CHAPTER XVI

Aeration in Theory and Practice

Water aerated naturally by flowing over sandy or pebbly beds or rocky falls has been extolled by writers of all ages and countries. Only a few of these enthusiasts realized that the waters they so highly praised were clear, bright, sparkling, tasteless and odorless when they reached the streams. In the eighteenth century, artificial aeration was directed at making up the oxygen deficiencies of distilled water and of rain water that had been stored in household cisterns. Toward the end of the eighteenth century and early in the next, aeration was applied to a few public water supplies carrying decomposed vegetable or animal matter. Not until the last half of the nineteenth century did aeration become a marked feature of municipal supplies. Even then, the number of applications was small and pertained chiefly to stored surface waters subject to taste and odors from algae growths. In this period, aeration was applied here and there, generally to ground waters, for the removal of iron, and then of manganese, and also to eliminate malodorous gases from sulfur-bearing ground waters.

There are two methods of aeration—the water may be discharged into free air, or air may be forced into a body of water. Apparatus used includes: low cascades; multiple-jet fountains throwing water to considerable heights; multitudinous spray nozzles discharging not far above the surface of a reservoir; superimposed trays or shelves; submerged perforated pipes; and porous tubes and plates. Motivation has been by gravity head for water, pumping head for water and pumping head for air. Chronologically, working installations consisted, first, of cascades and gravity-operated multiple-jet fountains; then forced aeration for a few years of commercial exploitation; then low-throwing spray nozzles; and, latterly, diffusion of air through porous tubes and plates in water.

Obsessed by the notion that removal of organic matter was the chief end and aim of aeration, many inventors and promoters centered their energies there. Chief among these was Professor Albert R. Leeds who patented and joined in exploiting a forced-aeration process in the 1880's and 1890's. In contrast, Professor Thomas M. Drown, after two years of laboratory experiment, announced that removal of organic matter from drinking water by aeration was not feasible and that elimination of gases causing bad odors and tastes was the desideratum. It is Leeds' due to tell that his method of forced aeration was used successfully by a few water works to prevent or counteract algae growths before the advent of copper sulfate treatment.

Concepts Before the Eighteenth Century

Theophrastus, an early Greek philosopher (c. 371–287 B.C.) (1), explains that running waters are generally better than standing water, adding, "and when aerated are still softer"—apparently smoother, less harsh. Columella (first century A.D.) (2) ranked as best, next to spring and rain water, running water from mountains, "provided it tumble down headlong over the rocks as at Guercenum." The *Charika-Samhita,* of about the same date in written form but probably much earlier in origin (3), said that the waters of rivers obstructed by rocks became clear and transparent by "constant beating." Pliny, late in the first century A.D. (4), noted that medical men justly condemn stagnant waters and approve running water as "being rendered lighter and more salubrious by its current and continuous agitation." Avicenna, a highly-esteemed Persian physician (10th century) (5), broadened the conception of nature's beneficent influence on water by putting spring waters first, "provided they flow from and over open ground exposed to the sun and wind." Contrariwise, he objected to water from wells or aqueducts because they are confined—"lacking oxygen" would be the modern term. Strangely, he deprecates the shaking up water gets in being drawn from wells or flowing down the slope of aqueducts. Later, he says well water "is cleaned . . . by the gases which bubble out of it in constant (molecular) motion." "Molecular" was apparently interjected by the translator.

Seventeenth and Eighteenth Century Ideas

Sir Francis Bacon (early 17th century) uttered the famous dictum "Running Waters putrefy not," in his *Sylva Sylvarum* (6), where he gave as the fourth way of preventing putrefaction, "*Motion* or *Stirring;* for *Putrefaction* asketh rest."

Clifton Wintringham, in 1718 (7), declared that nothing preserves "Water from corrupting and acquiring the most mischievous Qualities, so well as a brisk and rapid Motion." In the following year, Dr. Edward Baynard, in his jovial poem, *Health* (8), has this to say of water:

> Give it Motion, Room and Air
> Its purity will ne'er impair.

Dr. John Armstrong in his didactic poem, *Art of Preserving Health,* published in 1744 (9), wrote

> ——the lucid stream,
> O'er rocks resounding, or for many a mile
> Hurl'd down the pebbly channel, wholesome yields
> And mellow draughts . . . .

Between the two poets in point of time, and broader in conception of nature's own methods of making impure waters fit for use than any of the citations thus far given, is the assertion made in Plüche's *Spectacle de la Nature* (1732) (10) that the self-purification of rivers is effected by sedimentation, agitation and aeration.

At the very close of the eighteenth century the *Encyclopædia Britannica* (11), after noting that "Rivers which run through great towns are loaded with animal and vegetable substances," makes the questionable statement that those more remote "are purer than most springs," giving as the reason that "they run with more rapidity . . . and a great part of their impurities are thus vitalized." Confidence in the self-purification of rivers continued widespread until near the close of the nineteenth century.

Stinking Water Sweetened.—After two thousand years of recognition of the good effects on water of natural aeration, experiments on artificial aeration were reported. The first of these that has been found was in a paper on blowing showers of air through water being distilled, read by Dr. Stephen Hales on December 18, 1755 (12). Mr. Littlewood, a shipwright, came from Chatham, wrote Dr. Hales,

> ——purposely to communicate to me an ingenious Contrivance of his, soon to sweeten stinking Water, by blowing a Shower of fresh Air through a Tin Pipe full of small Holes, layed at the Bottom of the Water. By this means, he told me, he had sweetened the stinking Water in the Well of some Ships; and also a But of stinking Water in an Hour, in the same manner as I blow Air up thro' Corn [wheat, etc.] and Gunpowder, as mentioned in my Book on Ventilation (12).

For his experiments, Hales used "a Tin or Copper Air-box" 6 in. in diameter and 1½ in. deep, with its top perforated "full of holes $\frac{1}{20}$-in. diameter," about ½-in. apart. Rising from this was an air-

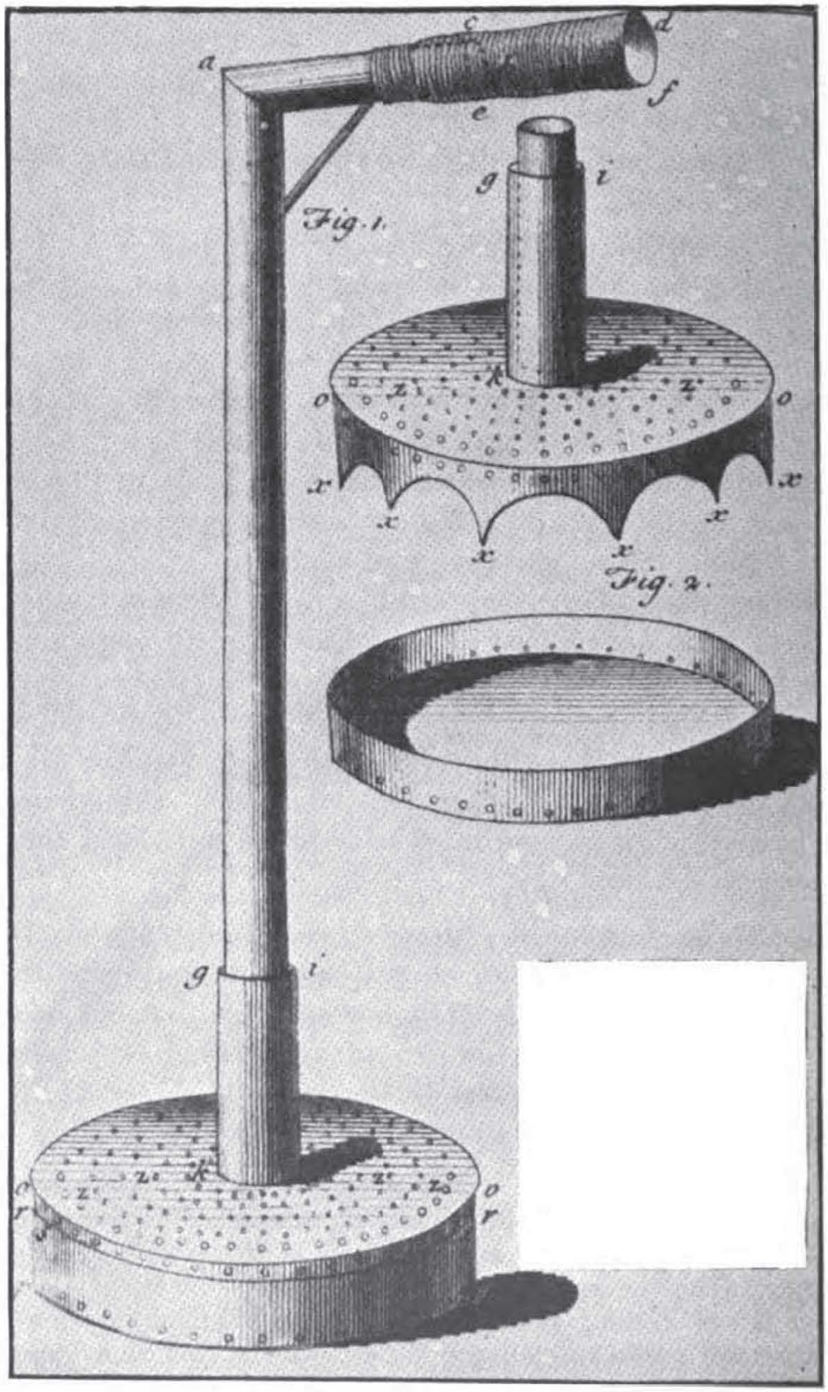

FIG. 67A. DIAGRAM OF LITTLEWOOD-HALES AERATOR FOR STINKING WATER
Bellows force air into perforated "box" immersed in water
(From reprint of Hales' papers read before Royal Society, London, 1756)

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Explanation of the FIGURES.

Fig. 1. (o o p r) a Tin or Copper Air-box, ſix Inches Diameter, and an Inch and half deep from (o to p.)

The Lid of the Box full of Holes, one twentieth Inch Diameter, and about a quarter of an Inch diſtant from each other.

(g i k l) a Nozel ſolderedto the Lid of the Air-box, into which theTin-pipe (a g i k l) is fixed ſo as to take in and out; this Pipe to be two Feet long, and ſix-tenths Inch Diameter.

(a b) a Bend in the Pipe five Inches long, to which is faſtened the leathern Pipe (c c d f) ſix Inches long; to which the Noſe of the Bellows is fixed at (d f.)

Fig. 2. (g i k l o o, x x) the Lid of the Box, whoſe Rim (o x o x,) is a quarter of an Inch deeper than the Box (o p Fig. 1.) that the Air-holes(o) may be pierced in its Upper-part; and the Lower-part is ſcol oped with wide Scol ops for the Air to paſs through the Holes (p p Fig. 1.)

FIG. 67B. EXPLANATION OF DIAGRAM OF LITTLEWOOD-HALES AERATOR (Reproduced from page 59 of Hales' papers) supply pipe to which was attached a leather hose connected with "the nose of the Bellows" used to force in air. Successful experiments with this device on milk and on water were reported by Dr. Hales in another paper read before the Royal Society, December 18, 1755. "Putrid water in marshy aguish countries," wrote Dr. Hales in the same paper, "may be the Cause of Ague, as well as the putrid Air carried into the Blood through the Lungs. . . . Blowing showers of Air up through the stinking Water of some aguish places may be beneficial." He also said: "Live fish may well be carried through several Miles, by blowing now and then fresh Air up through the Water, without the trouble of changing the Water. . . . But stinking Water will kill fish" (12).

In contrast with the Littlewood-Hales method of blowing air through water was the method of dropping water through the air, put into practical use apparently a little earlier. "Exposure to air in divided currents," says Dr. Edmund A. Parkes, Professor of Military Engineering in the Army Medical School (13), was

——proposed by Lind,* for the water of the African west coast more than 100 years ago. The water is simply passed through a sieve or a tin or wooden plate, pierced with many small holes so as to cause it to fall in finely divided streams. A similar plan, devised by Mr. Osbridge, has been used in the British Navy. A hand pump is inserted into a cask of water, and the water is pumped up, made to fall through perforated sheets of tin. It soon removes hydrosulphuric acid, offensive organic vapors, and, it is said, dissolved organic matters.

Postaeration in "a reservoir exposed to a current of air" was included in Montbruel and Ferrand's project of 1763–64 to supply Parisians with filtered water taken from the Seine above sources of pollution (see Chap. IV).

Aeration in Early Nineteenth Century Europe

At the Quai des Celestins water treatment plant, Paris, put in use by Happey in 1806, it is stated by Dunglinson (1835) that after the water had been settled, then filtered twice, it was aerated by being dropped like rain from the bottom of the second filters into clear-water tanks. This use of aeration is not mentioned by the earlier writers (see Chap. IV).

* James Lind, M.D., a British naval surgeon and hygienist. He wrote a book on scurvy (1753) and one on the health of seamen (1757) (see Chap. III, Refs. 11 and 12).

For restoring to water that has been boiled or distilled "the beneficial qualities of the atmosphere," Sir John Sinclair in 1807 (14) mentioned the well-known method of pouring water from one vessel to another. He proposed agitation in a "common barrel churn," and "machines on the principle of shower-baths." In large towns, aerated water "may be prepared in considerable quantities and sold so cheap as a half penny a bottle."

Of the many British patents on aeration taken out in the nineteenth century, the first was granted February 8, 1812, to Robert Dickinson and Henry Maudslay on "a process for sweetening water and other liquids." The process consisted "simply in forcing a stream or streams of air through the foul or tainted water." A bellows or preferably a pump could be used, the air being forced to the bottom of a water cask through a tube or hose ending in a tube of iron or copper perforated with small holes "to divide the air into numerous small streams, that the surface of water brought into contact with the air may be greater." The effect of the air is "that the offensive gas held in solution . . . will . . . be in a short time expelled from the water; after which the water should be left at rest for a little time, to allow its insoluble impurities to subside." Both the process and the apparatus are substantially the same in principle as those described in 1755 by Dr. Stephen Hales and patented again and again in England and America during the nineteenth century.

Of a dozen other British patents granted during the nineteenth century eight were for use on distilled water (generally sea water). Fraser took out a patent January 15, 1818; Peyre, February 23, 1836; Clark in 1843; Clegg and Fell, March 18, 1859; Normandy, March 27, 1860; Chaplin and Russell, October 23, 1862; Starnes on June 29, 1871.

Four other British patents on aerating fresh water, two of which were in general principle anticipations of American patents or practice, included: one by Theodore Cotelle December 1, 1838, which covered admitting air to a filter through tubes in the sides of the container; one by Richard Johnson, September 5, 1857, which covered dropping water for some distance in "jets, sheets or streams" upon a filter of broken slate, stone or other material so contact with atmospheric oxygen would cause "mineral particles held in solution by carbonic gas" to precipitate on the surface of the bed [similar to some American practices]; one by J. Storer on June 9, 1880, which covered rapidly rotating screw blades attached to a shaft; one by W. F. B.

Massey-Mainwaring and J. Edmunds on March 4, 1855, which covered "oxygenated" water or impressed air nearly down one side of a deep well of relatively small diameter, divided by a vertical partition, spreading it nearly at the bottom and letting the water rise through the other half of the well. In substance, this last process anticipated John W. Hyatt's United States patent of July 14, 1885.

The earliest known of the cascade type of aerator, working in series, was put into use in 1848 by the Gorbals Gravitation Water Co. to supply a district afterwards annexed to Glasgow, Scotland. Water from a large settling reservoir cascaded into a basin and from it into the first of three filters, arranged in steps. Similarly, there was a cascade between the first and second filters, the second and third filters and the last filter and a clear-water reservoir. The first three cascades were 9 in. and the fourth 12 in. high (see Chap. V).

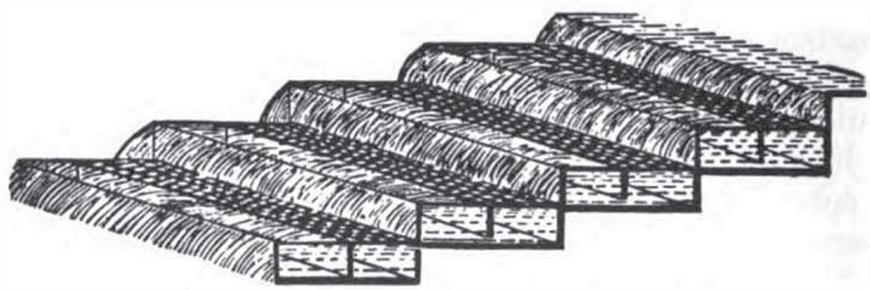

FIG. 68. RUSSIAN AERATOR, CIRCA 1860
Built for government paper mills on River Neva near St. Petersburg; water cascades upon and through wire network into trough with longitudinal partition; after several repetitions it falls upon sand filter
(From Humber's *Water Supply*, London, 1876)

In Russia, a dozen years later, an aerator was included in a water treatment plant built to supply a government mill on the River Neva at St. Petersburg (Leningrad). A detailed but vaguely worded description of the aerator was given in 1867 by C. E. Austen in a discussion of a paper by Edward Byrne describing experiments on the removal of organic and inorganic material from water (15). A condensation of the communication appears in Humber's *Water Supply*, accompanied by a sketch apparently made up from Austen's description (16). From these sources and from a memoir of Bryan Donkin (17), it appears that an engineering firm, which had been established in 1803 by the first Bryan Donkin, contracted with the Russian government in 1858 to build "a mill to supersede the existing hand-mill for the manufacture of State papers and Government bank notes." The contract included pumps, settling reservoirs, an aerator and sand filters. Young Donkin was sent to St. Petersburg in 1859 to superintend construction of the works. On "their successful completion in 1862 he received the personal thanks of the Czar through the Minister of Finance." Austen, who calls the aerator a strainer, describes the water of the Neva as soft but holding "in solution a large quantity of decomposing vegetable substances." The "strainer," he says, was made up of four "troughs" arranged in the form of steps. Each of these "was divided longitudinally by a partition which did not reach the bottom, into two compartments, the inner one of which was covered by wire gauze, and received the water as it fell from the step above, and the outer of which contained the horizontal-tipped orifices through which the water escaped as it flowed to the step below." Each step was 2 ft. high. The lowest step was superposed to one of four sand-and-gravel filter tanks, "each 558 ft. in area." After passing downward through filter tanks, the filtered water flowed to "deep wells in which it was stored for use." The rated capacity of the treatment plant was 100,000 cu.ft. in 10 hours, or about 750,000 gal. (U.S.). Strange as it now seems, Austen made this statement, which was apparently based on personal observation:

——the water entered the first step in a perfectly pellucid state, but before it had passed through two sheets of gauze it became turbid, and deposited a black scum on the wires which required constant cleaning, so great was the quantity of the deposit. In the first [filter] tank the water was partially covered with a black scum or froth, sometimes more than an inch in thickness, and a thin scum, having a metallic lustre, appeared on the surface of the second reservoir [filter].

Aeration in Twentieth Century Europe

Puech-Chabal Cascade Aeration.—The system of aeration most widely used on the Continent was that of cascades placed between Puech-Chabal multiple filters. The method was introduced early in the twentieth century, shortly after Puech-Chabal filters in series came into use. A notable example was afforded at Magdeburg, Germany, about 1910. Low cascades between the roughing filters were supposed to maintain the supply of dissolved oxygen (see Chap. IX). Over a half century earlier, cascades for aeration were placed between multiple filters in the Gorbals district of Glasgow (see Chap. V) and in 1892, as already mentioned, at Tacoma, Wash.

Candy's Compressed Air and Oxidizing Water Works Filter.—Candy's apparatus, described in a paper read by Don early in 1909 (18), is entitled to notice as a curiosity among both aerators and mechanical filters. Water admitted beneath the filtering material, after the filter has been drained, is passed up through the material. This, it is claimed, forces the interstitial air into the space between the top of the material and the dome of the filter tank and compresses it. For a filter 6 ft. in diameter, with a 5-ft. depth of filtering material and a 2-ft. space between the filter media and the top of the dome, 250 cu.ft. of free air is assumed to be compressed. Raw water is sprinkled into the compressed air through four radial arms just beneath the dome of the filter tank, drawing the compressed air with it into the filter. There are three layers of filtering media: at the top, crushed silica, graded from coarse downward to fine, designed to remove most of the suspended matter; "oxidium, for oxidizing and purifying," wherein the air contributes to oxidation; fine silica sand; and grit for final filtration. The layers are supported on grids. The filter is washed by reverse flow. When the air gage shows that the "impressed air is becoming exhausted through solution in the water" the air supply is renewed by recharging, as at the outset, generally once in 24 hours. Don suggested that doing this once a day, and wasting 1,000 gal. of water, might be obviated by using an air pump. This type of aerated filter, Don stated, was new and not widely used.

Aeration in America

The first known aerator * on an American water supply was a part of works built in 1860–61 by the Elmira, N.Y., Water Works Co. As described by a report of the *Tenth Census of the United States* (20), water from an impounding reservoir was admitted to a distributing reservoir "through a fountain discharging-trough—a cluster of holes for aerating and purifying." The *Manual of American Water Works* for 1897 (21) stated that on entering the distributing reservoir the conduit "turns up," making a fountain jet.

* Aeration was proposed but not adopted for Toronto, Canada, in 1854. Water pumped from Lake Ontario was to be delivered into a reservoir, above the water surface, through a perforated pipe "extending along one side of the reservoir." The plan was submitted by Henry Y. Hand, Professor of Chemistry, Trinity College, Toronto, and Sandford Fleming, a railway engineer, and won a second premium of £50 (19). None of the competitive plans was adopted.

James Caird, Troy, N.Y., consultant to the company and city since the late 1890's, states that "on the top of the riser was the figure of a crane with its neck stretched out and water spouting through its mouth." The original works for Elmira were designed by Alphonse Fteley and Francis Collingwood in 1860.

The next American aerator of record was of the single cascade type. It was part of the water works of Lawrence, Mass., completed in 1875. Water from the Merrimac River or an adjacent filter gallery was discharged from the force main through a bell-shaped mouth onto a stone platform from which it fell over six granite steps, each 10 ft. wide, into the reservoir (21).

Early Multiple-Jet Aerators.—Earliest of a number of American multiple-jet fountain aerators was a notable one for the water works of Rochester, N.Y., completed in 1876. Ten years later, J. Nelson Tubbs, Engineer and Superintendent of Water Works, wrote that the value of a thorough aeration of water had been an accepted fact for many years. Accordingly, when the works were constructed a device for aerating the supply during the summer had been provided (22).

In the center of the Mount Hope or Highland Park distributing reservoir, the 24-in. supply main bringing water from the Rush storage reservoir was carried up through a masonry tower and capped with an enlarged cast-iron dome. The dome was pierced with 20 circular 2-in. holes, arranged in two concentric circles around a central 6-in. hole. Into these holes were screwed threaded brass caps for the addition of reducers so the openings could be "adjusted and graded to any sizes desired to give adequate supply, and also to cause the ascending jets of water to assume varied and symmetrical forms." The head on the jets was the difference in elevation between the storage and distributing reservoirs, or about 118 ft. The height of the jets ranged from 60 to 100 ft.

> The water returns in finely-divided particles, almost in the form of spray, and in its passage through the air is thoroughly aerated. The fountain when in operation is a most beautiful and conspicuous object, being visible in some directions at a distance of at least twelve miles, and attracts a vast number of visitors during the season in which it is in operation (22).

A similar aerator was put into use at the Cobb's Hill Reservoir in 1908. During the winter season, the incoming water at each reservoir is discharged near the bottom of the reservoir. In 1941, both aerators were still operated from April to November (23).

Most elaborate of the early American fountain aerators was one put into use October 26, 1890, by the Utica, N.Y., Water Works Co. Seventy-six vertical pipes, with perforated caps, 1 ft. above high-water level, discharged into a distributing reservoir. This reservoir was fed from another, under a 44-ft. head when the upper reservoir was full. The risers were fed from 12-in. pipe laid in a quadrangle formed on each side by three 12-ft. lengths of cast-iron pipe joined by

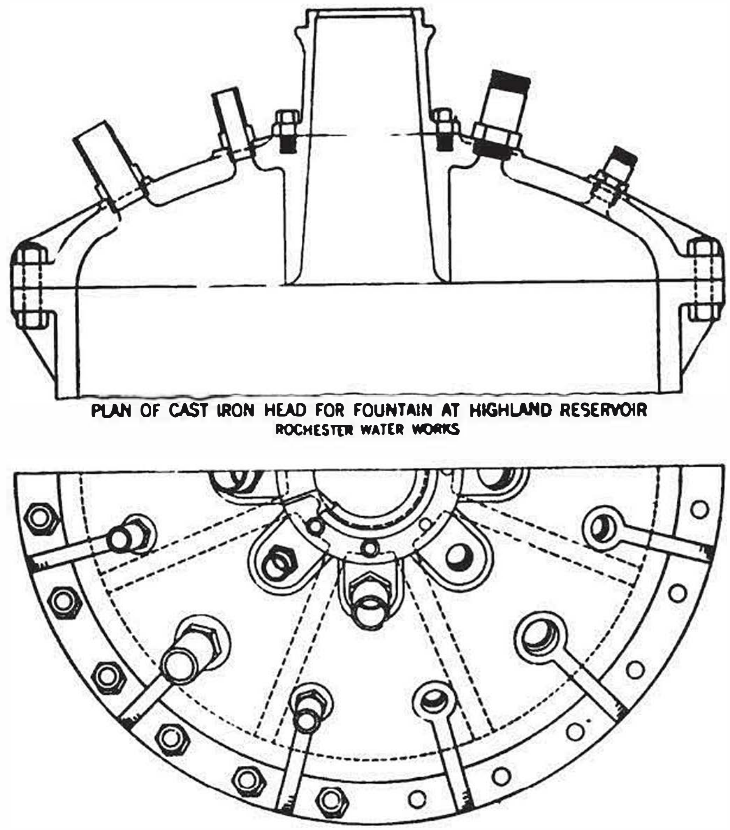

FIG. 69. MULTIPLE JET AERATOR AT HIGHLAND RESERVOIR, ROCHESTER, N.Y. Cast-iron fountain head on top of riser from gravity supply main; large jet in center, twenty smaller jets set at angles in two concentric rings (From drawing of March 29, 1875, supplied by Rochester Water Dept.)

quarter bends. This square was laid on the bottom of the reservoir in water 10 ft. deep. Attached directly to this quadrangular manifold were 71 2-in. vertical pipes about 2 ft. apart. Five branch pipes led to risers. Of these, four had diameters of 2 in. and led one from each corner of the square. A 6-in. branch led to a 4-in. riser at the center of the square. The caps of the 76 risers were perforated to give orifices of the following diameters: 16 1-in.; 16 ¾-in.; 16 ⅝-in.; 56 ½-in.; 80 ¼-in.; and 52 ⅛-in. The relation of these sizes to each other and their purpose is not stated. The jets converged toward the center of the fountain. Their total discharge capacity was 4,000 gal. per min. By means of screw joints the upper part of each riser could be removed to avoid ice damage.

The Utica aerator was designed by H. J. Wood, one-time secretary of the water company. Its object was to eliminate tastes and odors. When installed, the water supply was impounded in three reservoirs from which it passed by gravity to the distribution system. With the growth of the city the capacity of the aerator became inadequate, reservoirs were built at a higher level and the aerator was dismantled —probably in 1902 (24).

A fountain aerator with 70 ring nozzles to give aeration before slow sand filtration was put into operation as a part of water works for Ilion, N.Y., completed in September 1892. Water from a creek having a drainage area of cultivated farm land was carried through an 8-in. gravity pipeline 6,000 ft. to a storage reservoir having a flow line 180 ft. below the lip of the diverting dam. This main came into the bottom of the reservoir and was carried up through a masonry tower to a point a little above the surface of the water in the reservoir. The uptake pipe terminated in a cap having 70 ring nozzles, arranged concentrically, thus: at the center, a single ½-in. nozzle, then 6 ⅜-in., 14 ¼-in. and 49 3/16-in. nozzles. The center nozzle discharged vertically. the others at angles of 5, 10, 15 and 20 degrees, proceeding outwardly. The maximum compound discharge was nearly 0.9 mgd., and the maximum observed height of the central jet was 90 ft. "The water discharged is broken up into a multitude of small drops and falls into the reservoir in the condition of fine rain, so that aeration is very complete." Earle J. Trimble, Supervising Engineer, Ilion Water Works, wrote on July 8, 1942, that the fountain was still used, but in summer only. A similar jet fountain was installed for the water works of Frankfort, N.Y., about the same time (25).

An aerating canal or a series of cascades was included in the water works of Little Falls, N.Y., completed in 1888 with Stephen E. Babcock as engineer. The supply was an "exceptionally pure mountain stream," stored in a reservoir, but was conveyed 8¾ miles through a closed conduit. Just before reaching the distributing reservoir, the water was conveyed 1,600 ft. in an open trapezoidal-shaped canal, in which were sixteen weirs, each 2 ft. high and 10 ft. across. From the lower end of the aerating canal a cast-iron pipe was carried to the bottom of the distributing reservoir, turned up vertically and discharged over the top and sides of a low pyramid of masonry into the reservoir —"giving a final oxidation" (26).

At Tacoma, Wash., a few years later, aerating cascades and "windrows" of scrap iron were placed in a wooden flume ahead of upward-flow filters, simulating the Anderson process of producing metallic iron as a coagulant (see Chap. IX).

An air-induction aerating device was included in water works built in 1888 by a private company to supply Jefferson City, Mo. Professor J. B. Johnson, then of St. Louis, Mo., was engineer for the works. Water was pumped from the Missouri River to a 0.5-mgd. aerating and settling basin, 20 ft. deep. The force main discharged water downward into the settling basin through a flaring-mouthed pipe "containing bent tubes through which air was drawn" (27). L. W. Helmreich, Vice-President of the Capital City Water Co., stated on July 30, 1940, that notwithstanding extensive inquiries he could find no one who remembered an aerating device.

Aeration to remove sulfur taste from artesian well water at Jacksonville, Fla., has been practiced since about 1889. Water from a 10-in. artesian well, 1,020 ft. deep, sunk in 1888–89 to supplement smaller wells of lesser depth was discharged through a pipe, turned downward, 10 ft. above the surface of an octagonal settling basin 50 ft. across and 30 ft. deep. In 1896, two aerating basins, 50 ft. in diameter by 10 ft. deep, were put into use. These were open but have since been covered to exclude dust from nearby streets. Water from the artesian wells was discharged vertically at the center of the basins making a fountain aerator. In 1915, two new basins were built to aerate water from the old and from new wells. Each basin was about 50 ft. in diameter and 10 ft. deep. Water was discharged from their centers upon a table sloping gently in all directions and dotted with baffle blocks so spaced as to break up the water as it dropped from the table into the basin. In 1927, two additional aerating basins, similar to those constructed in 1915, were made. These receive water from wells at another location. All the aerating basins are screened and ventilated.

Forcing air up through a slow sand filter bed and also through the filter effluent at Nantucket, Mass., was provided for in a treatment plant designed in 1891 and completed in 1892, with J. B. Rider as engineer. The object was to remove tastes and odors caused by excessive growths of micro-organisms in Wannacomet Pond. Since no trouble occurred in 1892, the filter and aerator were not used until 1893. Air was delivered upwards into the filter through vitrified underdrains. W. F. Codd, Superintendent, Wannacomet Water Co., in a letter dated February 27, 1894 (28), stated that the air delivered through the underdrains caused air passages in the filter through which the water passed down without much filtration; and that it also caused craters at the surface of the filter thus making the sand of uneven thickness. In consequence, air was shut off from the underdrains. *Anabaena* appeared August 8, 1893, says Codd, whereupon the filter and aerator were put into use with good results. Contrariwise, the records of the Massachusetts State Board of Health, says Arthur D. Weston, Chief Engineer there (29), showed that the plant was not effective in removing tastes and odors caused in 1893 by large growths of *Anabaena*. The plant was used from time to time as late as the summer of 1919, says Weston, but "as it had never removed the tastes and odors to any considerable extent it was considered as abandoned." Since 1929, water has been taken from tubular wells at Wyers Volley. In 1939, J. H. Robinson, Manager at Wannacomet (30), wrote that "the filter and aerator were not entirely successful and after a few years were abandoned; cost of operation and lack of capacity were contributing reasons."

Professor Drown on Aeration.—The inability of man-made aeration to accelerate nature's method of oxidizing organic matter in potable water and the uses to which artificial aeration can be effectually applied were announced by Thomas M. Drown in 1892. His paper (31) was based on two years of experiments in the laboratory of the Massachusetts State Board of Health. The study was designed to test the "theory of accelerated oxidation." Drown said in part:

——it is not uncommon in water works practice to aerate water by causing it to flow over a series of steps, . . . by forcing it into the air as a fountain, or by pumping air under pressure into the distribution system. Whatever the method the idea behind it is that the water will thereby be purified by oxidation to a degree beyond that which would take place if the water were exposed to the air on the surface only. . . . The question, let it be clearly understood, is not one of supplying oxygen to an impure water, like sewage, which contains no oxygen, but this: Will impure water, which contains at all times more or less free oxygen in solution be purified more rapidly by oxidation if the amount of oxygen is increased by spraying the water or by pumping air into it; can the natural process of oxidation be hastened by these means? It is to this question that the experts give a negative answer. . . [Conclusions] (A) The oxidation of organic matter in water is not hastened by vigorous agitation with air or by air under pressure. (B) The aeration of water may serve a useful purpose by preventing stagnation, by preventing the excessive growth of algae, by removing from water disagreeable gases, and by the oxidation of iron in solution.

The significance of Drown's experiments and conclusions will become more apparent after considering the section on Leed's and Hyatt's patented processes of aeration, below.

Other American Aerators.—At Wilmington, Del., in 1894, George H. Sellers attempted aeration as a part of his elaborate water treatment plant modeled on the Anderson process (see Chaps. X and XIII). At Butte, Mont., in 1895, an air compressor, mounted on a flat boat propelled by a stern paddle wheel, was tried in combatting the tastes and odors caused by micro-organisms in a large reservoir. Air from the compressor was discharged through perforated pipe hung over the sides of the flatboat. "A few weeks experiments with this homemade contrivance convinced me that it was doing no good and the project was abandoned," Eugene Carroll, General Manager, reports (33).

Pre- and postaerators were put into use in March 1895, in connection with new gravity rapid filters on the water works of Lexington, Ky. This aeration-filtration system was adopted, wrote S. A. Charles, Secretary and Superintendent of the Lexington Hydraulic and Manufacturing Co. (34), "to remove algae and vegetable growths, principally, and also some mud from impounded surface water. . . . We think that we have provided for aeration to a greater extent than has previously been done." Pre-aeration was effected by letting the raw water fall 7 ft., in about 1,600 fine jets from perforated pipe, to the surface of the mechanical filters. This aerator was beneath "a sort of dome with adjustable openings designed to create a draft and assist in carrying off any gases which escape during the spraying." Effluent from the filters passed through a "vat of charcoal" 10 ft. square having a zinc bottom perforated with ⅛-in. holes, from which the water fell in showers into the clear-water basin.

An aerator for iron removal was completed at Reading, Mass., in July 1896 (35), to treat water from a filter gallery near the Ipswich River. The aerator basin was 33×19 ft. in plan $\times 4\frac{1}{2}$ ft. deep, and was placed above the coagulation basin. Water was delivered to the aerator through the bottom of a hopper at one end of the basin. In rising, the water met a descending supply of milk of lime. The limed water then passed into one of four longitudinal compartments in the settling basin and around end-to-end baffles, giving a total travel of about 130 ft. During this journey the water was violently agitated by air blown up through 23 1½-in. nozzles placed at intervals in the bottom of the compartments. Air was supplied by a blower with a guaranteed capacity of 150 cu.ft. per min. at a maximum pressure of 3 psi. or about 2½ psi. available pressure. Each particle of water, a contemporary description stated, received 23 successive aerations, thoroughly oxidizing the iron in the supply. On emerging from the basin the aerated water was dosed with alum and passed to the coagulation basin and then to Warren gravity mechanical filters. The entire plant was designed by F. L. Fuller, after experiments by Desmond FitzGerald and Thomas M. Drown (36, 37).

Forced Aeration Designs by Leeds

Nearly all of the aerators thus far described worked under gravity heads and discharged water into the air. In the last two decades of the nineteenth century, Professor Albert R. Leeds and John W. Hyatt patented forced aeration by means of which air or oxygen was discharged into water. Their systems were generally operated in conjunction with rapid filtration (38–43).

Leeds' system was initiated at Philadelphia, where water drawn from the Schuylkill River to supply Philadelphia in January and February 1883, was noxious to smell and taste. This was attributed to the ice cover from the Fairmount Dam to the headwaters of the stream which prevented restoration of oxygen absorbed by organic matter in the water. Leeds, who was Professor of Chemistry in the Stevens Institute of Technology and also chemist to the Philadelphia Water Department, showed by experiments in the institute laboratory at Hoboken that aeration of samples of water from the Schuylkill restored dissolved oxygen and decreased the organic content (38).

These results were submitted to Messrs. Chesborough, Merrick and Graff, members of a special water commission, and to Col. William M. Ludlow, chief engineer of the water works, with a proposal that all the water from the Schuylkill be purified by introducing air under pressure into the force mains. The idea was so novel to these men that they were unwilling to incur the responsibility of advising its adoption. But in November 1884, Colonel Ludlow converted one of the turbines at the Fairmount pumping station into an air pump. Delivery of 20 per cent by volume of free air into the 48-in. force main leading 3,000 ft. to the Corinthian Basin increased the oxygen in the water 17 per cent and decreased the free ammonia 80 per cent.

Subsequently, Ludlow procured air-compressors for all of the Schuylkill pumping stations but only at Belmont was the compressor used and there not after 1886. Conflicting reasons for the abandonment of aeration at Philadelphia were given. Leeds, in a lecture delivered before Franklin Institute, December 23, 1886 (39), stated that the other force mains were "too leaky to permit" their use for aeration. But the Philadelphia water works report for 1886 (40) declared: "This is not the reason, as the other pumping mains are all in good order." It added: "They are laid in such a manner [on such a profile?] that no engineer would care to assume the risk of damage to engines and mains that would probably result from the use of this process."

Whatever may have been the reason for ordering air compressors at all the Schuylkill pumping stations, putting them in use at only one and abandoning that one after some months of use, the dream of aerating a large part of the Philadelphia water supply soon faded.

Directly after his experiments on the Philadelphia water supply in 1883, Professor Leeds applied for apparatus and process patents on saturating water with oxygen or ozone by introducing air under pressure into water under pressure and in motion. These were granted in 1884.*

The object of his invention, Leeds stated in his specifications, was "to restore by a rapid and powerful method of aeration," oxygen lost by water when stored in reservoirs or when covered by ice, as in a stream, this loss causing the water to become foul and unwholesome. Furthermore, his object was to utilize the power of oxygen to destroy deleterious substances.

* Apparatus application filed September 17, 1883; granted April 8, 1884. Process patent, filed November 3, 1883; granted May 6, 1884. British patent, dated November 10, 1884. Leeds' American patents were soon assigned to a company (name unknown); they passed to the National Water Purifying Co. in 1886, the New York Filter Co. in 1891. Leeds or one of these companies acquired patents on aeration by introducing air directly into reservoirs, notably one or both of the D'Heureuse patents of 1871 and 1884.

In all the earlier artificial processes of oxidizing water for domestic supply, Leeds said, use of air under atmospheric pressure was proposed and during treatment the water was confined within wells, cisterns or reservoirs, as in the American patents of D'Heureuse, February 28, 1871; Collins, May 3, 1881; and McCurdy, October 7, 1882.

Professor Leeds' theory was that if air could be forced into water under high pressure the oxygen in the compressed air would "go into solution in the water to the almost entire exclusion of the nitrogen." His process could be applied by any convenient method, he said. The one shown in the patent was to force air into the lower end of a pump line delivering water into a reservoir through a submerged bell mouth. All air in excess of that absorbed by the water was to be "detained" in the closed system by means of "air-chambers . . . on the upward bends of the pipe."

Leeds did not limit his patent to the use of "oxygen contained in the air" but included either "ordinary pure oxygen," or else "the allotropic form of oxygen commonly called 'ozone' as well as any mixture of oxygen or ozone with air." The claims allowed in the patent were:

1. In the art of purifying water, the process of saturating water with oxygen or ozone, consisting of introducing into water while in motion, under pressure, compressed air also in motion, substantially as described.

2. In the art of purifying water, the process of saturating it with oxygen or ozone by causing the water to come in contact, while under artificial pressure and in motion, with compressed air in a system of pipes and air chambers, permitting both air and water to enter under pressure, to move through said system while under pressure, and to be discharged into a suitable reservoir, substantially as described.

These process claims were put into use at several places. In addition, compressed air was applied directly to the bottom of several reservoirs. Although in papers that he wrote Leeds claimed that these reservoir installations were under his system, they seem to have been reversions to the so-called inventions of the earlier patents acquired by the companies that took over Leeds' patents.*

Hackensack, N.J.—Largest and apparently the longest-lived installation of the Leeds system of aeration was made by the Hackensack

* Robert H. Thurston, well-known mechanical engineer, who filled important chairs of engineering at Stevens Institute of Technology, 1871–85, and at Cornell University, 1885–1903, took out an aeration patent on July 14, 1885. This was soon after the date of the Leeds' patent and may have been suggested by it, as they were both at Stevens Institute at the time. Thurston's single claim was for automatic apparatus to force air into the suction pipes of a pumping main.

Water Co. on the water supply of Hoboken and adjacent towns in New Jersey. Aeration was begun in September 1884. Positive evidence on how long it was used is lacking but it was used in 1897 and may have been continued until 1905. At first compressed air was admitted into the force main leading to a 15-mgd. distributing reservoir in Weehawken. Later, this was supplemented by an air compressor at the reservoir from which air was delivered into the bottom of the reservoir. When a second reservoir was built, this was supplied by air piped over from the compressor of the first reservoir.

Leeds wrote in 1892 (41) that during one of the hottest periods of the unusually warm summer of 1884, the water supply of Hoboken acquired "a very unpleasant vegetable odor and taste," originating at Weehawken reservoir. In "less than 24 hours, the previously clear water became covered with a thick coat of bluish-green algae." He proposed "that an air-compressor should be attached to the 30-in." force main at the New Milford pumping station. The air would thus have an opportunity to act on the water during its long flow to the reservoir, 100 ft. above the river.

Having in mind the statement in the 1886 report of the Philadelphia water works (40) (see above), Leeds noted that the force main passed over "two summits and through two submergences." He added (41):

> Some distinguished hydraulic engineers predicted failure on the ground that the air would fill the summits, and would act as a cushion against which the water might be pumped without advancing further in the main. But with the least possible delay, Mr. Charles B. Brush, the Chief Engineer, began the aeration. The growth of algae ceased immediately and the water was restored to its usual palatable condition. During the eight years that have elapsed, the trouble of either air-cushions or air-leaks in the main or distribution service has never occurred.

Prolonged heat in 1886, "brought about the formation of patches of algae in the corners of the distributing reservoir." The incoming water "contained its normal percentage of dissolved oxygen and carbon dioxide" but on standing oxygen was lost, the carbonic acid was increased, and "stagnation appeared." Thereupon, said Brush,

> I applied another patented feature of my aeration system,* which is the driving in of air through a pipe carried around the four sides of the reservoir

* Leeds' patents covered only forcing air into water in motion under pressure. The earlier patents of D'Heureuse (1871), Collins (1881) and McCurdy (1882), Leeds noted, were for admission of compressed air into wells, cisterns or reservoirs. These patents were acquired by the company that promoted Leeds' patents.

and terminating in many rose-jets placed at the ends of terminals going down nearly to the bottom. The air boils up at any or all of these points through the water, and the breaking up and disappearance of patches of algae take place forthwith. [Monthly analyses] show the beneficial effect of this system and the entire avoidance of the trouble, which it was introduced to remedy.

Chief Engineer Brush stated on May 1, 1889 (42): "We forced fresh air into our pipes in 1884 and up to this time we have had no repetition of trouble. We are now aerating the water in the reservoirs as well as in the pipes. The public sees the air bubbling up in the reservoir. It looks like springs and creates a favorable impression." In 1891, Brush said that air had been supplied to the force mains for seven years; and that one main was fifteen and another sixteen miles long (43). In 1893, he wrote that compressed air under 90 to 125 psi. pressure had been forced into the rising mains at the pumping station (44). On January 7, 1897, Brush reported that aeration had been used from April 15 to November 15 each year since 1884 (21). Each of two of its reservoirs was "encircled by 3-in. wrought-iron pipes from which at intervals of about 100 ft. a 2-in. wrought-iron pipe is laid down the slope of the reservoir, to which is attached at right angles a perforated pipe about 6 ft. long lying on the bottom of the reservoir. Each discharge pipe has a gate near its top for regulating the air." Writing in 1935 and 1936, M. W. Cowles, Health Officer of the Hackensack Water Co., stated that the company's files contained little information about aeration. So far as he could learn, aeration at the first reservoir was continued until the completion of the rapid filtration plant at New Milford in the fall of 1905 (45).

Champaign-Urbana, Ill.—Notwithstanding indisputable evidence that aeration in connection with National filters was put into use in June 1887, and was being used the following January at the water works supplying Champaign and Urbana, Ill., the officials of the company now owning the works can find no record of either filtration or aeration having been used there at the time. But a letter from S. L. Nelson, Superintendent, Union Water Supply, dated Champaign, January 14, 1888, to the National Water Purifying Co. (46), begins: "The filter plant which you placed in our works, June last, has been working satisfactorily, and the combined influence of Aeration, Lime Precipitation, and Filtration renders our water clear and bright, free from odor and vegetable matter and sparkling in appearance, resembling the namesake of our town (Champagne). It also removes the hardness of the water." Further on, Nelson uses the phrase "six months tests." Publicity matter issued by the National Water Purifying Co. and its successor in 1889 and 1893 cite these works among those having aerators for mains and reservoirs. The water works in question were completed in 1885 by the Union Water Supply Co. Water was taken from an abandoned coal prospecting shaft, 8 by 12 ft., by 40 ft. deep. It was pumped direct to the mains and to a 0.25-mil.gal. brick-lined reservoir in excavation and embankment, 60 by 60 ft., by 16 ft. deep. The source of supply was soon changed to driven wells. Years later, aeration was employed as a part of an iron-removal plant.

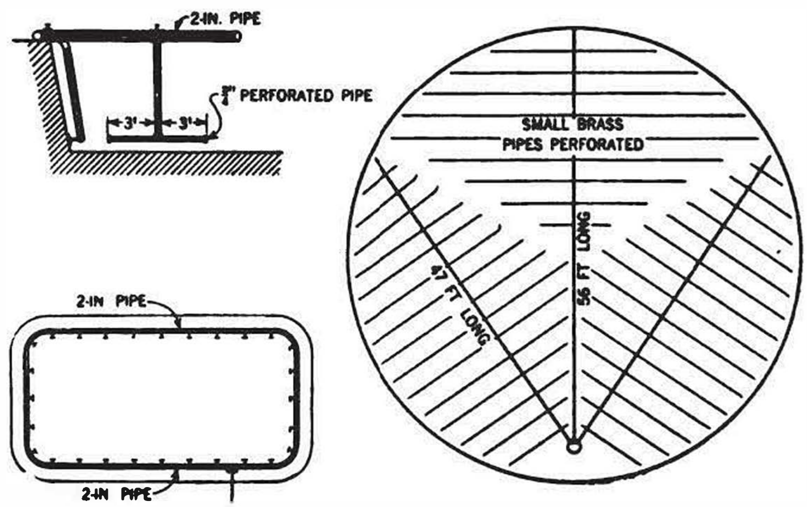

Fig. 70. Forced Aeration at Norfolk, Va., and Brockton, Mass.

Left: Norfolk (1888): compressed air delivered at bottom of reservoir through perforated iron pipes

Right: Brockton (1891): air delivered at bottom of 1.3-mil.gal. tank, 62 ft. in diameter by 59 ft. high, through grid of 39 small brass pipes with ⅛-in. perforations 3 ft. apart, supplied by 2-in. iron feed pipes

(Redrawn from (Norfolk) diagram dated June 5, 1888 and (Brockton) Leeds' "Mechanical Aeration of Water," *Stevens Indicator*, 1892)

Norfolk, Va.—A plant for aeration by compressed air in accordance with the Leeds patent was put into operation on the water works of Norfolk, Va., July 1888. It was installed by the National Water Purifying Co. in place of filters that had been recommended. The water supply was from impounding reservoirs, the bottoms of which were not stripped before being flooded. When the reservoirs were drawn down, vegetable growths occurred, followed by tastes and odors.

Aeration helped eliminate odors but the pumping engineer, in his report for 1889-90, stated that the compressor was too small for the average consumption of 3 mgd. (47). As first operated, compressed air was delivered through outlets from a pipe paralleling the inside of the reservoir. Replying to an inquiry, R. W. Fitzgerald, Chief Chemist, Norfolk Water Works, stated December 3, 1935 (48), that the installation consisted of "an air-pressure and perforated-pipe system which aerated the water in the pump suction and basin. It was operated intermittently until 1896 when a connection was made from the compressor directly to the delivery main. The records do not show how long air was pumped into this main but this system was not used after the installation of mechanical filtration [in August 1899]."

New Rochelle, N.Y.—Persistent attempts to aerate the water supply of New Rochelle, N.Y., were made during an uncertain number of years, probably beginning in 1890. The 1893 catalog of the New York Filter Co. cited New Rochelle as an example of water works employing aeration, under its (Leeds) patents, by injecting air under pressure into a continuous body of moving water, also under pressure. It did not tell when the system was installed. The New Rochelle Water Co. built works in 1885–87, with J. J. R. Croes as designing engineer and Charles W. Hunt as constructing engineer, the latter becoming operating engineer and superintendent. The supply was taken by gravity from an impounding reservoir on Hutchinson Creek. Late in 1896 there were two impounding reservoirs, both on the same creek. Water from the reservoirs was delivered in part by gravity, but some was pumped to standpipes (21).

E. T. Cranch, Manager of the New Rochelle Water Co., in 1941 (49) quoted John G. De Veau, a retired employee, who began working for the company at the pumping station in 1891. Cranch wrote:

> Mr. De Veau advises us that at the time he started with the Company there was a Clayton Air Compressor driven by a Backus Water Wheel which discharged air through a 2-in. line into the gatehouse from Reservoir No. 1. This method of aeration was found unsuccessful and discontinued. The next attempt at aeration was by means of a riser pipe installed in a standpipe at the Union Corners Pumping Station located at the foot of Reservoir No. 2. The riser pipe extended 5 ft. above the standpipe and all the water entering the standpipe was pumped through the river pipe. This method also proved unsuccessful and was discontinued. Westinghouse air compressors were then installed at the Union Corners Pumping Station and air forced into the gatehouse at the dam. This air was distributed by means of a ring of perforated

pipe at the inlet from the gatehouse to the pumping station. We understand that this equipment was kept in use for a number of years but was finally discontinued. All of the above work was done under the direction of Mr. Charles B. Brush. At no time have we had any filters.

Brush stated (43) that in 1890 he was called on to advise on the water supply of a small town, the water works of which were practically owned by a "wealthy, busy gentleman" [apparently Adrian Iselin, President, New Rochelle Water Co.]. Brush states that he set up an air compressor in a pipeline from a 100-mil.gal. reservoir, the compressor being driven by hydraulic pressure from the supply main—in general agreement with De Veau's statement concerning the first aerator. Air was forced back up the main, came out into the reservoir in large quantity and agitated the water with "considerable violence." Algae trouble was stopped.

Brockton, Mass.—In the spring of 1891, disagreeable tastes and odors in a large standpipe at Brockton, Mass., led consulting engineer Phineas Ball to confer with Leeds on aeration. As a result, states Leeds, Brockton purchased the right to use his system of aeration and Ball designed apparatus. The standpipe was 59 × 61 ft. and had a capacity of 1.25 mil.gal. Water from an impounding reservoir on Salisbury Brook was pumped to the standpipe for high service. An air compressor delivered about 172,000 cu.ft. of air per day into three 2-in. pipes radiating from one side of the bottom of the standpipe. From these, numerous ⅜-in. and ¼-in. brass pipes, with ⅐-in. perforations, 3 ft. c. to c., extended over the whole bottom of the standpipe. Superintendent W. F. Cleaveland stated that aeration had greatly improved the quality of the water (41).*

Charleston, S.C.—Algae growth in water from artesian wells led to installation of aeration apparatus at Charleston, S.C., late in 1891 or early in 1892. The wells were 2½ to 5 in. in diameter and about 2,000 ft. deep. They discharged into a reservoir from which water was pumped to a standpipe. The reservoir was about 135 × 195 ft. in plan and 22 ft. deep. A 6 × 10-in. air compressor in the adjacent

* In 1941, George E. Bolling, Director of Health and Water Laboratories, Brockton, was unable to give any definite information regarding the installation. Tradition had it that the system was installed without cost to the city and after a considerable period of trial was given up as not affording results commensurate with the cost of operation (50). It was not mentioned in a report for the *Manual of American Water Works* submitted in 1896 by the late Horace Kingman. I found nothing about it in gathering data on the early Brockton filter (see Chap. VI).

pumping station delivered air to a receiving tank from which a 1½-in. pipe led to and around the top of the reservoir. Twelve branch pipes, with a valve at the top of each carried air down the inner slope of the reservoir to its bottom, where it was delivered through three $\frac{1}{16}$-in. holes in the cap of each branch pipe. Superintendent C. A. Chisholm stated in June 1892 that a pressure of 15 to 20 psi. in the receiver was sufficient and that volume rather than pressure was needed (41). In 1941, J. E. Gibson, Manager and Engineer of the Charleston Water Department (51), stated that no records of aeration at Charleston were available. He thought that aeration might have been stopped in the 1890's when all the wells were equipped with air lifts. In the winter of 1926–27, an aeration system was installed in the sedimentation basin of the Goose Creek impounded supply. It has a capacity of 10 mgd. and consists of 200 Yarway involute-type cooling spray nozzles. These are placed about 2 ft. above the surface of the water and spray the water up about 2 ft.

The Charleston aerator seems to have been the last one of the Leeds type installed. About that time the National Water Purifying Co. was merged into the New York Filter Co., which seems to have given up aeration attempts.

Hyatt's Induced-Air Aerator

Scarcely had Leeds been granted his first aeration patent when John W. Hyatt, rapid filter pioneer (see Chap. VII), applied for a patent on a device for sucking air into and mixing it with water in its downward passage through a group of tubes. Soon afterward he applied for a patent on another air-induction aerator. Both patents were granted in 1885.* Apparatus in line with these patents was soon put into use at three water works. In 1887, Hyatt took out two other aeration patents.

All of Hyatt's patents were on apparatus. In his specifications of his first patent he said that by passing the combined water and air through a filter the particles of filtering material would finely subdivide the air and enhance its action. When the air and water were thus intimately combined, the water would absorb the oxygen of the air and the impurities in the water would be consumed or rendered inert. Any materials remaining, while probably not injurious until

* First application filed February 28 and granted September 15, 1885; second application filed May 2, 1885 and granted July 14, 1885.

after further decomposition, would be offensive to the eye unless removed by the filter.

In one of his devices, water was to be passed down through an inverted cone-shaped vessel pierced with holes articulated above and with a group of Sprengel air pumps. Water falling through these induction tubes was to suck in air and mingle it with the water. To mix the air and water still more, the combined fluid was to be passed over one or more such devices as small stones, horizontal perforated plates or baffles attached to the inside of the left arm of the U-tube containing the Sprengel pumps. The water was then to be passed up through the right hand arm of the U-tube, which might also be baffled, and into the top of the filter.

Hyatt's other patent of 1885 consisted of a closed tube sunk mostly in the earth and a small inner tube extending nearly to the bottom of the outer tube. The inner tube had a bend at the ground level, with a horizontal extension to a tank or reservoir. Slightly above the ground level, a perforated plate concentric to both tubes, was placed. From the perforations, small vertical pipes extended downward a short distance. Water under pressure, discharged into the closed space above the outer tube, passed through the small tubes down through a succession of concentric perforated plates to the bottom of the outer tube, then up through the central tube and to the bottom of the water in the tank. By this means the air sucked in was intimately mixed with the water. Any surplus of air escaped from the surface of the water in the tank. The pressure of the air could be increased as the water and air descended, diminishing the size of the air bubbles. [Compare with British patent issued to Massey-Mainwaring and Edmunds, March 4, 1885, two months before Hyatt filed the application for his tubes-in-the-ground patent (see above).]

Two other patents on aeration devices were granted to Hyatt, both in 1887, one on April 5, the other on July 5. The first of these was on apparatus for automatically mingling air with the contents of a conduit leading from an elevated reservoir without material loss of head. It was based on the principle that contraction of a descending fluid vein tended to produce a partial vacuum therein, drawing air into the current of water if the mouth of the conduit were parallel with the surface of the reservoir at a suitable distance below it. The fourth Hyatt patent was on injectors for aerating water. Sheet metal funnels or thin conical discs, slightly separated from each other by projections, were set with pipe nozzles at the opposite ends.

In a trade catalog of 1886 Hyatt stated that his aerating system combined 25 per cent or more of atmospheric air with water under static pressure, "oxidizing the impurities, destroying the conditions favorable to germ propagation, and so regenerating the water that it will keep sweet much longer in pipes and reservoirs than water not so treated." Hyatt seems to have been the only aeration patentee who claimed that aeration affected water-borne germs and he claimed inhibition rather than destruction.

Three aerators of the type of one or the other Hyatt patent of 1885 were installed: one in 1886 for the City Water Co. of Belleville, Ill.; one in 1887 for the Greenwich Water Co., supplying Greenwich, Conn., Rye and Port Chester, N.Y.; the third in 1888 for the Long Branch Water Supply Co. in New Jersey. The first two of these were of the tower and the third the underground or well type. All these companies are now controlled by the American Water Works & Electric Co., of New York City. No descriptions of the aerators are available in the company's records, nor are dates of installation and abandonment given (52).

Belleville, Ill., and Greenwich, Conn.—Meager descriptions of the Belleville and Greenwich aerators, cited in *Sanitary Era,* a Hyatt house organ of the eighties, have been found. In addition, brief statements are made of the nature of the water supplies concerned (53–55). The Belleville *Daily News-Democrat* of October 13, 1886, reporting the testing of the new filters on the previous day, said that "the water is first carried to the top of the tower through the aerator, by means of which it is charged with air [and then] passes through two filters" (53). The supply was Richland Creek, which in time of freshets was turbid and impure with organic matter from cultivated land (54). This source was abandoned in 1895 or early 1896 for deep wells, just after the installation of Jewell filters.

The Greenwich Water Works Co. contracted for Hyatt filters in March and put them into use in July 1887. The Port Chester *Journal* stated February 9, 1888, that four filters had "recently" been put in at the Collequam Reservoir. Two days later the Greenwich *Graphic* said that water passed up to the top of a tower to the height of the reservoir (50 ft.) then down again, sucking in air, then to and through an alum container and four filters (55). The supply was from impounded brooks and springs, never wholly free from discoloration, due to organic matter, presumably caused by slow disintegration of vegetable growths in swamp areas (55). In 1928, a new filter plant was put in use by the Greenwich Water Co. Forty-eight Sacramento-type aeration nozzles were placed on top of the settling basin (52).

Long Branch, N.J.—Best known of the Hyatt aerators was the one put in use June 28, 1888, by the Long Branch Water Supply Co. Water from springs and a small somewhat discolored creek was gathered in a pond, passed down one half of a 16-in. pipe sunk 100 ft. into the ground, and up through the other side of a vertical partition. As described in an engineering journal soon after the aerator was put into use (56), water passed down the open half of the pipe with great velocity, sucking in a large volume of air. The mingled air and water rose through the closed half of the pipe and entered the pump well from which, after receiving a coagulant, it was forced through a battery of Hyatt filters composed of sand and coke. Aeration and filtration combined, the article stated, removed all impurities in suspension and also a large part of the objectionable matter in solution.

Writing in 1895, Professor Leeds stated that on his recommendation combined aeration and filtration was adopted in 1887 for the 2-mgd. water supply of Long Branch. The object of aeration, there as elsewhere, he said, "was to charge the water itself with oxygen to the maximum and then allow this oxygenated water to purify the filter bed" (38). The Hyatt filters of 1888 still gave summer service in 1940 at the West End Station of the Monmouth Consolidated Water Co., but for some years had been operated by gravity. The change was probably made in 1929 when a clear-water basin was installed. The date on which aeration was abandoned cannot be ascertained (52).

Aeration in Twentieth Century America

Before summarizing twentieth century aeration developments in the United States, a few of the more interesting plants will be mentioned.

Alternate sprays and cascades produced by discharging water over the edge of plain pans and through perforated pans, superimposed, were produced by an aerator put in use at Winchester, Ky., late in 1900 or early in 1901. It was equipped with a ball float and cone adjuster. William Wheeler was designing engineer (57).

Double aeration and double filtration were put into use at South Norwalk, Conn., June 22, 1908, to treat impounded surface water subject to organic growths and tastes and odors. Water was aerated before and after filtration. Both aerators and the first filters were still being used early in 1940 but the final filter had been converted into a clear-water basin. Each aerator was a steel box, 6½ × 9½ ft., by 4 ft. deep, with bottom perforated by 6,836 3/16-in. holes, 1 in. c. to c. The plant was recommended in 1904 by Harry W. Clark and built four years later after designs by him and William S. Johnson, both of Boston. The aerators were based on experiments by Clark to find the best method of making up deficit of free oxygen due to much organic matter in a state of change (58) (see Chap. IX).

Unique aerators, designed by Malcolm Pirnie, at that time in the office of Hazen and Whipple, were put into use at Providence, R.I., and Poughkeepsie, N.Y., in 1926. A cluster of spray nozzles is controlled automatically by "utilizing that portion of the head between the water on the filters and in the clear well which remains after the water passes through the filters." These and similar aerators at Rahway, N.J., and West Palm Beach, Fla., were described by Pirnie in 1927 (59).

At Waukegan, Ill., air at atmospheric pressure is sucked in

———from an intake manifold by the velocity of water flowing past hundreds of air tubes—on the injector principle—into a specially designed orifice or mixing throat. . . . The mixture of air and water (and a chemical when introduced) then rises through a U-tube and discharges in violent turbulence over the circular, herringbone-baffle-studded discharge plate, a few inches above the water level in the basin. The entrained air is released, sweeping out with it the volatile gases—including CO_2—and supplying fresh oxygen.

This apparatus ("Aer-O-Mix"), says Herman Anderson, of the Vogt Brothers Manufacturing Co., was first used in January 1929, at Waukegan (60). The air-induction element of this apparatus has a family resemblance to the device patented by Hyatt in 1885, based on the use of Sprengel pumps (see above).

Porous tubes or plates for the diffusion of air through water, taken over from the activated-sludge method of sewage treatment, have been used at a few water works, beginning at Brownsville, Texas, in 1931. Under a patent granted to Henry E. Elrod, this type of aeration apparatus is being promoted as the "Aerator-Mixer" (61).

General summary.—In the four decades of the present century the proper objectives of aeration have been defined and various means of adapting apparatus to those objectives have been devised. Aeration for the reduction of organic matter, although widely used in sewage treatment, has been given up for water supplies. Its use continues for the reduction of odors and as an aid to the removal of iron and manganese.

Aeration by spraying into the air dominates. Other methods call for jets; weirs and pans; showers through small, closely-spaced perforations; coke trays; and compressed air admitted to the water at the bottom of basins. In no case reported is high-pressure air used; nor is there a single instance of compressed air admitted to a force main —two major principles laid down by Professor Leeds in his patents and papers (see above). St. Paul affords the most notable instance of the use of compressed air, where equipment was installed in 1926 after experiments made in the previous year (62, 63).

By far the largest aeration plants in the world are those below the Ashokan and Kensico reservoirs, in the Catskill supply of New York City. Each has 600 nozzles. At Ashokan the entire reservoir discharge of 600 mgd. passes through the aerator. These aerators were installed primarily for ornamental purposes (64).

The number of water works in the United States using some method of aeration early in 1942 is unknown. In 1931, the American Water Works Association's Committee on Water Purification and Treatment listed aeration at more than 100 works in the United States (65). The list seems to have been incomplete, even for that date, and since then there have been many installations. The United States Public Health Service Census as of early 1941 (66) lists aeration plants, but gives no totals except where aeration is an adjunct to "simple chlorination," the total of such being 83. In the tables by states, the aerator devices are classed as overflow trays, cascade or other splash types, contact beds, coke or other material, spray, patented, and other types, but no summaries under these heads are given.

The basic principles of aeration are discussed by Baylis in *Elimination of Taste and Odor in Water* (67). He gives tabular data on: odor control at 36 water works; reduction of carbon dioxide at fifteen works; removal of iron and manganese at eighteen works; and removal of hydrogen sulfide at four works. Duplications reduce the number of works to about 60. References are given to 68 original sources of information. Most of these are to articles published between 1920 and 1935; few go back of 1910; none cited appeared earlier than 1900. Broadly, all deal with current practice.

Chapter XV

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