consolidated companies just before it introduced a gravity supply from Loch Katrine, maps were drawn showing the old river works of each company, as of October 26, 1856. Copies of these maps, supplied for consideration here by John Cochrane, Engineer and Manager of the present Glasgow Water Works, show a maze of river intakes, pipes, filter galleries, settling basins, filters, clear-water reservoirs, drains and pumping stations crowded into a small space. At the site of the works of the Glasgow company there were two acres and at the Cranston Hill river works 1.6 acres of typical slow sand filters.

The Gorbals Gravitation Water Company

Three-stage upward-flow filters were built in 1846–48 by the Gorbals Gravitation Water Co., a part of works to supply water to a suburb that was soon annexed to Glasgow. Multiple filters were not new but William Gale, Engineer of the Gorbals Co. (22), made an innovation in their construction. Instead of superimposing different sizes of filtering material in one bed, as had Peacock in 1791, Thom in 1827 and Simpson in 1829, he put each in a separate unit: the coarsest material was in the first, which had the greatest depth; the medium grade was in the second, which had a larger area and a lesser depth than the first; and the finest grade was in the third, which had a still larger area but lesser depth than the second. Each unit had a false bottom of perforated flat tile, supported by brick on edge, as in Thom's filters, described below. Water was cascaded from a reservoir to the first filter, then from one to another unit and finally to a clear-water basin. Each of the first three cascades had a fall of 9 in.; the fall of the fourth was 12 in. The depth of water on each filter was only 4 in.

A Glasgow bleacher named Stirrat, testifying before a committee in 1850 (23), said that the third or sand filter worked for six to eight weeks before removal and washing of the sand was required. Plans and a description supplied to the committee by William Gale (24) at the same time, show that there were two sets of these filters, each narrow, placed end to end except for a channel between them to carry off the dirty wash water. Six years later, Darcy (25) wrote that these filters were washed by upward flow but that once a month a layer of sand about 1 cm. or 0.4 in. deep was removed.

William Gale anticipated, in his general design, the filters built by Walker in 1890 at Reading, England, by Armand Puech a little later at Paris, and by Puech and Chabal throughout France (see Chap. IX).

After the Gorbals works were bought by Glasgow, in 1856, Mackain made over the filters "upon the Lancashire principle," says James M. Gale (22). According to a description of the Gorbals filters as they stood in the early 1870's, they consisted of sand, then perforated tile 1½ in. thick, resting on gravel and stone (26). That is, the tile had been moved up between the gravel and sand. This arrangement was adhered to in a design for an additional filter made in 1881, in which the sand was supported by 3-in. fire-clay slabs resting on a checkerboard arrangement of brick underdrains. The efficiency of this remodeled type of filter, wrote Cochrane in 1936 (12), is shown by its continued use on all additions to the Gorbals filters, including those then under construction.

Filtration Proposals—1783–1825

Tantalizing in their vagueness are several early references to proposed filters. Data of great historical value might have been recorded then had its future importance been recognized.

At Glasgow, in 1783, David Young proposed construction to obtain a filtered water supply from the Forth and Clyde Canal. The volume must have been small, for the estimated cost of "a house at the canal, with a reservoir and filtering apparatus" was only £150. In 1804, a little before the two water companies built the first of the filters there, a supply from the Clyde, which was to be filtered, was proposed (27).

At London, also in 1804, Ralph Dodd, a British civil engineer of enough importance to be included in the *Dictionary of National Biography,* made reports to subscribers to projected London water companies, in which filtration was proposed as if it were too well known to need description. For projected works to supply South London he planned to draw water from that part of the Thames undisturbed by shipping and "throw" it into a reservoir by "tidal flow" for its "perfect purification." Here the water would be "sufficiently settled and clarified" for delivery to consumers. In a later report (November 2, 1804) to "subscribers to the intended East London Water Works Co.," he mentioned filtration, but did not say by what means. In this project, also, he proposed to divert water to large reservoirs at high tide. From these it would flow to lower reservoirs from which, after "settling and filtering," it would be forced to a summit reservoir for delivery to consumers (28).

At Manchester, a citizens' committee reported, on February 2, 1809, in favor of a filtered water supply from either the Irwell or the Tame (29). The former could be filtered through "beds of gravel and sand, either natural or artificial, at small expense." The better plan, it was suggested, would be to store flood water of the River Tame in reservoirs made in land of little value and convey it through the Ashton Canal to a reservoir near Manchester, "where it may be filtered and rendered pure." It would then be delivered into the highest apartments of any house in Manchester. Apparently the committee did not state the nature or estimate the cost of filters or give data on the adequacy of filtration. The committee was against a water supply proposed by "private adventurers," both because it believed in public ownership and because the proposed company intended to take water from a source that would cut off many springs and feeders which then supplied large printing, bleaching and dye works, and afforded condensing water for the steam engines of numerous cotton mills and other works. The committee's report was approved by a public meeting of February 2, 1809, but the town did not build water works. Instead, a company began supplying unfiltered water in 1809.

Many references to Lancashire filters in various later writings, and the fact that the Manchester water committee took it for granted that readers of its report needed no description of the filters it had in mind, suggest that filters were already in use at industrial works in the Manchester district in 1809 (see Lancashire Filters, above).

At Edinburgh, in 1811, Dr. Thomas C. Hope dismissed construction of "a proper filtering bed of sand" as too costly under local conditions and proposed settling reservoirs instead. Much of the imperfection in the water delivered to the city, the report stated, came from muddiness in two large ponds, following heavy rain or snow or high winds. Part of the yield of these ponds came from springs. Dr. Hope suggested that when the water of the ponds was muddy, the flow of springs into them should be diverted through earthen pipes into the conduit leading to the city; also that two settling reservoirs, each with a capacity equaling the water consumption of 48 hr., be constructed for use alternately. Formerly, said Dr. Hope, "Edinburgh was celebrated for the excellent quality of the water; but of late, it had become in an equal degree conspicuous for the badness of it" (30).

A reference to filtration which might fruitfully have gone into more detail, but one which is highly significant for what it does say, appeared in an article published in 1825 (31). The article is all the more interesting because it was printed in a Glasgow magazine conducted by a committee of civil engineers and practical mechanics. In that city both upward- and downward-flow filters had been used, while at near-by Paisley lateral-flow filters had been constructed twenty years earlier. None of these filters was specifically mentioned.

The object of the article was to advocate "A New Mode of Forming Artificial Filters" that would avoid the failure of earlier types. Ignoring the fact that a filter had been put into use at Paisley in 1804, the article noted that the inhabitants of that town were then much interested in finding the best mode of filtering the water from the River Cart. After showing a predilection for filter galleries, the article said that if Paisley could not get a "natural filter," great care should be taken in "forming an artificial one," since both Glasgow and Cranston Hill companies had wasted labor and expense in such undertakings.

Asserting that "we have seen not a few artificial filters," the article declared that "no matter how apparently well planned such filters had been, after a short time all [became] equally useless; got dirty and choked, and ceased to purify water as they once did. . . ." In view of this, the article urged that where natural filtration is not possible artificial filters should be built in the bed and bank of a river where they would be kept clean by water flowing over them.

The general plan of filter construction was to build large and expensive tanks through which the water flowed laterally, with no means of cleaning them provided or even possible. The editors were aware that many downward-flow filters had been built. They condemned alike downward-, upward- and lateral-flow filters that they had seen, and all of which, they declared, could be cleaned only by "emptying the filter entirely and removing the impurities which it had gathered." They said that downward-flow was correct, but the filter should be kept clean by the constant natural flow of a stream across the surface of the sand (31).

This discussion is the first critical review of filters for city water supply that has been found. It points out that the main cause of failure in filters was lack of means for cleaning them in place. It rightly asserts that both lateral- and upward-flow filters were wrong and downward-flow right in principle. But the method of cleaning suggested, natural lateral surface wash, was wrong. What these early editors failed to foresee was that the proper method for cleaning a filter was either by reverse-flow wash of the material in place or else scraping off, removing, washing and replacing the top layer of the sand. The time was coming when Robert Thom was to put into large-scale use the first of these methods, patented by Peacock in 1791; and when Simpson was to adopt the second method.

Thom's and Simpson's Filters

In the late 1820's, Robert Thom in Scotland and James Simpson in England blazed the trail for mechanical and for slow sand filtration. Thom's first municipal filter was put in use at Greenock late in 1827; Simpson's at London early in 1829. Each profited in his own way from past failures. Each based his design upon small-scale experiments.

Thom, with knowledge of several filters at and near Glasgow, concluded that their complete or partial failure was due to surface clogging, difficult, uncertain and costly to prevent, and so he devised a self-cleaning filter, washed by reverse-flow.

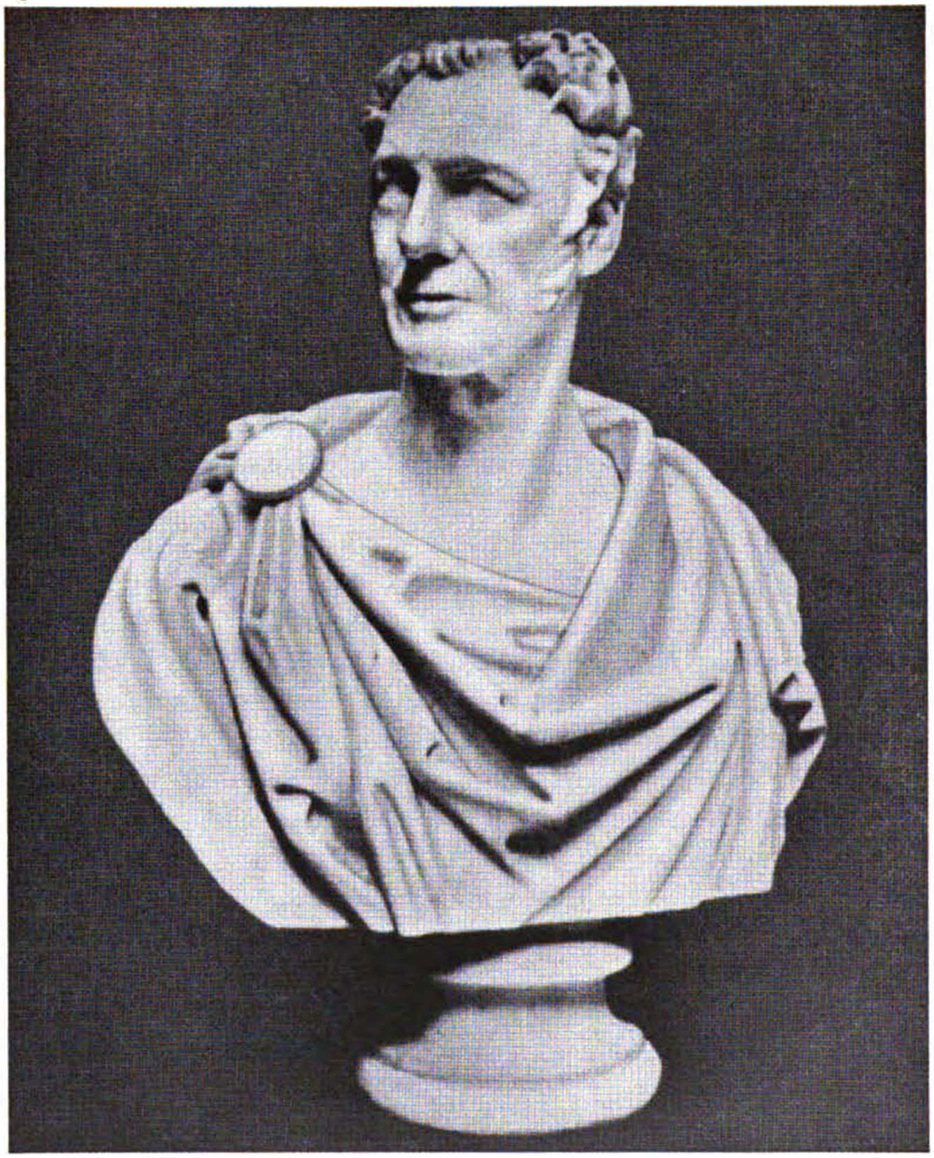


Fig. 23. Robert Thom (1774–1847)
Engineer from Ascog, Scotland; designer of reverse-flow-wash filters for Greenock (1827) and Paisley (1838), Scotland
(From *Centenary of Shaws Water Company's Works, Greenock, Scotland, 1827–1927*)

Simpson journeyed 2,000 miles to see filters in the north of England and south of Scotland. He concluded that a filter at a calico works near Manchester was better than the filter then used by one of the Glasgow water companies because it had coarser material at the bottom than at the top, thus facilitating the passage of water. Observing in his experimental work, as did Thom, that the dirt retained in filters was at and just below the surface, Simpson concluded that the best way to clean the filter was to scrape off the thin dirty top layer, remove, wash and restore it, and replace it at intervals.

Both Thom and Simpson used coarse material at the bottom of their filters and successively finer layers until the top was reached. Whether or not either the Scotchman or the Englishman knew it, careful arrangement of filter media, successively smaller from bottom to top, was called for in a British patent granted to Peacock in 1791 and justified scientifically in a pamphlet published by him in 1793 (see above). Peacock's filter, like Thom's, was cleaned by reverse-flow wash, and in using this method, each man was ahead of his time. Simpson set the model for the typical slow sand filters that are still dominant in conservative England. In Scotland, Thom's self-cleaning filter, either in its original or a modified form, was used for many decades in several towns and was still in use in at least one town in 1940.

Thom's Self-cleaning Filter

Like many other good enterprises, the water works system of Greenock, Scotland, in which Thom's first municipal filter was included, had its inception on a golf course. While Thom was "coursing" near his Rothesay cotton mills, in 1820, a companion asked whether the scarcity of water in Greenock could not be alleviated by an aqueduct similar to that by which Thom supplied water and power to his mills (32). After considering information regarding a stream near Greenock, Thom said he believed that water from the Shaws River could be brought to Greenock by gravity. Although invited to look into the matter the next year, Thom was too much occupied with his mills to do so. Early in 1824, he made a survey which showed that not only was a water supply for the town practicable, but also feasible was a large water-power development the capacity of which would exceed all the steam power then being used in and about Glasgow.

On the strength of this the Shaws Water Joint Stock Co. was incorporated in 1825. The first water for power was delivered April 16,

1827. Filtered water was supplied in the latter part of 1827, more than a year before Simpson's London filter went into service on January 14, 1829.

True, Simpson began studying filtration a few years before the date just mentioned. Apparently Thom did so still earlier. This is shown by Thom's letter of March 20, 1829, to a leading promoter of the Shaws water company (32). The letter was a 3,000-word exposition of Thom's self-cleaning filter, written by request and appended to Thom's final report of 1828, which barely mentions the filters.

Although filtration on a small scale had long been practiced, said Thom, all previous attempts to render turbid water pure on a scale sufficient to serve large cities had failed, the yield growing less and less until it entirely or nearly ceased. As examples, Thom cited the failure at near-by Glasgow of "artificial filters" built "by an eminent engineer" (Telford's name graciously omitted), later unsuccessful attempts on a different plan, followed by filter galleries ("natural filters") of gradually falling yield (see Glasgow, above). These failures Thom attributed "to the lodgment of sediment between the particles of sand." Solution of the problems thus presented had long occupied his attention. Finding that the grosser particles of extraneous matter lodged at the surface, the stirring or harrowing of which was not a permanent cure, and that frequent removal and renewal of a small quantity of surface material, while better than harrowing, was troublesome, expensive and incomplete, and that various other contrivances generally failed, he devised a self-cleaning filter. On a small scale this was tried for several years and was uniformly successful. Tried on a large scale at Greenock it gave equally satisfactory results.

The Greenock Filter.—In the permanent filter at Greenock, said Thom, water was made to pass, either downward or upward, at will, through about 5 ft. of very fine, clean, sharp sand. When the yield of pure water declined through lodging of sediment, the flow was reversed for a few minutes—carrying the sediment out over the top or down through the sand to the bottom, according to the direction of filtration. No evidence of upward filtration in any of the filters designed by Thom has been found.

In his paper of 1840 (33), Thom said that his filter at Greenock and the later one at Paisley removed not only suspended matter but also color due to moss water, thereby rendering the treated water similar to spring water. This he accomplished by means of a species of traprock or amygdaloid common in the hills about Greenock, broken down to the size of peas and smaller, and mixed with fine sharp sand. These filter media, he said, were rather expensive and in time became saturated and had to be replaced; therefore, great care was taken to exclude moss water from the filters by using a separate reservoir to supply the filters and diverting the moss water to the power reservoir.

"Cesspools for the deposit of sediment" were built at intervals in the aqueduct leading from the supply reservoir to the filters. There were three filters, each 12 x 50 ft. in plan, with walls 8 ft. high. There was also a clear-water reservoir with a capacity equal to a day's consumption.

The Greenock works were acquired by the town in 1836. Since then, both slow sand and rapid or mechanical filters have been built (34). Writing late in 1936, James MacAlister, Superintendent of Water Works in Greenock (35), said that he could not find out when or why Thom's filters were abandoned. There were no plans or other particulars regarding them in his office. A lease of land dated 1861 mentioned three 12 x 50-ft. filters, presumably Thom's filters of 1827.*

Second Paisley Filters.—Eleven years after completing his self-cleaning filters at Greenock, Thom built similar but larger filters for the near-by town of Paisley. These also treated an impounded gravity water supply, first delivered July 13, 1838. Twenty-four years earlier, the first known filters on a municipal supply had been put into use at Paisley (see above).

In June, 1843, in evidence before a Royal Commission, Thom said he had "created self-cleaning filters at Greenock, Paisley and Ayr" (41).

* In the years immediately after the Greenock filters were completed they received as much if not more attention in print than did Simpson's filters at Chelsea. C.-F. Mallet, Water Engineer of Paris, who in 1825 had proposed upward-flow filters for that city, translated Thom's expository letter of 1829 into French and published it in 1831 (36). J. C. Loudon, who saw the Greenock filter in 1831, described it briefly the following year in his *Gardeners Magazine* (37) and sent Thom's pamphlet to the *Mechanics Magazine*, where it was given extended notice in 1832 (38). In the United States Loammi Baldwin, in a report of 1834 on a new water supply for Boston (39), inserted notes on the Greenock filters taken from the *Mechanics Magazine*. Not having a copy of Thom's pamphlet, Baldwin translated back into English a goodly part of Mallet's French version of Thom's letter of 1829. In 1835, Baldwin's one-time pupil, Charles S. Storrow, described Simpson's Chelsea or London filter of 1829 at some length and Thom's Greenock filter briefly (40), crediting Mallet for the latter. Thus Thom got publicity for his self-cleaning filter in Scotland, England, France and the United States. Publicity for his Paisley filters is noted later.

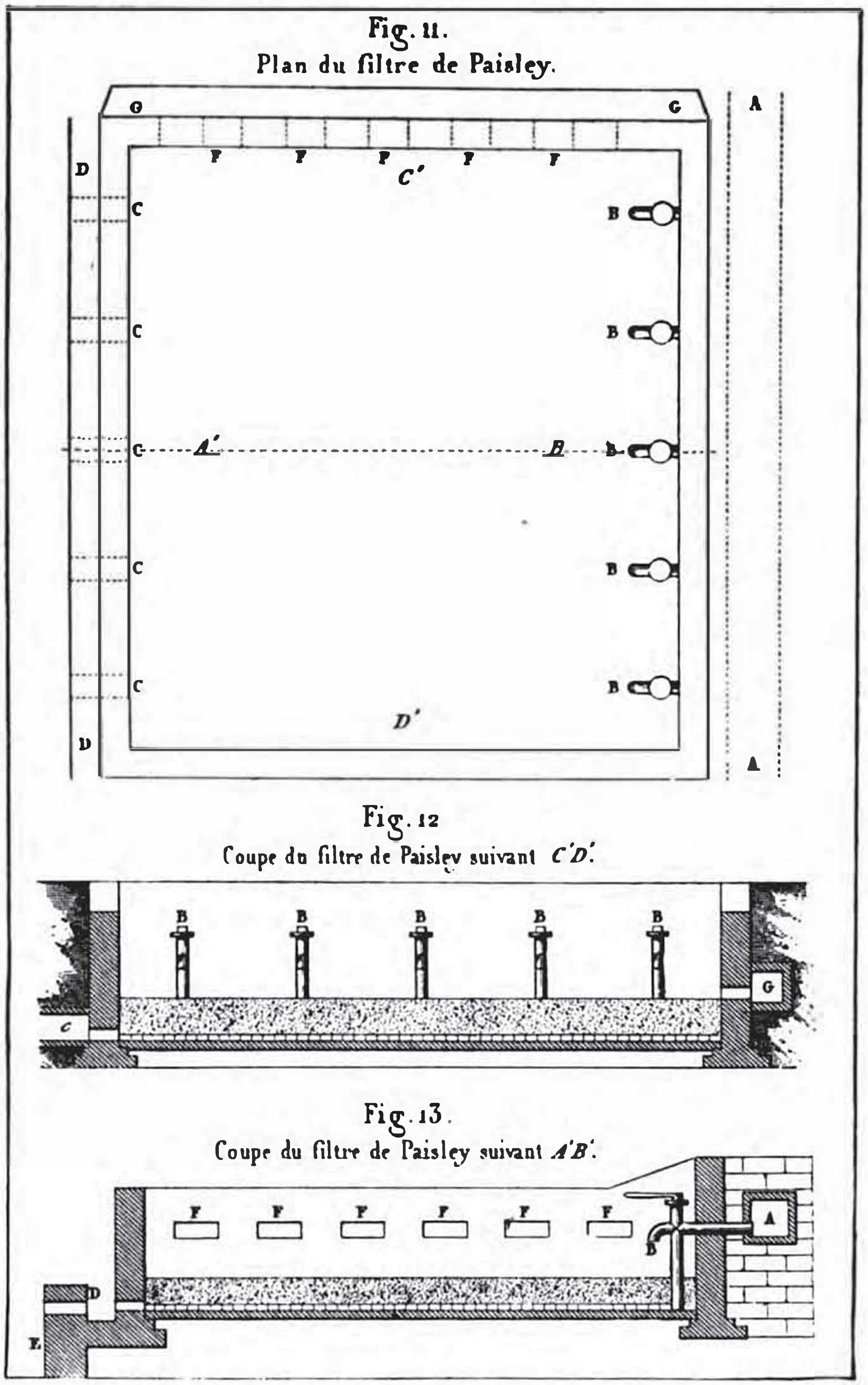


FIG. 24. THOM'S SELF-CLEANING FILTER AT PAISLEY, 1838

Media supported on false bottom of perforated flat tile; cleaned by reverse-flow wash; filter enclosed by rectangular masonry walls. Design similar in principle to rapid filters of 20th century, but rate of operation about same as that of Simpson's hand-scraped filters

(From "Atlas" of Darcy's *Les Fontaines Publiques de la Ville de Dijon*, Paris, 1856)

Thom's description of the filter at Paisley, which in essence was like that put in use in 1827 at Greenock, shows how carefully he designed his self-cleaning filter and how much it is resembled in form and in some details by the American mechanical filter.

The Paisley filter was 100 x 60 ft., with three compartments which could be used separately or together. The walls were of masonry in cement backed with puddle. The bottom was paved, had cement joints, and was supported by puddle. Much attention was given to the design of the underdrain and washing system. There was a false bottom of flat perforated tiles, similar to those used in oat-drying kilns—an example of how one industrial art builds on an earlier one. The holes were more than 0.1 in. in diameter and were very near each other. Fire brick on edge, resting on the paved bottom of the filters, supported the false bottom and formed underdrains 1 ft. wide and 5 in. high. These bricks were laid end to end, with ¼-in. open joints. Their upper edges were little more than 1 in. wide, so there would be little or no space in the false bottom without holes, and thus "nothing to prevent the water spreading equally over every part of the bottom of these drains," which "is particularly necessary," said Thom, "when the filters are cleaned by upward motion of the water."

The filtering materials from the bottom upward were: about 1 in. of 0.3-in. clean gravel, placed on the perforated flat tiles; five layers of gravel, each layer about 1 in. thick and of lesser size than the one below, the fifth described by Thom as coarse sand; and 2 ft. of "very clean, sharp, fine sand, similar to that used in hour glasses, but a very little coarser." Mixed with the upper 6 or 8 in. of this sand, in the ratio of 1 to 8 or 10, was animal charcoal, ground to about $\frac{1}{16}$ in. diameter. This gave a total depth of 36 to 38 in., mostly sand. The charcoal was used to decompose "any vegetable matter with which the water may be impregnated."

Although Thom claimed either upward or downward filtration in his report of 1829 on the Greenock filter, he says cleaning at Paisley was effected by manipulating the valves to change from downward to upward flow and wasting the dirty water. Cleaning was facilitated by stirring with a fine-toothed rake and admitting a little water through the raw-water conduit so it would flow over the surface.

The cost of the Paisley filter was given by Thom as £600 ($2,900) and the average quantity of water produced 106,320 cu.ft. [nearly 0.8 mgd. (U.S.)]. As the available area was under $\frac{1}{7}$ acre, the plant must have worked at an average rate of nearly 6 mgd. per acre or double the nominal rate of slow sand filters of that and later dates; and the rate was even faster when a compartment was being cleaned.

Thom's Influence.—The only known adverse criticisms of Thom's self-cleaning filters were uttered in support of filters patented by Fonvielle in France in 1835 and by Maurras in England in 1842 (see Arago's report and Sloper's testimony, below). The Maurras filter, which does not appear to have gone beyond the promotion stage, also employed reverse-flow wash, but under higher pressure than used by Thom. B. G. Sloper, probably an agent for the Maurras filter, testified before the Commissioners for Inquiring Into the State of Large Towns and Populous Districts in 1843: "We find that the return current of water [in Thom's filter, even under a head of 26 ft.] does not remove one-tenth of the dirt" (42). No supporting data were given. Presumably the Thom and Maurras filters were tested side by side at or near London.

Favorable comment was made by John Horsley in 1849 (43), who mentioned Thom's "self-depurating arrangement" used in "a modification of what has been called the Lancashire filter" (see Lancashire Filters, above).

Henry Darcy, in a book published in 1856 (25), says that besides being washed by reverse flow the Paisley filters were cleaned by removing 1 cm. of surface sand from time to time, and replacing it at longer intervals. He does not say how long this supplementary cleaning had been practiced.

The Paisley filter was used until 1874 when it was remodeled, wrote James Lee, Water Engineer of Paisley, in 1936 (11). It was abandoned in 1887 for new filters adjacent to one of the storage reservoirs. No plans of Thom's filters were available in the Paisley water office in 1936.*

A memoir of Thom published in 1848 (46) contains no details of his filters not already given here. It says that after his connection

* A plan and sections of the Paisley filter were shown on a folding plate accompanying Thom's testimony of 1843 before the Commissioners for Inquiring Into the State of Large Towns and Populous Districts (41). The plate was in the folio but not in the octavo edition. A section of the filter was shown in Tomlinson's *Cyclopedia* of 1852 (44) and in *Allgemeine Bauzeitung*, 1853 (45). Plate 24 of the Atlas to Darcy's *Fontaines de Dijon* (25) shows a plan and two sections of the filter, presumably from the Report of the Commissioners for Inquiring Into the State of Large Towns and Populous Districts.

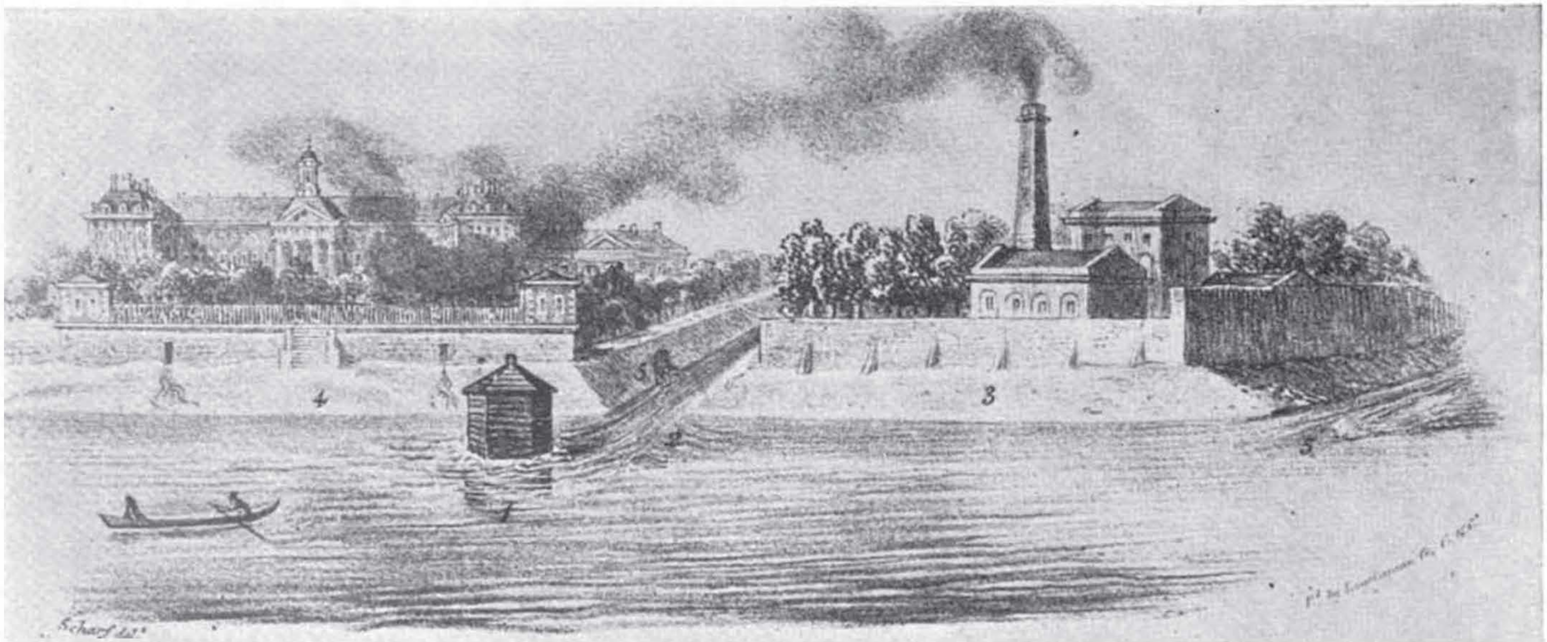
with the Rothesay cotton mills ceased in 1840 he retired to his estate at Ascog, intending to pass his remaining days at leisure, but he was induced to lend his advice and assistance on water supply to several towns in the United Kingdom and to consider many foreign schemes. In all these "he adhered to the gravitation principle" and used with success the large filters described in the Greenock pamphlet. These towns are not named in the memoir.

After Thom's death in 1847 filters more or less like his were built at several Scotch towns. A false bottom of perforated flat tiles supported by bricks set on edge was used in a slow sand filter completed in 1850 for the borough of Kilmarnock, Scotland. The filter was designed by James M. Gale, Water Engineer to the city of Glasgow (47). A filter modeled after Thom's design was put in use at Dunkirk, France, in 1870 (48). In some filters in Scotland, notably in the Gorbals works at Glasgow (see above), perforated flat tiles were placed between the gravel and sand instead of being used as false bottoms.

James Simpson and the Chelsea Water Works Company

Best known of all the filtration pioneers is James Simpson. He was born July 25, 1799, at the official residence of his father, who was Inspector General (engineer) of the Chelsea Water Works Co. The house was on the north bank of the Thames, near the pumping station and near what was to become the site of the filter that was copied the world over. At the early age of 24, James Simpson was appointed Inspector (engineer) of the water company at a salary of £300 a year, after having acted in that capacity for a year and a half during the illness of his father. At 26, he was elected to the recently created Institution of Civil Engineers. At 28, he made his 2,000-mile inspection trip to Manchester, Glasgow and other towns in the North, after designing the model for a working-scale filter to be executed in his absence. On January 14, 1829, when Simpson was in his thirtieth year, the one-acre filter at Chelsea, commonly known as the first English slow sand filter, was put into operation.

Of the eight water companies supplying Metropolitan London in the 1820's, five, including the Chelsea until early in 1829, served raw water from the always polluted and sometimes turbid Thames, taken within the tidal reach of the stream into which numerous sewers discharged. The Chelsea Water Works Co., probably led by James Simpson, was the first to give official attention to this deplorable con-



THE DOLPHIN OR GRAND JUNCTION NUISANCE.

1. — The Dolphin 3. — Grand Junction Water Works
2. — Grand Common Sewer 4. — Chelsea Hospital
5. Minor Common Sewers.

Geo. Cruikshank 1827

THE

DOLPHIN;

OR,

Grand Junction Nuisance:

PROVING THAT

SEVEN THOUSAND FAMILIES,

IN

WESTMINSTER AND ITS SUBURBS,

ARE SUPPLIED WITH

WATER,

IN A STATE, OFFENSIVE TO THE SIGHT,

DISGUSTING TO THE IMAGINATION,

AND

DESTRUCTIVE TO HEALTH.

"There is such a thing as Common Sense!"

Abernethy.

LONDON:

PRINTED FOR T. BUTCHER, 108, REGENT STREET.

1827.

FIG. 25. FRONTISPIECE (*left*) AND TITLE PAGE (*above*) OF *The Dolphin*
(Reproduced from George Cruickshank's signed copy)

FIG. 26. THE DOLPHIN, OR INTAKE, OF THE SOUTHWARK WATER WORKS CO.

An illustration which accompanied a broadside entitled "Royal Address of . . . Water King of Southwark," which was "a satire on the pollution of the Thames by the Walbrook sewer and other outlets, founded on the report of the Commissioners of Inquiry in 1828"

(From colored print by George Cruikshank (Reid's No. 1464; Cohn's No. 1952)) dition and the first to build a filter. In this the company may have been stimulated by a project, launched late in 1824 by the Thames Water Co., to bring "pure and unpolluted water" from a point upriver on the Thames in the vicinity of Richmond and Brentwood and to deliver it wholesale to the London companies for distribution.

The Dolphin.—Grievances against the companies had been growing since 1810 when, promising better service and better water, the companies divided the areas served between them and increased the rates. This resulted in complaints of monopoly and high rates, and in mounting criticism of the bad character of the water supplied. On March 15, 1827, a veritable explosion occurred with the publication of a thick pamphlet called *The Dolphin or Grand Junction Nuisance* (49). A frontispiece engraving showed the dolphin or water intake of the Grand Junction Water Works Co., and near it the outlets of a large sewer and several small ones, one of which came from the Chelsea Fever Hospital. The pamphlet led to commission hearings and reports on the quality of the London water and projects for new sources of supply (50, 51).

Simpson's Working-Scale Filter.—It is to the credit of the Chelsea Water Works Co. that its first steps toward filtration were taken a year before *The Dolphin* appeared. Undoubtedly, the pamphlet spurred on both the company and Simpson. His filter-inspection trip and working-scale filter came after *The Dolphin* had been published and about the time of the creation of a royal commission. His permanent filter was already under construction when he testified before the commission.

Simpson's Inspection Tour.—Hope of finding that a detailed report by Simpson on his filter-inspection trip still exists was ended late in 1935 when Lt.-Col. J. R. Davidson, then Chief of the London Metropolitan Water Board, wrote that an exhaustive search of documents in the Board's Muniment House disclosed no evidence that a printed or written report had ever been made (52).* Fortunately, unpublished

* Similar disappointment resulted from an appeal made in 1937 to Clement P. Simpson, grandson of James Simpson. In answer to a request for data for use here, he wrote that as executor of the wills of James Simpson Jr., and Charles Liddell Simpson, a grandson of James Simpson Sr., he had access to all papers and documents belonging to them. He remembers no material which would be of assistance here. The journey of his grandfather to the North of England and Scotland has "always been rather obscure and so far as I know there is little documentary evidence of detail" (53).

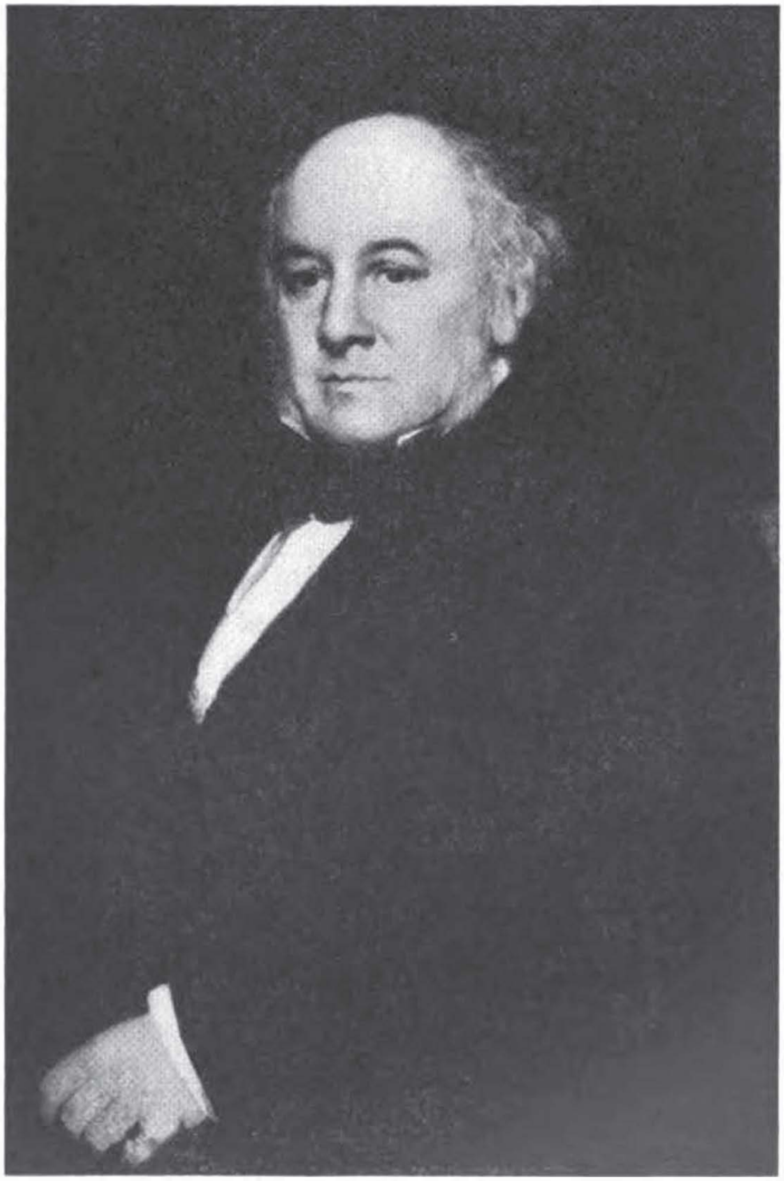


Fig. 27. James Simpson (1799–1869)

Engineer of Chelsea (London) and designer of hand-scraped filters for the Chelsea Water Works Co., 1829

(From a painting by Sir William Boxall, R.A., exhibited at the Royal Academy, London, 1856; photograph supplied by E. Graham Clark, Secretary, Institution of Civil Engineers)

Minutes of the Chelsea Water Works Co. contain several brief references not only to the trip but also to preceding and subsequent events. Extracts from the Minutes (54) were kindly supplied for use here by Col. Davidson. From these, from Simpson's testimony of 1828 before two Parliamentary Commissions (50, 51), from material supplied by Simpson for a lecture by William Thomas Brande (55), and from data supplied by Simpson for Telford's *Autobiography* (15), a consecutive story of all of Simpson's early filtration activities has here been constructed for the first time.

Rearranged chronologically, the minutes of November 1, 1827 (54), showed that filtration on a large scale had occupied Simpson's attention for the two previous years and that he had made many filtration experiments at the water works. (Elsewhere (15) Simpson said that the experiments were begun in the spring of 1826.) In January 1827, Simpson received permission from the directors of the company to make "experiments on a larger scale than he had been able to do privately." In August, 1827 (five months after the appearance of *The Dolphin* (49) and a few weeks after the public-protest meeting inspired by this pamphlet), "the directors manifested some impatience," and "directed" Simpson "to turn his whole attention to the subject; and having heard that a filter bed was working at Glasgow, he received permission to proceed there." A brief report on his northern trip was submitted to the directors on November 1, 1827, whereupon "he was ordered to make certain further experiments which he had proposed and report the results to the next Board."

Apparently, that was too short a time, for on November 7, Simpson submitted instead another account of his filter-inspection trip. This, as spread on the minutes, is so brief and yet is so important in the history of filtration, that it is given here in full:

> During the journey to Manchester and Glasgow, which he undertook with permission of the Court [directors], he saw several large filter beds at work, and from the information he obtained, he has no doubt of being able to filter the quantity of water the Company requires. Filtration of water through the simple medium of sand and gravel, possesses so many advantages compared with reservoirs, that he feels assured that it will be the best method of purifying the water.
>
> He takes the liberty of stating that from results of reservoirs in other Water Works, where various sums of from £10,000 to £50,000 have been expended, the improvement in the quality and appearance of the water has not in a single instance equalled his expectations. The River Thames is

often affected by land floods, particularly during about 20 days every year when reservoirs are of very little use, but filtration will improve this water very much and render the loamy appearance scarcely perceptible. (54)

A little additional information regarding what he saw on his trip was given by Simpson in testimony before a committee of the House of Commons in July 1828 (51):

———he travelled over Britain, and examined many plans in operation for filtering water; he had travelled 2,000 miles, and in Lancashire, Lincolnshire * and Scotland, he had seen many manufactories and some waterworks supplied by filtered water. The filter beds he had seen had been in operation for various periods, some for four months, and others for longer periods up to 16 years.

Asked by the committee whether his proposed filter for the Chelsea company was like that of the Cranston Hill Water Works Co. at Glasgow, Simpson replied:

The plan I have adopted is partly like that; but I consider it improved by making use of a process [element in design] which they use in the neighborhood of Manchester, and that is by having a lower stratum of gravel, that the water may pass freely off.

[Asked] "Has the plan at Glasgow or at Manchester perfectly succeeded?" [Simpson replied:] "The plan at Manchester is used in the calico works, and they have been at work many years."

Out of the obscurity of a century ago, the foregoing notes are all that can be found on what Simpson saw on his inspection tour, the second journey of the kind on record, Mallet of Paris having visited Britain to study filtration, and water works generally, about 1824.

What a pity that Simpson did not put on record descriptions of the filters he saw, the names of their designers and the dates they were put into operation! Even the location of the filters and an indication of whether they were treating water for industrial works or municipal supply would be welcome information. A phrase in one of the passages cited—"many manufactories and some water works"—indicates that most of the filters which he inspected were for industrial supplies.

* No record can be found of filters in Lincolnshire as early as 1827. The water engineers of Lincoln (56) and Boston (57), the largest communities in the county, report that sand filters were included in the first works for general water supply, built in 1847 for each community. They could find no evidence of earlier filters, either municipal or industrial, in their part of the county. A county gazetteer, published about 1812, mentions water works for only one town—Stamford—to which water was brought in cast-iron pipes from the Walthorpe springs (58).

Completion of Experimental Filter.—At a meeting of the directors of the water company on November 15, 1827, Simpson reported that the experimental filter was completed November 7; the "water had been cleaning the sand every day since." On November 8, after 27 hours work, the filtrate was cloudy, but "as pure as the Water taken from Hyde Park Basin, when it had been at rest 84 hours." On November 9, the cloudy appearance had gone off and after the following day the water was quite clear. To show "that this process of filtration did not render the water at all vapid but pure and brilliant—he laid a sample thereof before the Court" (54).

Convinced thus of the efficacy of the working-scale filter, the directors, on the same day, ordered the construction of a permanent filter "upon the Plan proposed by the Engineer"—who had just submitted cost estimates.

By far the most complete description of the large experimental filter was that supplied by Simpson to William Thomas Brande (55). He told Brande that the "pond" containing the filter was 44 ft. square at the top, 26 ft. square at the bottom and 6 ft. deep. The filter had a top surface of 1,000 sq.ft. and a depth of 4 ft. After the "pond" had been made watertight, a drain was laid to a clear water well and open-jointed branch drains of brick were laid. The filter media, from the bottom up, were gravel, graduated from coarse to fine, 2 ft., and sand, graduated from coarse to fine, 2 ft. Both the gravel and the sand were selected with great care and well washed. Two settling reservoirs, each 32 ft. square at the top, 20 ft. at bottom and 4 ft. deep, were provided. Their low-water line was level with the high-water line of the filter. The reservoirs worked alternately, regulated to filter 12,000 cu.ft. or 90,000 gal. (U.S.) per 24 hr. This would be 90 gal. per sq.ft. or about 3.9 mgd. per acre. The method of cleaning the sand and the underlying principle of filtration as seen by Simpson when he had operated his experimental filter some two months deserve to be given in his own words:

> The silt which was stopped on the sand, was regularly cleaned off with a portion of the sand every fourteen days; the principle of the action depends upon the strata of filtering material being finest at the top, the interstices being more minute in the fine sand than the strata below; and the silt, as its progress is arrested, (while the water passes from it) renders the interstices between the particles of sand still more minute, and *the bed generally produces better water when it is pretty well covered with silt than at any other*

time. [Italics mine.] Silt has never been found to penetrate into the sand more than 3 in., the greatest portion being always stopped within the top half-inch of the sand; and in cleaning the silt off, it has never been found necessary to scrape any more of the sand off with the silt than the first half-inch depth and sometimes only half that depth was removed. The small air-pipes from the drains are to prevent injury to them or the filtering materials by condensation or otherwise. (54)

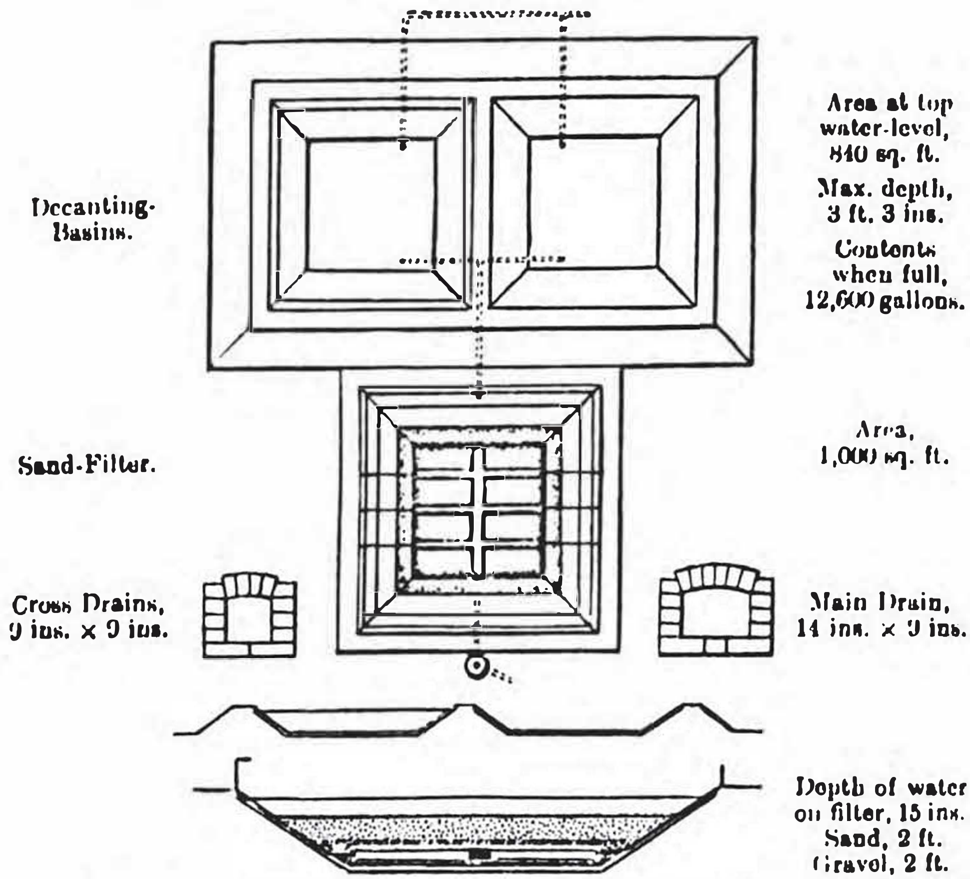


FIG. 28. JAMES SIMPSON'S EXPERIMENTAL FILTER OF 1827–1828
(From drawing in possession of Charles Liddell Simpson; previously reproduced in *Proc. Inst. M.E.*, April 1916, p. 300)

The experimental filter was continued in use at least eight months, for in his evidence before the Select Committee on the supply of Water to the Metropolis, given July 7, 1828 (51), Simpson said that the filter "is now in work." In answer to questions Simpson, on the same day, said that the head on the test filter "varies according to the state of the material; when the material is clean, it will go off very well with four inches head, and the head water increases as the material becomes clogged." This was once in 14 days, whereupon, "the sand was made dry, and men were sent in with common spades and [they] scraped off the surface."

Skepticism as to the wholesomeness of filtered water in 1828 and Simpson's reassurances on the subject are amusing today. At the hearing before the Royal Commission (50) a member asked whether any persons had been in the habit of drinking the water filtered on a small scale. "Yes," answered Simpson. Had they complained of the water "being insalubrious, giving them cholic or any other complaints?" To this, the engineer replied that none of the more than 100 men working on the ground (presumably on the permanent filter) had complained of the filtered water but there had been complaints of the "land spring-water being injurious." Fish, the commission was assured, did not die in the filtered water. Simpson willingly admitted that "water may contain so many ingredients chemically dissolved, that filtration will not purify it." Asked whether the discharge from King's Scholars Sewer could be "so filtered as to be fit to drink," Simpson cannily said he had never tried it. Asked whether filtration would remove bad taste from water, Simpson replied that "Thames water has a taste, according to season, of animal and vegetable matter"; filtration "seems to deprive it of the whole of that, and we cannot discover it after it has passed the bed."

The Chelsea Filters.—After three years of experimentation, travel observations and construction, Simpson's permanent filter was put into use January 14, 1829. Within a few days of that epoch-making date in the quest for pure water, Simpson provided Brande with a description of the filter (55). It was even shorter than the description of the experimental filter already noted. Simpson said that the large filter had a surface of nearly an acre and was "constructed precisely on the same principle as the experimental bed," and added that the details of forming and operating the large filter had been "greatly improved and adapted to the enlarged scale." How, he did not say, but this he indicated later.

In January, 1829, the filter was "working with the greatest success during the inclement season," testified Simpson, "and although the water on the bed is this day covered with ice five inches thick, it does not impede the filtering process" (55). This is the earliest testimony on the effect of ice on filtration that has been found.

More information on the design of the large filter, with data also on his experiments, was supplied by Simpson for inclusion in Telford's *Autobiography* (15)—presumably shortly before Telford's death on September 2, 1834, when the filter had been in use five years.

Simpson's Researches and Studies.—When he began his preliminary studies, Simpson wrote to Telford, the art of filtration "upon a large scale was yet to be acquired, and improvements [were yet] to be made upon the works at Glasgow, Manchester, and other places, where it appeared that instances of failure, as well as of success, had occurred." Anticipating by many decades the conclusions of other engineers "that preliminary experiments were indispensable" before venturing on large capital outlay "several trials were made on superfices exceeding 1,000 sq.ft. to ascertain the most approved principle, and the fitness of the various materials proposed to be employed." Moreover:

> All the modifications of lateral and ascending filters proved disadvantageous; difficulties were encountered in preserving the various strata in their assigned position, according to the sizes of their component particles; and effectual cleaning could not be accomplished without the removal of the whole mass of the filtering medium. All devices by currents, reactions of water, and other means, also proved either inefficient or inconvenient and expensive. (15)

Mention of "lateral" and of "ascending" filters suggests that Simpson may have seen or heard of the Paisley filter of 1804 and that he talked with Robert Thom about his "self-cleaning filter, worked by ascent or descent" (see above), put into use just before Simpson visited Scotland late in 1827. At Glasgow, he may have seen or heard of four different filters and extensive filter galleries built by the two water companies in the previous twenty years.* The only Glasgow filter mentioned by Simpson was one of three built by the Cranston Hill Water Works Co. at various times. Of that, Simpson says only that it was something like his Chelsea filter, having a ridge-and-furrow surface. This may have been the Glasgow filter that Simpson had in mind in testimony of 1828 (50, 51).

As a result of what he saw on his filter-inspection trip and learned from his experiments, Simpson decided on filtration "by descent"

* So far as has been found, no municipal filters had been built in England when Simpson made his filter journey of 1827, while in Scotland the only ones were those at Paisley (already abandoned?), Glasgow and Greenock.

through fine and coarse river sand, shells and pebbles, small and large gravel, and with the surface disposed in ridges, giving an undulated appearance. According to his letter to Telford:

> The first experiments by descent failed; sufficient care had not been taken in the selection and separation of the materials. Explosions of condensed air in the tunnels for collecting the filtered water deranged the strata occasionally, but were obviated by air drains. The filtration was, in one instance, stopped by the addition of fresh sand without having previously removed the old sand, which should be applied as the upper stratum; although in this case, the surface had been thoroughly cleansed previously. A film or puddle was formed on the original sand, and was sufficiently supported by the particles of sand to sustain five feet head of water, at first acting to impede, and eventually to stop the filtration. The process was greatly improved by the introduction of the small shells, such as are usually found at Shellness, the flat surfaces of which overlap, and assist in the great desideratum of separating the sand from the gravel, and thus tending to preserve the free percolation in the lower strata, which is essential for ensuring filtration sufficiently rapid for waterwork [*sic*] purposes. . . . The lower stratum of gravel contains the tunnels for collecting the filtered water. They are built up with cement blocks, and partially open-jointed, two spaces of an inch and a half on the bed and the heading joint of each brick being open. The fine gravel, pebbles and shells, and the coarse and fine sand are laid upon the large gravel. (15)

Water was let into the filter at nine places, discharged from pipes "fitted with curved boards to diffuse the currents of water and prevent the surface of the sand from being disturbed." Because the interstices of the fine top sand were smaller than those of the next lower stratum, the impurities were arrested near the surface. Careful examination showed that the sediment sometimes penetrated to a depth of 6 to 9 in., depending on the state of the land floods in the Thames. But it was never necessary to scrape off more than an inch of sand from the surface at one time, "the remainder tending rather to improve filtration by rendering the interstices between the sand still more minute." "From these observations," wrote Simpson, "it must not be inferred that the process is merely a fine mode of straining; for something more is evidently effected; an appearance resembling fermentation being discernible when water is in contact with the sand" (15). What was meant by "fermentation" is not apparent.

"The undulated surface" of the filter, wrote Simpson, "admits of parts of it being washed, and others drained; and it aids in cleansing, by admitting the grosser particles of the silt to slide down the ridges.

and form a sediment easily manageable." This is not convincing today, but as Simpson ridged his later filters he must have continued to think it worth while.*

The amount of water being filtered when Simpson supplied data to Telford was from 2.25 to 3 mgd. (U.S.) and as the filter had an area of an acre that was also the filtration rate per acre. The period of sedimentation was probably short.

Reverse-flow wash and harrowing were used to supplement hand scraping of the London filters operated under Simpson's direction. This he stated in evidence given in July 1851, when asked if he had "adopted new means of cleaning filters" (59).

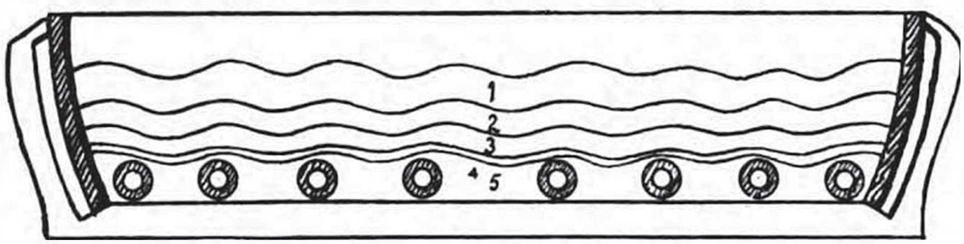


FIG. 29. CROSS SECTION OF SIMPSON'S ONE-ACRE FILTER FOR CHELSEA WATER WORKS CO., 1829

Media were: 1. fine sand; 2. loose sand; 3. pebbles and shells; 4. fine gravel; 5. large gravel, containing "brick tunnels" or underdrains. Similar undulating surfaces used by Simpson in several other filters and by Hiram F. Mills in filter at Lawrence, Mass., in 1893

(From communication by Simpson to Telford reproduced in latter's autobiography)

Water in relation to public health is barely mentioned by Simpson in anything he wrote on the Chelsea filter.

Simpson's Later Work

The Chelsea filter was continued in use until 1856, when the company began filtering water from an intake at Surbiton, higher up the Thames (52). These Surbiton filters were designed by Simpson, who

* The second of the three filters of the Cranston Hill Water Works Co. at Glasgow also had an undulating surface, raw water being passed longitudinally along the valleys. As designed, it was to be cleaned by discharging water through the valleys in a direction opposite to the normal flow, thus carrying away the sediment. For some reason not made clear by the available data this caused excessive wear on the pumps and the cleansing system had to be given up. (See "Glasgow," above.) A ridge-and-furrow surface was provided for the slow sand filters at Lawrence, Mass., put into use in 1893, but the stated object was to distribute the raw water without disturbing the surface of the layer.

was still Engineer of the Chelsea Water Works Co. He also designed filters completed in 1851 for the Lambeth Water Co. of London, which he likewise served as engineer for many years. In 1846, he advised the construction of filters for the water company at York, England, "in every respect except as to size, the same as those he had so successfully constructed at Chelsea." These were built soon afterward (61). It is also known that he designed filters built at Aberdeen, Scotland, in 1864 (62).

Simpson was president of the Institution of Civil Engineers in 1854–55. At the time of his death early in 1869 he was the oldest living member of the Institution.

Including Thomas Simpson, father of James, the family practiced engineering from late in the eighteenth until well into the twentieth century. James Simpson had three sons—James Jr., John, and Arthur Telford Simpson. All three were in some way connected with engineering and both James Jr. and John with water companies. All four sons of the second James were connected with both engineering and water companies—Charles Liddell, Thomas B., Edward P., and Arthur B. Simpson—the last still living in July 1937. John, son of the first James, had one son, Clement P. Simpson, writer of the letter from which these data are taken (53).

In 1851, James Simpson Jr. joined in the extensive engineering practice of his father. Six years later, he became a member of Simpson & Co., manufacturers of Woolf compound engines (63).

Charles Liddell Simpson, son of James Simpson Jr., and grandson of the first James Simpson, joined the firm of James Simpson & Co. in 1888, and became Managing Director in 1896. Later he became interested in the Worthington-Simpson Co., a combination of the Worthington Pump Co. and James Simpson & Co. (64). Keeping step with the march of engineering progress this grandson of the "father of the slow sand filter" used the Davis and Riddell type of American rapid filter when it was introduced in England in 1890 (65).*

The Maurras Filter

A multiple pressure filter much like Fonvielle's (see Chap. IV) was registered in the British patent office by André Eustache Gratien

* For help in obtaining data regarding James Simpson Jr. and Charles Liddell Simpson, I am indebted to Brig.-Gen. Magnus Mowatt, Secretary of the Institution of Mechanical Engineers.

Auguste Maurras * on November 15, 1842 (No. 9,520). Several filters were placed one above another in a closed tank. Water under pressure could be applied to either the upper or lower unit alternately, or from both directions at once. Pressure could be applied either from a reservoir at any desired elevation or by a pump. The filtering material could be cleaned in place.

In testimony submitted to the Commissioners for Inquiring Into the State of Large Towns and Populous Districts in 1844, B. G. Sloper, apparently agent for the Maurras filter, said he had examined 60 to 70 filter patents granted in England and on the Continent, besides inventions of many others who had not, according to him, thrown their money away on patents (42). Two recent inventions had seemed likely to become rivals—cotton and wool filters. Both failed because after a time they imparted impurities to the water. The compressed wool filter, Sloper said, was excellent so far as "minute porosity was concerned" and, he asserted, its inventor [Souchon] had influence enough to obtain a very favorable report on it by the French Academy of Medicine and its adoption for some of the public fountains of Paris, but in the last year [1843] the defects common to all organic filtering media had become manifest enough to overcome the influence employed to obtain its adoption, and its use in the fountains had been discontinued. [If some Souchon filters were abandoned, their use in Paris was resumed (see Belgrand tests of 1856, Chap. IV).]

Sloper claimed that a filter 5½ x 5½ ft. in plan, with a working surface of 60½ sq.ft. [counting both faces] had a capacity of 180,000 gal. (U.S.) in 24 hours when working under a 12½-ft. head. This capacity, he said, was based on continued working of a filter for three out of the four months it was in operation at New River Head [works of the New River Co., London]. Placing one unit over another would reduce the ground area required but increase the cost of operation. [The rate of filtration specified would equal 135 mgd. (U.S.) per acre with no allowance for time out for cleaning. No evidence of a permanent Maurras plant, big or little, has been found.] Illustrated descriptions of the Maurras filter are given in Tomlinson (44) and in Delbrück (45), apparently based on the Sloper article.

* The patent gave a London address for Maurras but searches made by the Reference Department of the New York Public Library indicate that he was a lawyer and *agent d'affaires* of Paris. He did not take out French or American patents.

Growing Concepts of Filtration; Early Nineteenth Century

At the beginning of the nineteenth century concepts of the nature and function of filtration were vague and sometimes contradictory. At its close they were well defined and generally in accord. Removal of suspended matter or turbidity was for many years the chief objective. Gradually more and more attention was given to organic matter. Whether it was harmful and, if so, how and why were moot questions.

Filtration was long regarded as a mere straining process, limited by the size of the interstices between the particles of media. Only charcoal, many held, had the power of removing, or at least transforming, organic matter in solution. Whatever the media, it was generally agreed that the finest-grained should be placed at the top of the filter, with coarser and coarser material below. One school was for upward-, the other for downward-filtration. The former believed that in upward flow through progressively finer material, gravity would carry most of the suspended matter to and below the bottom of the filter and that what remained lodged in or on the sand could be removed by reverse-flow wash. The downward-flow school, observing that most of the dirt was intercepted at the top of the filter, removed it by scraping off a thin layer of media. This school prevailed throughout Great Britain but in Scotland reverse-flow wash came into use just before scraping was adopted in England. At and after the close of the nineteenth century reverse-flow wash was employed wherever the American type of rapid filter was adopted.

Midway in the century, men of vision, aided by research, showed that organic matter, with possible harmful contents, was reduced by filtration. Toward the end of the century it was proved that slow sand filters, as perfected long before bacteria were more than dreamed of, were as efficient in removing bacteria as in effecting their original objective—clarification.

For convenience there have been assembled here notes and comments on methods and concepts of filtration, drawn from various British encyclopedias, a few books, government reports and papers before engineering and other scientific associations. The better to show progress these have been arranged chronologically.

Failure of English cyclopedias to keep pace with the quest for pure water during the first half or more of the nineteenth century is amazing. For the most part they did not go beyond generalities and mention of patented filters. Some of the books did better. In the last half of the century growing understanding and appreciation of filtration is noticeable.

Rees's *Cyclopedia* of 1819 (66) said that the filter most generally used was a porous stone basin. Its cost and liability to clogging had given rise to more simple filters, of sand, of powdered glass, or of charcoal. The last, because of its antiseptic qualities, corrected putrid water besides separating suspended matter. "Isaac Hawkins, of Twitchfield St.," made charcoal filters for use in the metropolis where the water, in general, required such treatment. Three small household filters were described.

The London Encyclopedia (1829) (67), although published the year Simpson's first sand filter was put into use and after the construction of the filters at Glasgow and Greenock, Scotland, does not mention a single filter for municipal supply.

Abraham Booth, who classed himself as "Operative Chymist," published a noteworthy little book on water in 1830 (68). In it he gives a comprehensive review of water purification as understood by a chemist familiar with what had been done on a small scale up to his day but with little knowledge or appreciation of accomplishments in the field of municipal filtration. Instead of describing any of the municipal filtration plants built within his time, Booth generalizes on filtration, noting that passage of water through filtering stones or through sand, gravel, or pounded glass would clarify water but would not remove "putrescent vapours," which could, however, be taken out by filtering through charcoal.

Matthews' *Hydraulia* (1835) (21), although written largely in defense of the London water companies, the qualities of whose supplies had recently been violently attacked, includes a wide-ranging review of water supply and purification in several countries. He describes "filtering reservoirs constructed at Chelsea, Glasgow and Greenock" and adds: "Probably at no very distant period, the practice of filtering the whole of the water supplied from rivers to the inhabitants of great towns for domestic use may be universally adopted."

The Penny Cyclopedia (1838) (69), says under "Filter" that within the previous few years various filters had been used for either domestic or culinary supplies, and were generally composed of sand or small pebbles and charcoal. In its final volume (1843) under "Water," it says that sand filtration will remove suspended matter. Charcoal is recommended to remove matter in solution or any taint from "putrid vegetable or animal substances." The *Cyclopedia* describes the Chelsea filter, London, with credit to its engineer, James Simpson.

Ure's *Dictionary of Arts* (1839) (70), strikes a new note by asserting that "agitation or vibration is of singular efficiency in quickening percolation," displacing particles and opening pores that have become closed. Dr. Ure sums up, as none of his predecessors do, the advantages of "hydrostatic or pneumatic pressure" to speed up filtration. In a closed vessel, this could be effected by piping water from a reservoir, by using a pump to exert pressure on the surface of the filter, by using an air or steam pump to create a partial void beneath the filter, or by means of a common siphon; however, pressure could not be pushed very far without chance of deranging the filter bed or making water muddy. Ure mentions no municipal filters.

The Encyclopedia Britannica (1842) (71) in its article on filters, takes up the Robins household filter, and even includes exterior views of three highly ornamental household filters of this manufacturer. The writer of the article disclaimed certain knowledge of the composition of the Robins filter but said he understood that it included sponge above "various strata of filtering material." He had great doubts of the validity of the patentee's claim for "voltaic action which decomposes soluble substances, and reduces the water equal in purity to distilled water," but he had "no doubt, from testimonials . . . that the filter is a very good one." This claim for voltaic action seems to be the first of a long series of attempts to win purchasers by alleging electrical action in water and sewage treatment. No Robins filter is included among British water filtration patents.

Cresy's *Encyclopedia of Civil Engineering* (1847) (72) makes available concise descriptions of Thom's self-cleaning filter at Greenock and Simpson's Chelsea hand-scraped filter, but without critical comment.

The Report on Supply of Water to the Metropolis, made in 1851 by three leading chemists (73), notes that filtration will not wholly remove turbidity and suggests coagulation. The committee was informed by one of the London water companies that seven grains of alum per Imperial gallon would clarify and deodorize water of the Thames.

Tomlinson's *Cyclopedia of Useful Arts* (1852) (44) contains a comprehensive review of water purification. It describes "repose in large reservoirs"; takes up coagulation at some length; outlines the principal filters thus far built for municipal service and describes chronologically many British and French filter patents. The article remarks on "the multitude of inventions and contrivances for domestic filters" and fire escapes. "In either class," it says, "examples are as numerous as attempts to solve the problem of perpetual motion, or to square the circle. Almost any kind of porous substance has been enlisted into the service of filters." All organic materials except charcoal were condemned by the writer because after they had been kept wet for a period of time they "underwent decomposition, and imparted impurities" to the water.

Samuel Hughes, a civil engineer, in what seems to have been the first comprehensive British book on water works design (74), describes several filters of his day (1856), which he classes as Scotch and English. In the Scotch filter, he says, "the various kinds of filtering material are placed in separate compartments," while in the English they "are placed in successive layers, one above the other." This is the only known credit to the Scotch for having evolved a distinctive type of filter—credit well deserved. But he errs in telling what the type was. In view of the pains taken by Hughes to present up-to-date descriptions of Scotch and English types of filters, his error is unfortunate.

Growing Concepts of Filtration; Later Nineteenth Century

New concepts of what filtration could do were manifested at the middle of the nineteenth century. At intervals these were enlarged until in the 1890's even the majority of the skeptics had recognized that, instead of being a mere straining process for the removal of suspended matter, filtration removed deadly germs of disease. For some time the broader views centered on the reduction of organic matter, both suspended and dissolved.

A pioneer in the broader concept of filtration was Dr. Angus Smith—now best known for his preservative coating for cast-iron pipe. His ideas on filtration were expressed in papers before the British Association for the Advancement of Science in 1848 and 1851. Formation of nitrates, he said in 1848 (75), is one of many ways in which water purifies itself from organic matters. "In large operations, carbon is also oxidized. A filter . . . as an oxidizing agent, acts in proportion to its cubic contents." Three years later (76) he expressed the belief that filtration was more potent than distillation in removing organic matter from water "and, more than any other known method, improves the taste and appearance."

Determined to learn the precise nature of the effects of filtration upon ordinary river water, Henry Witt, Assistant Chemist at the Government School of Applied Science, in 1855–56 made chemical analyses of water before and after filtration (77). Besides studying the efficiency of Simpson's slow sand filters at the Chelsea Water Works, London, he made laboratory tests on less polluted water taken higher up the Thames at the site chosen by the Chelsea company for new filters. The Chelsea tests appear to have been, if not the first, the most thoroughgoing investigations up till then made of the purification effected by a slow sand filter. Taking into account both the Chelsea and the laboratory studies, the latter including both sand and charcoal as filter media, Witt concluded that "sand, charcoal and probably other porous media, possess the very peculiar property of removing, not merely suspended impurities but even dissolved salts from solution in water." Although, of the two, charcoal was the more efficient in removing dissolved organic matter, sand was capable of doing so, but in less degree. These properties of porous media "have important bearings upon hygienic science," he said. The paper contained detailed figures significant in the history of chemical analyses of water.

Wholly different from Witt's conclusions were those expressed by Edward Byrne, in "Experiments on the Removal of Organic and Inorganic Substances in Water," a paper read in 1867 (78). The paper was perhaps not as significant as the lengthy discussion it elicited from engineers and others. The discussion indicated, however, the wide range of opinion on what filtration would do. Byrne, it should be understood, was a pronounced advocate of obtaining public water supplies that did not require purification—a doctrine afterwards expressed by the phrase, "innocence is better than repentance."

Much of Byrne's study was designed to determine whether vegetable matter, either nitrogenous or non-nitrogenous, is dissolved in water. To settle this point he evaporated bog or peaty water from an uninhabited area. Finding vegetable nitrogenous matter present, he concluded that it, like animal organic matter, could be decomposed into ammonia and nitric acid. This, he believed, disproved the conclusions of Dr. Edward Frankland (79) that, after deducting the nitrogen corresponding to the nitrates and nitrites, any remaining nitrogen must be due to sewage matter.

Next Byrne made laboratory experiments on the removal of organic matter from water by filtration through various kinds of charcoal, using water from a garden well in Dublin. His final conclusion was that filtration was valuable in removing suspended matter from water but for matter in solution it was "manifestly useless." Hence, "the inconsistency of bringing home foul water to undergo a delusive method of purification, instead of . . . procuring water which itself is naturally pure."

Outstanding in fifty pages of discussion of Byrne's paper were remarks by Thomas Hawksley, then Vice President of the Institution of Civil Engineers (78). Chemists, he says, had given valuable information on water purification but it did not enable engineers to make better water works. "Attempts should be made to understand how filters operated; whether the charcoal was necessary or unnecessary; and whether the common and ordinary sand filtration was sufficient." Twenty years of experience led him to believe that filters operated chemically as well as mechanically and that the chemical changes depended very much on the state of the organic matter in the water and on the admission of free atmospheric oxygen. He makes the significant statement that "the sand cleaned the water mechanically by the agency of the principle of the attraction of aggregation." During the slow passage of the water through the filter "the minute particles of matter suspended in it were attracted and held by the facets of the sand and adhered there, and the water became clear. . . . Scarcely in any filter did the water remain foul for more than a few inches from the surface." A filter 12 in. deep was as effective as one of 2 to 3 ft. The sand filter actually destroyed organic matter.

H. Shield, after considering analyses of Thames water which had been passed through various types of experimental filters (those studied by Witt, mentioned above) expressed the opinion (78) that the action of the sand on organic matter was due to adhesion of the impurities to the surface of the sand, and consequent neutralization of much of the organic impurities. "Possibly the portion of organic matter removed was that which was in a state of decomposition, and which alone was noxious to health."

Edwin Chadwick, social and sanitary reformer (78), said that water supplies from unpolluted sources might be contaminated en route or stagnate in open reservoirs, the latter condition giving rise to "rapid growth of vegetation, then animalcules, then decomposition of animal and vegetable matter, which subsequently public or private filtration only partially removed." He suggested a "competent examination, by scientific men, free from professional interest or bias, who would compare promises with results, in money as in quantity and quality, of the supplies given." Filters of sandy or other soil not containing "vegetation," said Chadwick, were little more than sieves while those containing "vegetation," as shown by chemical analyses made by Professor Way, removed much if not all the matter held in solution. Where filters containing "vegetation" could not be obtained it would be more economical to keep impurities out of water than to filter them out. Where water was derived from gathering grounds underlaid with granite or other primitive rocks, he suggested stripping off their commonly thin covering of peat or other vegetable matter down to bare and clean rock. The water should then be led in covered channels to covered reservoirs and thence direct to houses. This "large order" overlooked the magnitude of the task of stripping an entire water-collecting area for cities with even as low a consumption as prevailed in England in the sixties; but it anticipated the stripping of the sites of large storage reservoirs which was to be practiced for a time by some cities in the northeastern United States a few decades later.

The oxidizing power of carbon, in terms of albuminoid ammonia, was announced in 1872 by the *British Medical Journal* (80, 81). This conclusion was based on tests of a small commercial filter of silicated carbon made for the *Journal* by Professor J. Alfred Wanklyn, noted English chemist.

After decades of widespread belief that, unless charcoal was used, filtration removed only suspended matter from water, the contrary opinion, which had been voiced from time to time by the more progressive men, was reinforced in 1873 by William Corfield, Professor of Hygiene and Public Health at the University College, London (82), who stated that considerable chemical as well as mechanical action took place in a sand filter. Corfield, however, failed to mention what Hawksley had said in 1867, namely, that considerable chemical action is caused by the air held between the particles of sand coming in contact with the finely divided water passing through the filter. The resulting oxidation of organic matter and its transformation into "innocuous matter," Corfield says, is the "first important point to understand about filters," whether for water or sewage.

It might be well to interject here that while English contemporaries were centering their thought on the removal of dead organic matter from water, an investigator in Italy directed his attention to living organisms in sewage. "Microscopical observations" convinced Dr. Dario Gilbertini of Parma (83) that "germs of zymotic disease, especially cholera, could not be removed by filtration."

The efficacy of sand filtration was concisely summarized in the sixth report of the Rivers Pollution Commission (1874) (26). Mineral matters in suspension in water are almost always innocuous, it says, but "impart a repulsive appearance which often leads to the rejection of a wholesome water for a bright and sparkling though dangerous one." Slow filtration through sand almost always removes suspended matters whose separate particles are readily seen, but washings from clayey soils are very difficult to render bright by sand filtration. Organic matters in suspension have not only the objectionable quality of suspended mineral matters but in addition they are sometimes actively injurious and "always promote the development of crowds of animalculae." Finely divided organic matters in suspension cannot be entirely removed by filtration. Elsewhere in the report much space was given to "Propagation of Cholera by Water" in the light of deductions made and facts gathered concerning cholera epidemics of 1832, 1849, 1854 and 1866. Data are given showing the relatively light incidence of cholera after the introduction of slow sand filtration.

The Encyclopedia Britannica, which in earlier editions had not reflected progress in water purification, put itself nearly abreast of scientific progress in 1875 (84). It stated in its article on filters that putrescent organic matter may include "minute invisible disease germs" which should be removed from drinking water. Numerous outbreaks of "virulent disease, such as typhoid," had been "clearly traced to water so contaminated." It was pointed out too that the danger was much greater because "such water may be bright and sparkling, and peculiarly palatable."

To the astonishment of most of his listeners, Percy F. Frankland announced before a meeting of the Institution of Civil Engineers on April 16, 1886 (85), that filtration removed most of the bacteria from water. This had recently been proved by counts of the water supplied by the London water companies. The bacterial cultures were made by the recently devised "gelatin process" of Robert Koch. Besides his studies of the results of filtration at the large plants of the London companies, Frankland reported laboratory tests with various filter media and other tests to ascertain the effect of agitating water containing finely divided matter. He showed that storage alone greatly reduced the number of bacteria in water.

For the last four months of 1885, filtration reduced the average number of bacteria in the Thames 97.9 per cent while for the River Lee the reduction was 98.5 in November and 88.8 in December. Frankland's pronouncement deserves quotation; so does his tribute to engineers who in doing their best to accomplish known physical objectives incidentally achieved remarkably beneficial results in the realm of what was so long unknown:

> Thus for the first time a definite conception has been obtained of the effect of sand-filtration upon these lower forms of life. Hitherto those who were acquainted with the size of these minute microscopic organisms on the one hand, and with the dimensions of the pores in a sand filter on the other, have believed that little or no barrier could be offered to these organisms by the comparatively spacious pores of the filter, and even the strongest advocate of sand filtration could not have reasonably anticipated that filtration through a few feet of material could effect the remarkable reduction in the number of micro-organisms to which the above table bears witness.
>
> It is most remarkable, perhaps, that these hygienically satisfactory results have been obtained without any knowledge on the part of those who construct these filters, as to the conditions necessary for the attainment of such results. In the construction of filter beds, water works engineers have certainly never been guided by an acquaintance with the habits of micro-organisms and yet by carefully improving their methods, so as to secure the removal of visible suspended matter, they have hardly less successfully, although unconsciously, attacked the invisible particles, and reduced them to an extent that is surprising. (85)

The ability of storage to reduce bacteria is best utilized, asserted Frankland, by allowing water, when bad, to go on its way downstream instead of into the reservoir. Higher quality water may be stored, and the bacteria therein will be carried to the bottom of the reservoir with other forms of matter in suspension.

Frankland concluded that: Complete removal of micro-organisms demands the best filtering material, its frequent renewal, and reduction in the usual rate of filtration. Agitation of the water with certain finely divided solids may sometimes remove a large part of the organic matter in water, but that method is unreliable. Chemical precipitation will largely reduce bacteria in water.

Unfortunately, the Institution of Civil Engineers, apparently not fully realizing the importance of Frankland's paper, did not print it in full.

Rideal's Summary.—The evolution of nineteenth century concepts of what slow sand filters do and how they do it was aptly summed up early in 1902 by Samuel Rideal, noted English chemist (86).

> Sand filters were first regarded simply as strainers; and the fineness and cleanness of the sand was the most important point. Analyses later proving that the soluble constituents were considerably affected, an explanation was sought in surface action. Afterwards from the fact that nitrates and carbonic acid were formed, a chemical theory of simple oxidation arose. Three discoveries, however, threw new light on the process: (1) The size of the finer mineral particles is only about 1/1,000,000 inch . . . and that of most bacteria 1/25,000 inch, or larger, but both are smaller than the interstices between the grains of even fine sand, consequently it follows (a) that the cleaning is not accounted for by simple straining, (b) that the organisms would be retained first. (2) Piefke in Berlin, about 1886, found that sterilized sand effected hardly any purification and did not retain microbes. It had previously been noticed that sand filters did not become efficient for several days after re-laying. (3) When the oxygen of the air, and the water, were sterilized little or no oxidation of organic matter occurred.
>
> It was proved, therefore, that for the proper mechanical and chemical effects the action of organisms is essential. It must be remembered that some organisms have long flagella, while a large number, such as diatoms and bacteria, are normally surrounded by a gelatinous envelope which greatly increases their size, and enables them to adhere to surfaces, so that in a short time the sand of a new filter becomes covered with a living slimy layer which entangles suspended matters and effects the main part of the purification. This is called *schmützdecke*. (86)

Subsequently, less emphasis was put on *schmützdecke*, a term and idea taken over from German writers. It should be understood that Rideal's summary related to slow sand filters and was written in England at a time when rapid or mechanical filters were but little used there.

Chapter V

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