

CURRENT PRACTICE IN WATER TREATMENT

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(Presented at the New England Conference on Urban Planning for Environmental Health, Tufts University, September 8, 1965.)

For centuries, man has been confronted with the problem of obtaining a satisfactory water supply. His early experience included the search for adequate quantity; the discovered sources must then have undergone some primitive assessment as to quality, especially with regard to taste and general appearance. Although some ancient societies experimented with, and used, various methods of physical improvement, including coagulation, sedimentation, and filtration, the major concern until recently has been with supply and distribution rather than with quality control.

Time has compounded man's problems in water supply. Centralization of population, general population growth, and technological progress have multiplied the demands on available sources of water. Hygienic quality has become as important as quantity. The use of water bodies and courses for the disposal of a multitude of domestic and industrial wastes has made the modern day approach to water supply a far different consideration from that of even a few decades ago. The entire problem of furnishing a useful supply of safe, potable water represents one of the great challenges to 20th century man. Millions of dollars are spent annually in the improvement of inferior quality raw sources to a condition such that these supplies may be used at home and in industry without undue concern for harmful effects that might otherwise be encountered. Some of the current practices directed toward this improvement will be discussed here.

Disinfection

Current water treatment practice centers around one all-important goal: the provision of domestic water which is *safe* for the consumer. It follows, therefore, that the signal treatment process is that of disinfection. Although many large cities in Europe use ozone as a water disinfectant, chlorine is by far the most common germicide used in American water supply. Chlorine became available commercially in

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TABLE I
TREATMENT OF PUBLIC WATER SUPPLIES OF 100 LARGEST CITIES
IN THE UNITED STATES, 1962
(From Ref. 2)

Treatment	No. of Cities	Population Served	
		No. in 1,000's	Percentage of Total
A. Surface Water			
Chlorination	66	39,939	65.9
Sedimentation and coagulation	54	27,772	45.8
Filtration			
Slow sand	7	2,536	4.2
Pressure	2	356	0.6
Rapid sand	51	26,511	43.8
Iron removal	4	1,475	2.4
Softening			
Lime	10	4,649	7.7
Lime-soda ash	9	3,359	6.0
B. Ground Water			
No treatment	1	150	0.2
Chlorination	19	5,565	9.2
Iron and manganese removal	5	1,474	2.4
Sedimentation and coagulation	7	2,147	3.5
Rapid sand filtration	7	2,970	4.9
Softening			
Lime	3	1,055	1.7
Lime-soda ash	1	320	0.5
C. Mixed Surface and Ground Water			
No treatment	1	72	0.1
Chlorination	13	14,015	23.1
Iron and manganese removal	1	500	0.8
Filtration			
Rapid sand	8	1,921	3.2
Slow sand	1	33	0.1
Sedimentation and coagulation	7	8,770	14.5
Softening			
Lime*	2	340	0.6
Lime-soda ash	1	259	0.4
Cation exchange	2	698	1.2

* At least one city supplements lime softening with soda ash during critical periods.

TABLE II
 WATER TREATMENT OPERATIONS IN THE NEW ENGLAND STATES, 1963—
 FACILITIES SERVING 100 OR MORE USERS
 (Compiled by the author from data in Ref. 3)

TYPE OF TREATMENT	No. of Facilities by State						N.E. Total
	Conn.	Maine	Mass.	N.H.	R.I.	Vt.	
A. <i>Aeration</i>							
Contact beds or trays, coke or other	0	0	3	2	1	0	6
Patented aerator	1	0	2	0	0	0	3
Spray aerator	1	1	9	0	3	0	14
Overflow trays, cascade or other splash	1	0	1	1	1	0	4
Other types	0	1	0	0	0	0	1
Not specified	4	0	4	0	0	0	8
B. <i>Chemical Coagulation or Softening</i>							
Alum	17	10	14	5	9	3	58
Iron Salts	0	0	2	0	1	0	3
Lime	10	6	6	2	9	0	33
Soda ash	10	6	4	1	3	2	26
Activated Silica	0	0	0	0	0	0	0
Other coagulant	0	1	4	0	0	0	5
C. <i>Disinfection</i>							
Chlorine gas	53	50	72	18	9	27	229
Hypochlorite	48	76	40	54	19	34	271
Chlorine dioxide	0	2	0	0	0	0	2
Ozone	0	0	0	0	0	0	0
Other means	0	0	2	0	0	0	2
Dechlorination	0	0	2	1	0	1	4
D. <i>Filtration</i>							
Anthraflit	0	0	2	0	2	0	4
Diatomaceous earth	0	2	0	0	0	0	2
Sand	10	20	24	6	10	6	76
Zeolite	1	1	1	2	2	0	7
Pressure	2	3	1	1	5	2	14
Gravity (slow)	2	6	16	3	0	0	27
Gravity (rapid)	17	13	13	6	8	4	63
Roughing	0	1	0	0	0	0	1
Unspecified	4	0	0	0	0	0	4
E. <i>Chemical Stabilization or Corrosion Control</i>							
Phosphate compounds	30	9	46	4	8	0	97
Chlorine gas	3	6	0	0	0	0	9
Hypochlorite	2	1	0	0	0	0	3
Sodium silicate	1	0	0	1	0	0	2
Alkali for pH adjustment	18	12	40	7	10	0	87
Unspecified	0	0	3	0	0	0	3

TABLE II (Continued)

TYPE OF TREATMENT	No. of Facilities by State						N.E. Total
	Conn.	Maine	Mass.	N.H.	R.I.	Vt.	
F. <i>Mixing Process, Unspecified Purpose</i>							
Air agitation	1	0	0	0	0	0	1
Baffles	0	3	2	0	0	0	5
Hydraulic (standing wave flume)	0	0	0	0	2	0	2
Injection or pump suction	0	7	0	0	0	0	7
Slow mechanical	1	2	7	0	3	0	13
Rapid mechanical	0	2	5	1	1	2	11
Other, or unspecified	0	3	3	0	1	0	7
G. <i>Ammoniation</i>							
Ammonium compound	0	2	0	0	0	0	2
Ammonia gas	0	7	0	0	0	0	7
Unspecified	1	0	0	0	0	0	1
H. <i>Sedimentation</i>							
Basins, baffled main portion	0	0	6	0	2	2	10
Covered basins, other than housed	2	4	7	1	2	0	16
Open basins, may be housed	0	4	1	0	8	0	13
Mechanical sludge removal	0	0	1	0	0	0	1
Unspecified	18	1	7	0	0	2	28
I. <i>Taste and Odor Control</i>							
Activated carbon	3	6	6	2	6	0	23
Chlorine dioxide	0	1	3	0	1	0	5
Sulfur dioxide	0	1	0	0	1	0	2
Ozone	0	0	0	0	0	0	0
Other	0	1	0	0	0	0	1
J. <i>Fluoride Adjustment</i>							
Hydrofluosilicic acid	5	3	1	0	0	0	9
Sodium silicofluoride	3	2	5	0	7	1	18
Sodium fluoride	4	11	15	3	3	3	39
Other fluorides	0	0	0	0	0	0	0
Fluoride reduction	0	0	0	0	0	0	0
K. <i>Summary</i>							
No treatment	48	44	191	44	19	126	472
Total number supplies, 100 or more users, no duplication	148	194	376	115	46	184	1,063*
Percent receiving some type of treatment	67.6	77.3	49.2	61.7	58.7	31.6	55.6

* Actually 1,427 communities of 100 or more are supplied by 1,063 separate facilities.

1910. That year produced an important legal decision also, when the court, having ordered a New Jersey water company to furnish water "pure and safe," rendered a favorable opinion on the question of chlorination of the Jersey City supply: "I do therefore find and report that [chlorination] is capable of rendering the water delivered to Jersey City pure and wholesome . . . and is effective in removing from the water those dangerous germs which were deemed . . . to possibly exist therein at certain times" (1). The application of chlorine, in one form or other, has been common practice in this country ever since. Usually it is added in sufficient quantity to result in a small residual after 10 or 15 minutes contact. There is no question that the process has all but eradicated many water-borne diseases, but whether chlorination as it is presently performed is effective against viral organisms is an unknown requiring continuing research. As indicated in Table I, of the water supplies for the 100 largest cities in the United States in 1962 (2), 98, serving a combined population of almost 60,000,000, were chlorinated. In New England, as indicated in Table II, of the 1,063 different supplies serving communities of 100 or more in 1963, 502, or 47%, applied chlorine for the purpose of disinfection (3).

Filtration

Modern filtration of water dates from the 19th century in England, and has evolved from the early slow sand filters (SSF) to the rapid sand filter (RSF) developed largely by the Lawrence (Mass.) Experiment Station. The differences in the two processes are evident primarily in the flow-through rates, and therefore, in the relative areas required.

Most of the filtering¹ in the SSF is accomplished at the surface of the sand bed after enough particulate matter has collected to form a *schmutzdecke*; typical rates are in the vicinity of 4 mgad (million gallons per acre per day). In the RSF the entire bed of 24-30 inches of filter media effectively participates in particulate removal, at a rate approximating 120 mgad. (There is some tendency toward higher rates, and experimentation has indicated that there may be little reduction in effluent quality with rates as high as 230 mgad provided pretreatment is adequate (4).) Filter media is usually sand, but may include crushed coal, or, in the case of pressure filters, magnetite or diatomaceous earth.

¹ "Filtering" is a misleading term, implying a purely mechanical straining action. Evidently other processes occur within the filter as well, including biological adsorption, flocculation and sedimentation.

Again referring to the 1962 data on supplies for the 100 largest U. S. cities (Table I), filtration was accomplished in 76, and 87% of these were RSF installations. In New England there were 63 RSF, 27 SSF and 14 pressure filters operating in public water supply in 1963 (3).

Coagulation

The clarification of colloidal suspensions by coagulation and sedimentation is not a modern technique. The Chinese used alum for this purpose centuries ago in the treatment of river waters. Londoners did the same thing in Old England for the improvement of turbid pump water. Whereas the electrochemistry of the process was little understood in the earlier applications, the present-day approach to coagulation has at hand a fairly well established body of technology. Commercial alum ($\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$), according to Ockerhausen (5), is the most commonly used coagulant, and is an excellent index of the "vigor of the water industry"—approximately 300,000 tons are used annually by municipal and industrial water plants. Iron salts are also employed in substantial quantity. Recent experimentation with coagulant aids may develop new applications of great importance. Cationic organic polyelectrolytes, although not generally approved as yet for public water supplies, may eventually find economical usage for specific removal problems (6).

The coagulation process, usually associated with surface water supplies, involves 1) a short flash-mix period for immediate distribution of the added chemical, 2) formation of a gelatinous floc from the ionized chemical (coagulation), 3) a longer mixing period offering continued opportunity for contact of the floc with colloidal particles in the raw water (flocculation), and 4) a final period of quiescent settling or sedimentation, which allows gravity removal of agglomerated matter. The settled water is much reduced in turbidity, perhaps substantially improved with regard to color, and has undergone some reduction in bacteria and other organisms. The process is followed by filtration.

The "jar test" continues as the most useful mechanism for establishing and maintaining optimum chemical dosage, both in the laboratory for experimentation and design, and in the full-scale plant. Adjustment of pH is often required for efficient operation. In 1962, of the 100 largest cities in the U. S., 66 used only surface water supplies and an additional 14 used a combination of ground and surface waters. Of these 80 facilities, 61 were treated by coagulation and sedimentation.

Of 20 ground water supplies, 7 used coagulation. In New England in 1963, 58 plants used alum coagulation and 3 used iron salts, as reported by the USPHS. (See Tables I and II.)

Taste and Odor Control

Tastes and odors may be imparted to water by decaying vegetation, by algae and protozoa, and by a host of organic and inorganic compounds, some in extremely minute quantities. Since its first practical application at New Milford, N. J., in 1930 (7), the use of activated carbon² for adsorption of taste and odor-causing compounds has become standard. Generally the practice has been to add the carbon in a powdered form, or in a slurry, and, after sufficient contact time, to remove the carbon and adsorbed matter in a sedimentation process. Some plants use beds of activated carbon in granular form. As carbon in this form can be regenerated by several processes, it is possible that this type of application may find increasing future usage (4). A continuous dosage in the powdered form of a few parts per million is in many cases sufficient to remove odors and tastes associated with both organic and inorganic matter.

Other chemical additives for control of tastes and odors include chlorine dioxide, sulfur dioxide and ozone. Breakpoint chlorination results in the destruction of chloramines. Aeration may be attempted for removal of odors associated with gases. In New England in 1963, 23 plants utilized activated carbon and 8 used other compounds for taste and odor control. (See Table II.)

Corrosion Control

Of the several chemical stabilization processes used in water treatment, some of those used for corrosion control will be discussed here. Corrosion of metals occurs in the presence of an oxidizing agent and moisture containing an electrolyte. It is important, therefore, in order to control corrosion, to produce and maintain a barrier between water and the metal surfaces with which it comes in contact. All metal pipelines, tanks, meters, valves, hydrants, and other appurtenances are subject to corrosion, and thus must be protected against it. Properly applied, paint serves as an adequate protective film. In much of New England, with its coastal location, the salt-laden atmosphere offers a

² "Activated" carbon is manufactured by closely controlled charring of wood at a temperature below 500°C, followed by slow controlled burning at a temperature near 800°C. Finely divided activated carbon is estimated to provide 3,000,000 square feet of adsorptive surface per cubic foot (8).

real challenge to water works personnel. Metal water storage facilities in this area require a continuing maintenance program—it is about average for such facilities to require repainting every 3 to 5 years. Inland, paint coatings may stand up for 7 years or more, but vigilance for tell-tale signs of corrosion is necessary nevertheless.

Most cast iron pipe is now cement-lined before installation, but many appurtenances need additional protection—usually furnished by chemical treatment. Addition of phosphates in the form of sodium hexametaphosphate has become rather common practice. In 1963 there were 97 such facilities in New England, representing almost 10 percent of all the supplies serving communities of 100 or more. Complex phosphates act as sequestering agents in forming soluble complexes with iron that may be in the water initially, and with iron dissolving at anodic areas in a pipeline. The resulting complex serves to prevent precipitation of iron as tuberculation and “red water” (9). Polyphosphates serve further as corrosion inhibitors apparently by depositing thin films on metal surfaces by adsorption. Usual dosages of metaphosphates are on the order of 2 to 6 mg/1 to maintain a smaller residual (8). (The housewife has made phosphate treatment an ordinary occurrence through the use of “Calgon” as a conditioning agent.)

Adjustment of pH is another important method of stabilization. Water in the acid range serves to promote many corrosion processes. Treatment which promotes the formation and maintenance of a calcium carbonate film in the system is effective in controlling corrosion, but it may not result so much from the film itself as from the fact that a high pH is maintained at the metal surface which interferes with the corrosion process (10). Upward adjustment of pH through the addition of lime or other alkalis, such as sodium hydroxide, is a common method of corrosion control. In New England, 87 facilities included such a process as regular treatment in 1963. Other methods of corrosion control include aeration for reduction of carbon dioxide, deoxygenation for boiler feed water, and addition of chromates to cooling waters.

Iron and Manganese Removal

The 1962 Drinking Water Standards (11) changed the previous recommended limits on iron and manganese in drinking water from a combined concentration of 0.3 mg/1 to 0.3 mg/1 for iron and .05 mg/1 for manganese. Neither has public health significance in commonly encountered concentrations but the colors and stains, and possibly

tastes, associated with these elements make their occurrence objectionable. In addition, manganese may interfere with quality control (11). Iron and manganese are frequently problematical in New England ground waters. Treatment for removal of both iron and manganese is similar and often consists of precipitation by oxidizing the compound, as of iron, from the soluble ferrous state to the insoluble ferric state. Aeration, performed by using diffusion nozzles, surface aerators, cascades or sprays, may also be accomplished by contact or catalysis processes. Beds of coke or other crushed material, besides providing opportunity for aeration, may act as satisfactory contact agents, and already-precipitated iron and/or manganese serve as a catalyst for further removal in the beds. Oxidation by other agents, such as potassium permanganate and chlorine, may also be effective. Both iron and manganese compounds may be reduced in water softening precipitation processes and some may be removed in ordinary coagulation. The treatment for removal, however, has seldom been accomplished readily by any process. In 1963 there were 6 contact bed or tray facilities in New England water supply and 14 spray aerators. Other applications are indicated in Table II.

Softening

Calcium and magnesium ions are the usual causative agents of hardness. These ions react with fatty acid radicals in soap to form unwanted precipitates resulting in added expense to the consumer.

Treatment involves a precipitation process, usually from an addition of lime, or lime and soda ash. If bicarbonate is available in sufficient quantity in the raw water, the addition of hydrated lime results in the formation and precipitation of calcium carbonate, and thus the removal of hardness-causing calcium. Otherwise, normal carbonate ions are added directly through the use of soda ash (sodium carbonate). Magnesium is removed as a hydroxide and its removal may be aided by providing an excess of lime. Sedimentation and filtration are necessary finishing operations.

Fortunately, New England communities are not often saddled with extreme hardness problems, although the fact that there were 33 facilities applying lime³ and 26 applying soda ash in 1963 indicates that some problem exists.

³ Some of these may have been for purposes other than softening.

Fluoridation

Since the first installation in 1945, fluoridation of water supplies has been a controversial issue in the United States. Its most rapid period of growth was from 1950 to 1953; this was followed by a period of growing and well-organized opposition (from 1953 to 1962 the communities served by nearly 100 systems in the United States voted to discontinue fluoridation) (12). By the end of 1961, however, according to Maier, almost 2200 communities (42,000,000 persons) were receiving artificially fluoridated water.

Although "practically every physical, mental, or moral illness to which human flesh is heir has been attributed by the opponents of fluoridation at one time or another to drinking fluoridated water"⁴ fluoridation has been approved by an impressive list of medical, dental and health authorities throughout the world as a safe and effective means of reducing the occurrence of dental caries.

The optimum dosage ranges from 0.7 to 1.2 mg/l depending on annual average maximum daily temperature (11). Application does not require a large investment in equipment. Some communities have voted fluoridation in again after having previously voted to discontinue it. On a national basis the most commonly used chemical compound as a source of fluoride, because of its low cost, is sodium silicofluoride, a crystalline powder, for which hydrofluosilicic acid is the raw material. It is usually introduced to the supply through a dry-feeder and solution sequence. Silicofluoride is handled and applied with difficulty. Sodium fluoride, with its unique solubility characteristics, lends itself to almost foolproof application but the chemical is comparatively expensive. Hydrofluosilicic acid, a corrosive liquid, is often applied by pumping directly from the drums used for shipment. In New England, in 1963, there were 66 systems using fluoridation, 39 of which used sodium fluoride as the chemical source and 18 used sodium silicofluoride.

Conclusion

Only the more universal treatment practices have been considered here. Nothing has been mentioned of watershed management, which in itself is really a method of preventive treatment; of reservoir control of tastes and odors through application of chemical algicides such as

⁴ F. J. Maier in reference (12), p. 215.

copper sulfate; of removal of specific ions by ion exchange, and many others.

Gradually, the engineer and the plant operator have developed a scientific and useful approach to old treatment methods and old water quality problems; however, the problem is not static. New waste products entering our streams and the underground reservoir, mushrooming population and demand for water, the necessity for reuse of waste effluents, and recreational use of reservoirs, will soon make the present-day approach to water treatment old-fashioned, outmoded and obsolete. The day of the ordinary water treatment problem is coming to an end—soon every potential water supply will demand an extraordinary approach. The sanitary engineer is thus confronted with a continuing challenge which cannot go unmet. This is the most vital aspect of urban planning for environmental health.

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