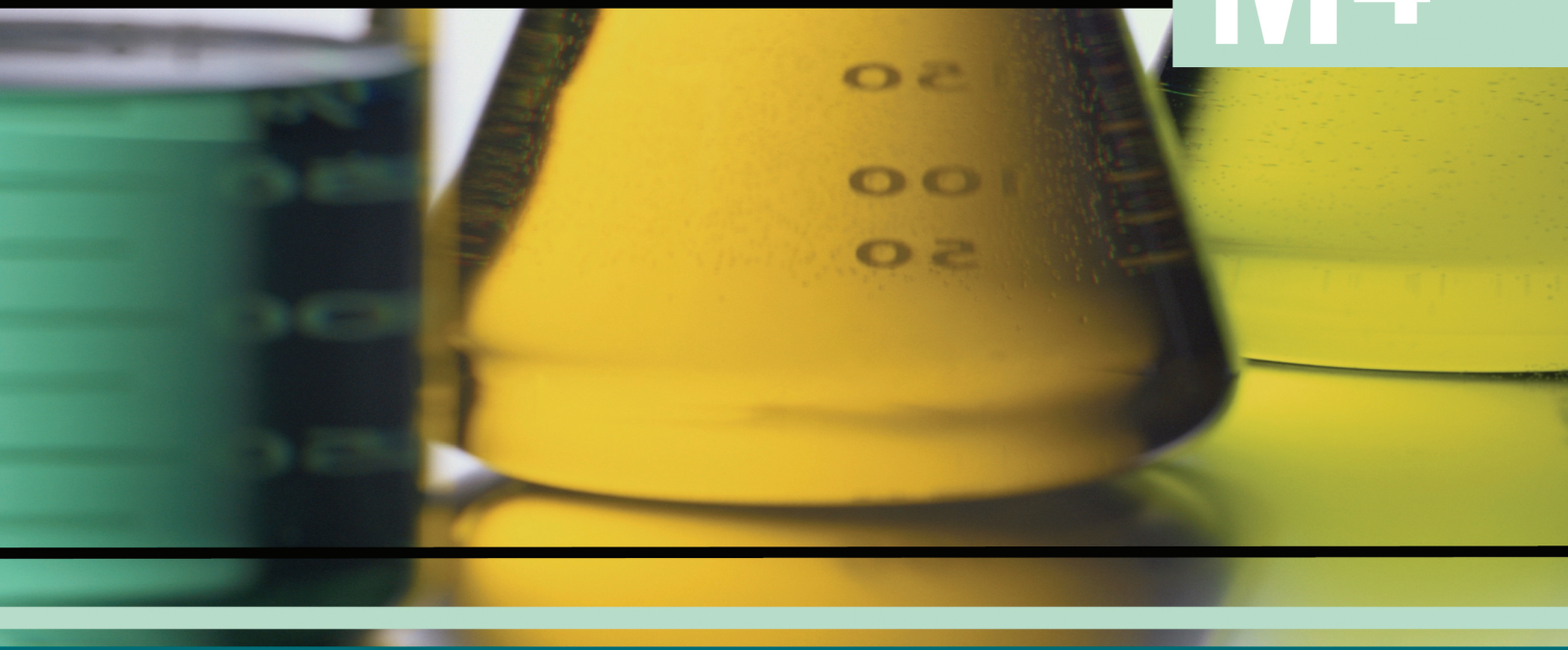
Water Fluoridation Principles and Practices

MANUAL OF WATER SUPPLY PRACTICES M4



Fifth Edition

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The Authoritative Resource on Safe Water℠

Water Fluoridation Principles and Practices

AWWA MANUAL M4

Fifth Edition

American Water Works Association

Science and Technology

AWWA unites the drinking water community by developing and distributing authoritative scientific and technological knowledge. Through its members, AWWA develops industry standards for products and processes that advance public health and safety. AWWA also provides quality improvement programs for water and wastewater utilities.

MANUAL OF WATER SUPPLY PRACTICES—M4, Fifth Edition

Water Fluoridation Principles and Practices

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Foreword

This manual assists decision makers planning fluoridation installations, engineers designing them, and water utility personnel operating them. The manual presents guidelines and is not intended to take the place of expert advice. Anyone planning or using fluoridation should carefully consider fluoride research, regulations, and methods.

The first edition of AWWA Manual M4 was prepared from material supplied and previously published by the US Environmental Protection Agency. This fifth edition updates the following major areas:

- Health effects
- State and federal regulations
- Defluoridation treatment

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Acknowledgments

This edition was prepared by William C. Lauer (AWWA Water Quality and Treatment Engineer). The revision (chapters 1–4) was reviewed by Thomas G. Reeves, Centers for Disease Control and Prevention (Atlanta, Ga.). Frederick Rubel Jr., Rubel Engineering, Inc., (Tucson, Ariz.) authored chapter 5. AWWA wishes to thank these individuals, for without their valued input, this manual could not have been completed.

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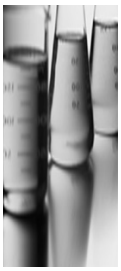


Chapter 1

History, Theory, and Chemicals

Fluoridation treatment in this manual refers to the addition or removal of fluoride from drinking water to maintain an optimum level to reduce tooth decay. Fluoridation has been practiced for more than 50 years. This chapter discusses the history of fluoridation and the theory of how it reduces tooth decay. The chapter summarizes the results of health effects studies and addresses legal issues. The common chemicals used in fluoridation are also discussed.

HISTORY AND THEORY

Fluoridation History

In 1908, Dr. Frederick McKay, a dentist in Colorado Springs, Colo., became concerned because the teeth of many children in the community were mottled or discolored. Investigations showed that excessive amounts of fluoride in the local water supply caused the mottling. In other towns using naturally fluoridated water, mottled teeth appeared only when, as in Colorado Springs, the fluoride content of the water was abnormally high. This mottling was later termed *dental fluorosis*. Fluorosis occurs only when fluoride is consumed during childhood tooth formation, generally between the ages of 6 months and 3 years.

In the 1920s, the teeth of thousands of children and the water supplies of the communities in which they lived were evaluated. By 1931, the results showed significant relationships between the fluoride concentration in the drinking water and the incidence of tooth decay, technically called *dental caries*. Three distinct relationships were discovered (Figure 1-1).

1. When the fluoride level exceeds approximately 1.5 mg/L, any further increase does not significantly decrease the incidence of decayed, missing, or filled teeth, but higher levels do increase the occurrence and severity of mottling.

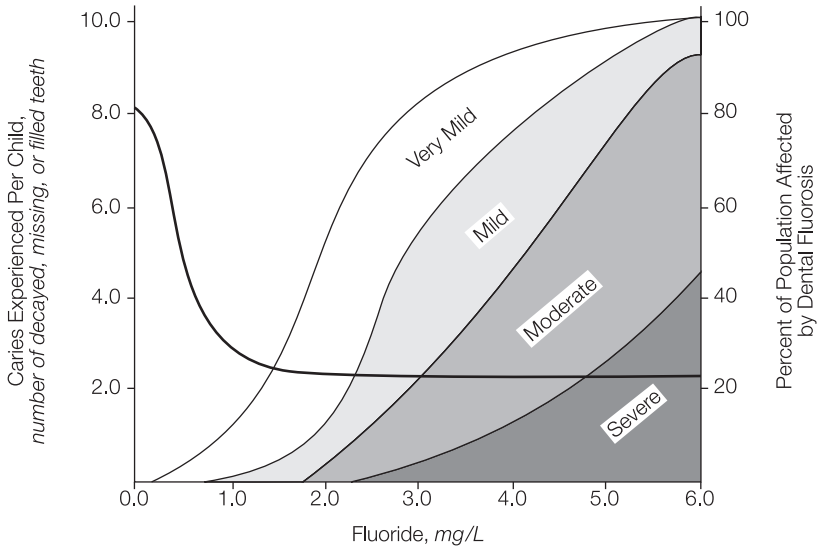


Figure 1-1 Dental caries and dental fluorosis in relation to fluoride in public water supplies

2. At a fluoride level of approximately 1.0 mg/L, the optimal condition exists: maximum reduction in caries with no aesthetically significant mottling.
3. At fluoride levels below 1.0 mg/L, caries reduction diminishes; the drop in benefits is much greater than the drop in fluoride levels. For example, when the fluoride level drops 20 percent over a period of time (from 1.0 mg/L to 0.8 mg/L), there is a 50 percent drop in benefits.

In the 1930s and 1940s, studies determined that fluoride added to drinking water supplies would reduce dental caries. In 1950, the US Public Health Service (USPHS) endorsed fluoridation. In 1962, the USPHS set fluoride levels in drinking water at 0.7 mg/L (in warmer climates) to 1.2 mg/L (in colder climates). The range was recommended because average water consumption varies with average daily air temperature. The range is discussed in more detail in chapter 2 of this manual. The USPHS also recommended that drinking water with natural fluoride levels twice the recommended adjusted level not be used. The agency, however, had no power to force water suppliers to remove excess fluoride.

Although school water fluoridation was widely practiced in several states, the Centers for Disease Control and Prevention (CDC) no longer recommends this practice. At its peak, school water fluoridation had a total of 170,000 children in 13 states with 470 school fluoridation systems. It is no longer recommended because operating and maintaining small fluoridation systems create practical difficulties. These operational problems have occasionally caused higher than recommended fluoride concentrations in school drinking water but no lasting effects among children have been observed.

Since 1974, the US Environmental Protection Agency (USEPA), under the Safe Drinking Water Act, has regulated drinking water. In 1986, USEPA set a maximum contaminant level goal (MCLG) and a maximum contaminant level (MCL) for fluoride of 4 mg/L. An MCLG is a health-related goal, and an MCL is a technologically feasible goal. Although the MCL and the MCLG for a single contaminant in drinking water may be different, in the case of fluoride both levels are

the same. The fluoride regulation applies to community water systems and requires removal of excess fluoride. The MCLG and MCL are intended to protect against adverse health effects, in particular crippling skeletal fluorosis. A secondary MCL was set at 2 mg/L to protect against dental fluorosis. Secondary MCLs are federally unenforceable recommended levels intended to prevent aesthetic health effects. In 1990, the USEPA began the required three-year review of the MCLG and MCL.

The optimal fluoride level is usually established by the appropriate state regulatory agency. USPHS and CDC recommend concentrations and control ranges that can be used as guidelines if state limits have not been established (see chapter 2).

Fluoridation has traditionally been justified based on the economics of a 40 to 65 percent reduction of tooth decay. Water fluoridation has been shown to be the least expensive method of dental caries reduction; the other methods being school water fluoridation, topically applied pastes or gels, and fluoride tablets or drops. However, fluoridation has not been without controversy. Some of the arguments against fluoridation have been the lack of long-term health risk studies and the perception that fluoridation is mass medication, infringing on personal choice.

In the United States during 2000, approximately 162 million people (or about 66 percent of the population served by public water systems) received optimally fluoridated water. This is about 58 percent of the total US population. Table 1-1 lists the population receiving optimally fluoridated water by state and compares the values for 2000 with 1992. Approximately 54 percent of the Canadian population using public water supplies received controlled fluoridated water. (Table 1-2 lists the years when Canadian cities began fluoridation.)

Table 1-1 Number of people and percentage of the population receiving optimally fluoridated water through public water systems (PWS), by state—US, 1992 and 2000

State	2000 Fluoridated Population	2000 Total PWS Population	2000 Percentage Fluoridated	1992 Percentage Fluoridated	Change in Percentage 1992–2000
Alabama*	3,967,059	4,447,100	89.2%	82.6%	6.6
Alaska	270,099	489,371	55.2%	61.2%	–6.0
Arizona	2,700,354	4,869,065	55.5%	49.9%	5.6
Arkansas†	1,455,767	2,431,477	59.9%	58.7%	1.2
California	9,551,961	33,238,057	28.7%	15.7%	13.0
Colorado†	2,852,386	3,708,061	76.9%	81.7%	–4.8
Connecticut	2,398,227	2,701,178	88.8%	85.9%	2.9
Delaware	505,747	624,923	80.9%	67.4%	13.5
District of Columbia	595,000	595,000	100.0%	100.0%	0.0
Florida	9,407,494	15,033,574	62.6%	58.3%	4.3
Georgia	6,161,139	6,634,635	92.9%	92.1%	0.8
Hawaii*	109,147	1,211,537	9.0%	13.0%	–4.0
Idaho	383,720	845,780	45.4%	48.3%	–2.9
Illinois	10,453,837	11,192,286	93.4%	95.2%	–1.8
Indiana	4,232,907	4,441,502	95.3%	98.6%	–3.3
Iowa	2,181,649	2,390,661	91.3%	91.4%	–0.1

* Reported PWS population exceeded total state population; PWS population was set to the 2000 U.S. census of state populations.
† Complete data were not available from Water Fluoridation Reporting System; additional information was obtained from states.

Table continued next page.

Table 1-1 Number of people and percentage of the population receiving optimally fluoridated water through public water systems (PWS), by state—US, 1992 and 2000 (continued)

State	2000 Fluoridated Population	2000 Total PWS Population	2000 Percentage Fluoridated	1992 Percentage Fluoridated	Change in Percentage 1992–2000
Kansas	1,513,306	2,421,274	62.5%	58.4%	4.1
Kentucky	3,235,053	3,367,812	96.1%	100.0%	–3.9
Louisiana*	2,375,702	4,468,976	53.2%	55.7%	–2.5
Maine	466,208	618,033	75.4%	55.8%	19.6
Maryland†	4,124,953	4,547,908	90.7%	85.8%	4.9
Massachusetts†	3,546,099	6,349,097	55.8%	57.0%	–1.2
Michigan	6,568,151	7,242,531	90.7%	88.5%	2.2
Minnesota	3,714,465	3,780,942	98.2%	93.4%	4.8
Mississippi	1,227,268	2,665,075	46.0%	48.4%	–2.4
Missouri*	4,502,722	5,595,211	80.5%	71.4%	9.1
Montana	143,092	645,452	22.2%	25.9%	–3.7
Nebraska†	966,262	1,243,713	77.7%	62.1%	15.6
Nevada†	1,078,479	1,637,105	65.9%	2.1%	63.8
New Hampshire	347,007	807,438	43.0%	24.0%	19.0
New Jersey	1,120,410	7,208,514	15.5%	16.2%	–0.7
New Mexico	1,187,404	1,548,084	76.7%	66.2%	10.5
New York†	12,000,000	17,690,198	67.8%	69.7%	–1.9
North Carolina	4,862,220	5,837,936	83.3%	78.5%	4.8
North Dakota	531,738	557,595	95.4%	96.4%	–1.0
Ohio	8,355,002	9,535,188	87.6%	87.9%	–0.3
Oklahoma†	2,164,330	2,900,000	74.6%	58.0%	16.6
Oregon†	612,485	2,700,000	22.7%	24.8%	–2.1
Pennsylvania	5,825,328	10,750,095	54.2%	50.9%	3.3
Rhode Island	842,797	989,786	85.1%	100.0%	–14.9
South Carolina	3,086,974	3,383,434	91.2%	90.0%	1.2
South Dakota†	553,503	626,221	88.4%	100.0%	–11.6
Tennessee	4,749,493	5,025,998	94.5%	92.0%	2.5
Texas	11,868,046	18,072,680	65.7%	64.0%	1.7
Utah*	43,816	2,233,169	2.0%	3.1%	–1.1
Vermont	240,579	443,901	54.2%	57.4%	–3.2
Virginia	5,677,551	6,085,436	93.3%	72.1%	21.2
Washington†	2,844,893	4,925,540	57.8%	53.2%	4.6
West Virginia†	1,207,000	1,387,000	87.0%	82.1%	4.9
Wisconsin	3,108,738	3,481,285	89.3%	93.0%	–3.7
Wyoming*	149,774	493,782	30.3%	35.7%	–5.4
Total	162,067,341	246,120,616	65.8%	62.1%	3.7

* Reported PWS population exceeded total state population; PWS population was set to the 2000 US census of state populations.
† Complete data were not available from Water Fluoridation Reporting System; additional information was obtained from states.

Source: Centers for Disease Control and Prevention.

Table 1-2 Years when Canadian cities began fluoridation

Belleville	1965	Moose Jaw	1963
Borden	1969	North Bay	1962
Brampton	1968	Oshawa	1953
Brandon	1955	Oakville	1963
Brantford	1945	Ottawa	1965
Burlington	1961	Peterborough	1973
Calgary	1991	Pointe-Claire	1955
Chateauguay	1970	Prince Albert	1960
Cornerbrook	1970	Prince George	1956
Cornwall	1962	Quebec City	1986
Dartmouth	1956	Red Deer	1958
Dorval	1957	Saint John	1992
Dryden	1962	Sarnia	1971
Edmonton	1967	Saskatoon	1955
Estevan	1961	St. Lambert	1971
Glace Bay	1975	St. Thomas	1965
Halifax	1956	Sudbury	1952
Hamilton	1967	Swift Current	1954
Huntsville	1986	Sydney	1968
Kamloops	1966	Toronto	1955
Kindersley	1959	Waterloo	1967
Laval	1958	Welland	1963
Lethbridge	1976	Weyburn	1955
London	1967	Windsor	1962
Mississauga	1961	Winnipeg	1956
Moncton	1970		

Source: Health Canada. 1992. *Canadian Cities with Fluoridation.*

The American Water Works Association policy on fluoridation was adopted by the organization's board of directors on Jan. 25, 1976, and reaffirmed on Jan. 31, 1982, and revised Jan. 20, 2002. The official text follows:

"The American Water Works Association (AWWA) supports fluoridation of water supplies in a safe, effective, and reliable manner that includes adequate monitoring and control of fluoride levels within limits prescribed by health officials subject to community and local decision-making processes."

Bone and Tooth Incorporation of Fluoride

The mineral and hard tissue structures of bones, teeth, and other parts of the skeleton contain fluoride. Soft body tissues do not retain fluoride, except as found in calcified deposits. Fluoride enters the teeth either topically or systemically. The topical effect occurs when a portion of the fluoride in drinking water is retained by fluids in the mouth. The fluoride is then incorporated at the surface of the tooth. The

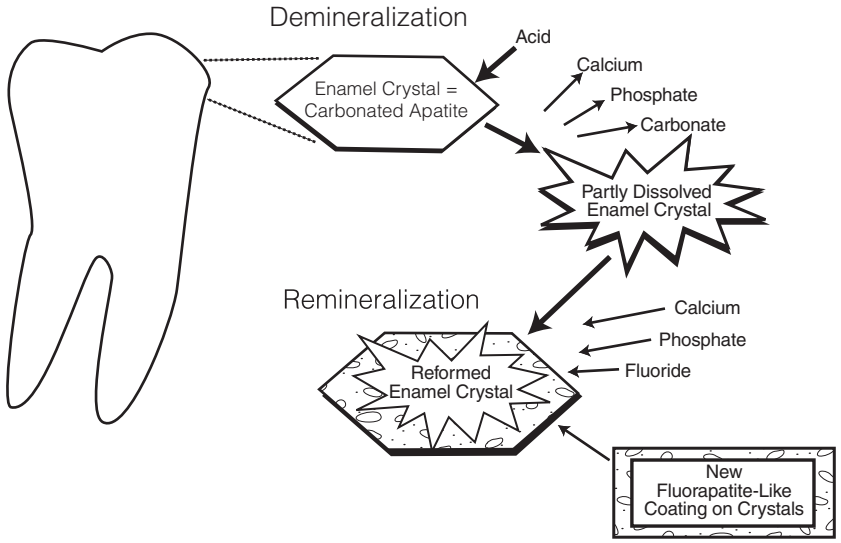
systemic effect occurs when fluoride diffuses through the walls of the stomach and intestines. The fluoride is distributed throughout the body in the blood. The fluoride is then available to all the skeletal structures, including the teeth. Fluoride not deposited in bones and teeth is excreted through the kidneys.

Fluoride incorporation by the teeth is most rapid during the time of a child's formation and growth, roughly from the fourth month of pregnancy to the tenth year. The eighth year generally marks the end of the maximum rate of incorporation of fluoride in the teeth. Teeth differ from other parts of the skeleton in that once they are formed, with the exception of the inner part of the tooth and the root, there is very little cellular activity.

Tooth Decay

A tooth is composed of enamel, dentin, pulp, and cementum (Figure 1-2). Tooth decay occurs when acids destroy the tooth structure. These acids are produced by the action of bacteria and enzymes on sugars and carbohydrates in the mouth. This action takes place beneath the plaque, which is an invisible film composed of gummy masses of microorganisms that adhere to the teeth. Oral bacteria alone can convert some of the simple sugars into acids. Bacteria and enzymes acting together convert carbohydrates and more complex sugars into acids. Cavities, or caries, form when the acids dissolve tooth enamel.

Nearly everyone suffers from dental caries, making tooth decay the most prevalent chronic human disease. Before the widespread use of fluorides, more than 98 out of every 100 Americans experienced some tooth decay by the time they reached adulthood. Tooth decay begins in early childhood, reaches a peak in adolescence, and diminishes during adulthood. The highest tooth decay activity is found in school-aged children. In age group 12–17, the average US resident will have 4.09 decayed, missing, or filled teeth.



Source: Adapted from Featherstone, J.D.B. 1999. Prevention and reversal of dental caries: Role of low-level fluoride. *Community Dent Oral Epidemiol 27:31–40. Reprinted with permission from Munksgaard International Publishers Ltd., Copenhagen, Denmark.*

Figure 1-2 The demineralization and remineralization processes lead to remineralized enamel crystals with surfaces rich in fluoride and lower in solubility

Fluoride reduces tooth decay in several ways. Fluoride strengthens the enamel against decay when the enamel layer incorporates fluoride during childhood tooth formation. Another way in which fluoride reduces decay is through constant demineralization and remineralization, which takes place on the surface of the teeth. Acids that form in the mouth cause demineralization through the exchange of ions. Fluoride inhibits the formation of acids, which allows remineralization to occur. Another mechanism that occurs during remineralization is the incorporation of fluoride ions into the enamel, which strengthens it.

Health Effects

High concentrations of fluoride in drinking water have been found to cause adverse health effects.

Skeletal fluorosis. Skeletal fluorosis is an adverse health effect caused by an accumulation of too much fluoride in bone. The stages of skeletal fluorosis range from preclinical (no reported symptoms) to crippling. Symptoms include

- pain in bones and joints
- formation of bone spurs
- osteoporosis in the long bones (loss of bone mass and increase in porosity)
- osteosclerosis (increase in bone density and formation of unusual crystalline structure)
- weakness of extremities
- fused vertebrae

Crippling skeletal fluorosis results from intakes of fluoride of 20 mg/d over periods of 20 years or more. A drinking water fluoride concentration of 10 mg/L, combined with a 2-L/d water consumption rate, would correspond to this value. This is a very rare occurrence in the United States but does occur in other countries, such as India, where some areas have very high fluoride levels.

Severe dental fluorosis. Severe dental fluorosis causes teeth to be stained, pitted, and brittle. USEPA research indicates that at 4 mg/L, 7 percent of the population experience moderate dental fluorosis and 23 percent experience severe dental fluorosis. Doses as low as 2 to 5 mg/L can cause the preclinical and earlier stages. Figure 1-1 indicates the percent of people affected by varying levels of dental fluorosis, from very mild to severe, and the incidence of caries experienced from 0 to 6 mg/L fluoride. As the line indicating the number of caries experienced shows, the optimum benefits from fluoride occur around 1 mg/L fluoride. Recent studies have shown a slight increase in dental fluorosis in communities with nonfluoridated water. The cause may be fluoride in sources other than drinking water. These sources include toothpastes, dietary supplements, mouth rinses, professional applications, and foods and beverages processed with fluoridated water.

Other health effects. Other health effects have been studied, though less extensively than fluorosis. The studied risks include

- kidney disease
- hypersensitivity (allergic reactions)
- gastrointestinal problems
- intelligence

- thyroid (goiter) effects
- substances added during fluoridation
- dietary exposure to metals
- effects on bioavailability or toxicity of toxic metals (aluminum and lead)
- enzyme and mutagenic (gene-altering) effects
- birth defects
- cancer

The evidence of fluoride's part in any of these health risks is largely discounted. The strongest recommendation comes from the National Kidney Foundation, which advises that dialysis patients use mineral-free (fluoride included) water for their treatments.

A National Toxicology Program study released in 1990 indicates equivocal (uncertain) evidence of carcinogenicity in rats fed sodium fluoride. This evidence is based on a small number of bone tumors. As a result of the equivocal evidence ruling, the USPHS conducted a comprehensive review of the benefits and risks of fluoridation. Its 1991 report recommends the use of fluoride to reduce dental caries and supports optimal fluoridation of drinking water.

A National Research Council panel, in a report issued Aug. 17, 1993, found that there was no credible evidence that fluoridation causes cancer, kidney disease, or birth defects. The panel found some studies that suggested long-term exposure to fluoride increases hip or vertebra fractures in people after age 80. However, the evidence was uncertain. The National Institutes of Health is organizing a long-term study to see whether these fractures are related to fluoridation.

The Medical Research Council (MRC) issued a report in September 2002 that reviewed the current status of fluoridation and health. The report based its conclusions on a review conducted in 2000 by the University of York, United Kingdom, and many other relevant studies. The beneficial effect of water fluoridation on dental caries was confirmed. However, the MRC identified some areas of uncertainty regarding the benefits and risks of water fluoridation. Some of the conclusions included in the MRC report follow:

- The public needs additional information to make informed decisions regarding fluoridation.
- Further work is warranted on the impact of fluoridation on caries that includes an understanding of combined impact of fluoride from all sources (e.g., toothpaste).
- The available evidence suggests no effect on the risk of hip fracture.
- The available evidence suggests no link between water fluoridation and cancer.
- There is no evidence for any significant health effects on the immune system, on the kidney and gastrointestinal tract, or for reproductive and developmental defects.
- There is no evidence for any significant health effects caused by chemicals added during the fluoridation process or for indirect effects, such as increased leaching of lead from pipes and aluminum from cooking utensils, although these areas should be kept under review.

Legal Issues

The legality of fluoridation has been tested in the courts several times. Beginning in 1952, injunctions were sought in some communities to prevent the initiation or continuance of fluoridation. These cases were generally based on several of the following types of arguments: violation of religious freedom, violation of pure food acts, abuse of municipal authority, an unreasonable or unnecessary measure, wasteful or illegal use of public funds, an unsafe measure or nuisance, availability of alternatives, breach of contract, class legislation (i.e., only children benefit), and deprivation of fundamental liberties.

In all cases, fluoridation has prevailed. During 30 years of litigation, fluoridation has withstood challenges under constitutional objections (related to the First, Tenth, and Fifteenth Amendments); it has been upheld in the highest courts in more than a dozen states; and it has withstood legal challenges in more than 25 states. At least eight times the US Supreme Court has denied review, generally on the grounds that no constitutional question was involved.

Even though the basic issues involved in fluoridation litigation were resolved more than a decade ago, cases based on the same issues occasionally appear. A few of these suits have been successful in obtaining injunctions. Some referendums to prohibit or discontinue fluoridation have been successful. In the last few years referendums have been used to authorize about 50 percent of the new fluoridated water systems.

CHEMICALS

In theory, any compound that forms fluoride ions in water can be used for fluoridation. However, several practical considerations are involved in the selection of which compounds to use.

- The compound must be sufficiently soluble to permit its use in routine water treatment plant practice.
- The cation (positively charged ion) to which the fluoride ion is attached must not have any undesirable characteristics.
- The material should be relatively inexpensive and readily available in grades of a size and purity that are suitable for the intended use.

The three most commonly used fluoride compounds are sodium fluoride, fluorosilicic acid, and sodium fluorosilicate. Before 1992, fluorosilicic acid was known as hydrofluosilicic acid, and sodium fluorosilicate was called sodium silicofluoride. The AWWA standards that address fluoride compounds are

- AWWA Standard B701, Sodium Fluoride
- AWWA Standard B702, Sodium Fluorosilicate
- AWWA Standard B703, Fluorosilicic Acid

The chemical, physical, and other characteristics of these three compounds are summarized in Table 1-3. Other compounds have also occasionally been used for fluoridation, as discussed later in this section.

Table 1-3 Characteristics of fluoride compounds

Item	Sodium Fluoride (NaF)	Sodium Fluorosilicate (Na_2SiF_6)	Fluorosilicic Acid (H_2SiF_6)
Form	Powder or crystal	Powder or very fine crystal	Liquid
Molecular weight	42.00	188.05	144.08
Available fluoride ion—percent (100% pure material)	45.25	60.7	79.2
Pounds required per million gallons (grams required per cubic meter) for 1.0 mg/L F^- at indicated purity	18.8 (2.225) (98%)	14.0 (1.678) (98.5%)	46 (5.512) (23%)
pH of saturated solution	7.6	3.5	1.2 (23% solution)
Sodium ion contributed at 1.0 mg/L F^-	1.17	0.40	0.00
F^- ion storage space—ft^3/100 lb (m^3/kg)	22–34 (0.0137–0.0212)	23–30 (0.0143–0.0187)	54–73 (0.0337–0.0455)
Solubility—at 25°C, g/100 mL water	4.05	0.762	Infinite
Weight—lb/ft^3 (kg/m^3)	65–90 (1,000–1,400)	55–72 (880–1,150)	10.5 lb/gal (30%) (1.26 kg/L)
Typical commercial purity—percent	97–99	98–99	20–30
Shipping containers	50-lb bags 100-lb bags 125- to 400-lb Fiber drums, bulk	50-lb bags 100-lb bags 124- to 140-lb Fiber drums, bulk	13-gal carboys 55-gal drums Tanks cars, bulk

Sodium Fluoride

The first fluoride compound used in adjusted fluoridation was sodium fluoride. It was selected not only on the basis of the criteria just specified but also because its toxicity and physiological effects had been studied thoroughly. Once fluoridation became an established practice, other compounds came into use.

Sodium fluoride is a white, odorless material available either as a powder or as crystals of various sizes. Its formula weight is 42.00. Its solubility is practically constant at 4 g/100 mL of water at temperatures generally encountered in water treatment. When added to water, sodium fluoride dissociates into sodium and fluoride ions:

$$NaF \Leftrightarrow Na^+ + F^- \qquad (1\text{-}1)$$

Solution pH varies with the type and amount of impurities, but solutions prepared from the usual grades of sodium fluoride exhibit a pH near neutral (approximately 7.6). Sodium fluoride is available in purities ranging from 90 to more than 98 percent. Impurities consist of water, free acid or alkali, sodium fluorosilicate, sulfites, and iron, plus traces of other substances.

Powdered sodium fluoride is produced in different densities; the light grade weighs less than 65 lb/ft^3 (1,000 kg/m^3), and the heavy grade weighs about 90 lb/ft^3

(1,400 kg/m^3). A typical sieve analysis of powdered sodium fluoride passes 99 percent through a 200-mesh sieve and 97 percent through a 325-mesh sieve.

Crystalline sodium fluoride is produced in various size ranges, usually designated as coarse, fine, and extra fine; however, some manufacturers can provide lots in specific mesh sizes. The crystalline type is preferred for utilities using manual handling because it results in a minimum of dust. Sodium fluoride is commercially available in both 50- and 100-lb (23- and 45-kg) bags.

Sodium fluoride must be made into a solution before being added to water supplies. The chemical can be dissolved in a mixing tank, a saturator, or a dissolving chamber. Equipment requirements are discussed in detail in chapter 3.

Fluorosilicic Acid

Fluorosilicic acid is available as a 20 to 35 percent aqueous solution of H_2SiF_6; it has a formula weight of 144.08. The most common concentration used in water treatment is 23–25 percent. When pure, it is a colorless, transparent, fuming, corrosive liquid having a pungent odor and an irritating action on the skin. On vaporizing, the acid decomposes to form hydrofluoric acid (HF) and silicon tetrafluoride (SiF_4). Under conditions where an equilibrium between the fluorosilicic acid and its decomposition products exists, such as at the surface of strong solutions, etching of glass can occur.

Fluorosilicic acid dissociates virtually 100 percent in solution, releasing hydrofluoric acid and silicon tetrafluoride:

$$H_2SiF_6 \Leftrightarrow 2HF + SiF_4 \tag{1-2}$$

Hydrofluoric acid strongly dissociates, lowering the pH of the solution:

$$HF \Leftrightarrow H^+ + F^- \tag{1-3}$$

Silicon tetrafluoride is a gas that easily volatilizes out of solution if present in high concentrations. It also reacts quickly with water to form silicic acid (H_2SiO_3) or silicon diocide (SiO_2):

$$SiF_4 + 3H_2O \Leftrightarrow 4HF + H_2SiO_3 \tag{1-4}$$

$$SiF_4 + 2H_2O \Leftrightarrow 4HF + SiO_2 \tag{1-5}$$

All solutions of fluorosilicic acid exhibit a low pH (approximately 1.2). Even at a concentration low enough to produce 1 mg/L of fluoride ion, the pH of poorly buffered waters can be lowered. For example, in water containing 30 mg/L of total dissolved solids with a pH of 6.5, after H_2SiF_6 is added to produce 1 mg/L F^-, the pH drops to 6.2.

Fluorosilicic acid is manufactured as a by-product of phosphate fertilizer; it is relatively impure and seldom exceeds 30 percent strength. Acid prepared from phosphate rock (as part of fertilizer manufacture) contains colloidal silica in varying amounts. Although this is of little consequence when the acid is used as received, dilution results in the formation of a visible precipitate of the silica. Some suppliers of by-product fluorosilicic acid sell a fortified form that has a small amount of

hydrofluoric acid added to prevent the formation of precipitate. Acid prepared from hydrofluoric acid and silica does not normally form a precipitate when it is diluted.

Because fluorosilicic acid contains a high proportion of water, shipping large quantities can be expensive. Large users can purchase the acid directly from the manufacturer in bulk lots (tank cars or tank trucks), but small users must obtain the acid from distributors, who usually package it in drums or polyethylene carboys. Rather than attempt to adjust the acid strength to some uniform figure, producers sell the acid as it is produced and adjust the price to compensate for acid strength greater or less than the quoted figure. Suppliers usually provide assay reports of the acid strength of each lot.

Attempts to dilute the acid are subject to errors in measuring both the acid and the diluting water. The acid should be used undiluted as it comes from the shipping containers. If the acid is too concentrated for the solution feeder to handle, then a smaller sized feeder should be used or a weaker solution of other, less expensive compounds should be used, such as saturated solutions of sodium fluoride. (Very small metering pumps are available.)

Sodium Fluorosilicate

Fluorosilicic acid can readily be converted into various salts, one of which, sodium fluorosilicate, is widely used in fluoridation. Sodium fluorosilicate is one of the least expensive compounds currently in use. The conversion of fluorosilicic acid, essentially a low-cost by-product containing too much water to permit economical shipping, to a dry material containing a high percentage of available fluoride results in a compound having most of the advantages of the acid with few of its disadvantages. Sodium fluorosilicate is a white, odorless, crystalline powder. Its molecular weight is 188.06. Its solubility varies from 0.44 g/100 mL of water at 32°F (0°C) to 2.45 g/100 mL of water at 212°F (100°C). When sodium fluorosilicate is dissolved in water, virtually 100 percent dissociation occurs rapidly:

$$Na_2SiF_6 \Leftrightarrow 2Na^+ + SiF_6^{--} \tag{1-6}$$

Silicofluoride ions, SiF_6^{--}, may react in two ways. The most common reaction is hydrolysis of SiF_6^{--}, releasing fluoride ions and silica. Silica, the main ingredient in glass, is very soluble in water.

$$SiF_6^{--} + 2H_2O \Leftrightarrow 4H^+ + 6F^- + SiO_2 \tag{1-7}$$

Alternatively, SiF_6^{--} dissociates very slowly, releasing fluoride ions and silicon tetrafluoride:

$$SiF_6^{--} \Leftrightarrow 2F^- + SiF_4 \tag{1-8}$$

Silicon tetrafluoride reacts as described in Eq 1-4 and Eq 1-5. The pH values of the solutions are acidic (generally about 3.6). Sodium fluorosilicate is available in purities of 98 percent or greater, with the principal impurities being water, chlorides, and silica.

Sodium fluorosilicate is sold in two commercial forms: regular and fluffy. The regular form has a density of about 85 lb/ft^3 (1,400 kg/m^3), the fluffy form about 65 lb/ft^3 (1,000 kg/m^3). A typical sieve analysis of the regular grade allows more than 99 percent through a 200-mesh sieve and more than 10 percent through a 325-mesh sieve. Depending on feeding characteristics, other size specifications can be selected. Experience shows that a low moisture content plus a relatively narrow size distribution results in a material that is handled better by dry feeders.

Considerable quantities of sodium fluorosilicate are imported. Sodium fluorosilicate is normally packed in bags and drums similar to those used for sodium fluoride. As with sodium fluoride, sodium fluorosilicate must be made into a solution in a dissolving chamber before being fed into the water supply.

Other Fluoride Compounds

Ammonium silicofluoride, magnesium silicofluoride, potassium fluoride, calcium fluoride (fluorspar), and hydrofluoric acid have also been used for fluoridation. Each has particular properties that make the material desirable in a specific application, but none of them has widespread application in the United States. Fluorspar is used occasionally in South America, particularly in Brazil.

Ammonium silicofluoride has the advantage of supplying all or part of the ammonium ion necessary for the production of chloramines, when this form of disinfectant is used.

Magnesium silicofluoride and potassium fluoride have the advantage of extremely high solubility, which is of particular importance in applications, such as school fluoridation, where infrequent refills of the solution container are desired. In addition, potassium fluoride is quite compatible with potassium hypochlorite; a mixture of the two can be used for simultaneous fluoridation and chlorination.

Calcium fluoride (fluorspar) is the least expensive of the compounds used for fluoridation and also the least soluble. One feed technique is to first dissolve it in alum solution and then use the resultant solution to supply both the alum needed for coagulation and the fluoride ion. However, this method of operation is wasteful because of fluoride loss during alum coagulation and filtration (see chapter 4).

Hydrofluoric acid, although low in cost, presents too much of a safety and corrosion hazard to be acceptable for general water fluoridation. It has, however, been used in a specially designed installation.

Other fluoride compounds have been suggested for use in water fluoridation, among them ammonium bifluoride and sodium bifluoride. These materials have the advantages of high solubility and low cost, but their potential corrosiveness has made them generally unacceptable.

The manufacturers or suppliers of the various fluoride compounds can provide technical data and specification sheets that will assist the prospective purchaser in selecting the appropriate grade of chemical for the type of feeder used.

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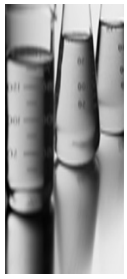


Chapter 2

Fluoridation System Planning

This chapter introduces general types of fluoridation systems. It also presents guidelines for planning fluoridation systems. Included are chemical selection guidelines, feed rate and dosage calculations, example feed rate problems, and examples of preliminary planning.

Fluoridation systems are usually planned in coordination with the state or provincial agencies responsible for drinking water regulations. The regulations may address fluoride levels, recommended systems, monitoring requirements, and record keeping. The agencies may have final approval of systems. Among the considerations in choosing the right fluoridation system for a particular situation are

- optimal fluoride level
- population served or water usage
- water system characteristics (such as source of supply, treatment, storage, distribution, personnel)
- chemical availability
- cost

Although no type of fluoridation system is solely applicable to a specific situation, some general limitations are imposed by the size and type of water facility. For example, the manager of a large metropolitan water plant usually should not consider a fluoridation system involving the manual preparation of batches of solution, and the manager of a small facility consisting of several unattended wells should not consider a large dry feed system.

GENERAL SYSTEM CONFIGURATIONS

This section introduces the general configurations of fluoridation systems. Specific information on fluoridation equipment is found in chapter 3.

The simplest fluoridation system (Figure 2-1) is one based on the use of fluorosilicic acid. The acid is supplied in carboys or drums, mounted on a platform scale. A solution feed pump, mounted on a shelf above the carboy, injects the acid into a water main in proportion to the water flow. The feed pump should not be mounted more than 4 ft (1.2 m) above the top of the carboy. An antisiphon valve is usually part of the feeder, and auxiliary equipment, such as a loss-of-weight recorder, can be added.

A sodium fluoride saturator system is almost as simple. This system requires slightly more space and piping than a straight acid feed system (Figure 2-2). Many of the same comments made regarding acid feed systems apply to the saturator systems. The metering pump should be located not more than 4 ft (1.2 m) above the low saturated water line in the saturator. The suction line should be as short as possible. The metering pump should be equipped with an antisiphon valve. There should also be an antisiphon valve at the fluoride injection point if the fluoride solution is injected into a water main. Once the solution has been adjusted, the only operator attention required is the occasional replenishing of chemical (without weighing) and the cleaning of the saturator.

The fluoride saturator does not need to be sealed as tightly as the acid carboy. Saturator systems should have a water meter and, if necessary, a water softener. The feedwater line should contain a Y-strainer and sufficient unions to allow easy removal of piping. When mounting a metering pump on a shelf or platform above the saturator, it is advisable to offset it sufficiently to permit access to the container for filling and cleaning. Mounting the metering pump on the lid of the saturator is not recommended. A saturator should never be pushed to its design capacity limit for any length of time. When a saturator's capacity is approached, another method of fluoridation should be considered, such as the use of fluorosilicic acid.

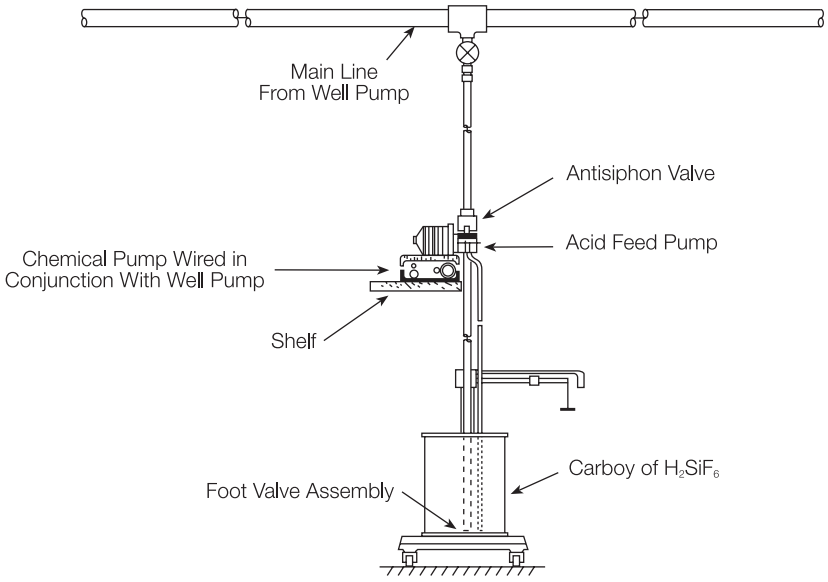


Figure 2-1 Acid feed installation

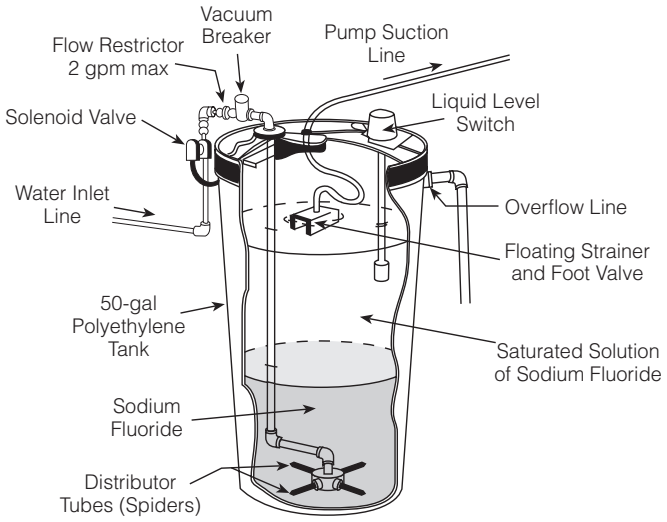


Figure 2-2 Solution fluoride saturator

Dry feeding of sodium fluorosilicate or sodium fluoride is limited to water plants large enough to accommodate a volumetric or gravimetric feeder. Volumetric dry feeders (Figure 2-3) are capable of feeding at very low rates, and some of the smallest disk types, such as those used for pilot-plant installations, are able to handle water rates as low as 25 gpm (95 L/min). If an open channel for feeding by gravity from the dissolving tank is not available, an eductor or centrifugal feed pump can be used for injecting fluoride solution into a main. The roll-type and screw-type volumetric dry feeders are capable of handling flow rates from less than 100 gpm to several million gallons per day (400 L/min to several megaliters per day). Gravimetric dry feeders can treat flows from about 2 mgd (7.6 ML/d) up to the greatest water usages encountered (Figure 2-4).

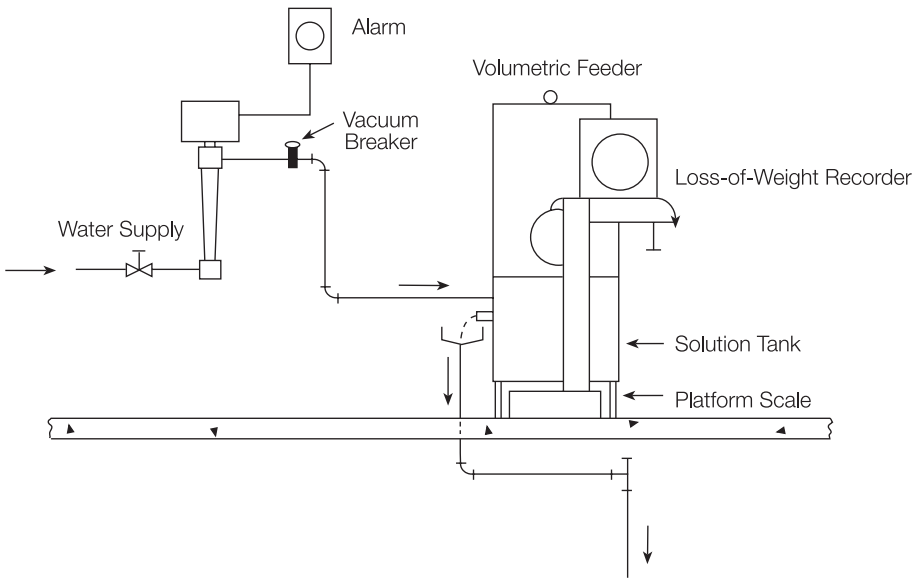


Figure 2-3 Dry feed installation with volumetric feeder

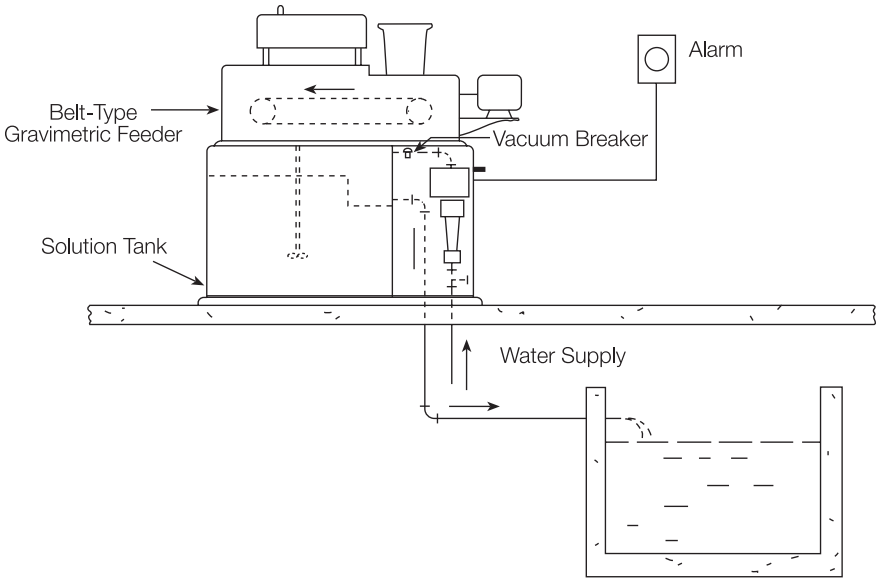


Figure 2-4 Dry feed installation with gravimetric feeder

The fluoridation system with the lowest equipment cost feeds a fluoride solution into a water flow in a pipeline. The only requirements are to prepare a fluoride solution of known concentration and to pump it into the water so that the necessary fluoride concentration in the water is achieved. Of the most commonly used fluoride compounds, sodium fluoride and fluorosilicic acid are of sufficient solubility to make up solutions of fixed strength that can then be fed with a metering pump. Fluorosilicic acid, normally purchased as a solution, can be fed either directly from the shipping container or from an intermediate storage tank (day tank).

For small water plants, some type of solution feed is usually selected. There is almost no lower limit to the ranges of the smallest metering pumps. In addition, if the feed rate for solution feed is impractically low, a more dilute solution can be fed (although this is not preferred). Conversely, there is almost no upper limit to the capacity of gravimetric dry feeders or pumps. Large water plants can select either dry feed using sodium fluorosilicate or direct feed using fluorosilicic acid. All other water plants have a choice, modified by individual circumstances. Assistance can be obtained from state health department engineers, manufacturers' representatives, and consultants.

CHEMICAL SELECTION GUIDELINES

For small water plants, the amount of chemical used is small enough that the cost per pound is not a major factor. Therefore, sodium fluoride or fluorosilicic acid, even though relatively expensive in small lots, can be used. The decision to use fluorosilicic acid, a manually prepared sodium fluoride solution, or a saturator depends on the quantities to be fed, the skill of the operator, and the availability and desirability of acid. Table 2-1 is a checklist, based mainly on water pumping rates, that can be used as a rough guide in differentiating between the various types of fluoridation installations. The population divisions in this table are general guidelines and will overlap.

Table 2-1 Fluoridation planning checklist

Operating Parameters	Manual Sodium Fluoride Solution Preparation	Automatic Sodium Fluoride Solution Preparation	Fluorosilicic Acid 23–30%	Dry Feed	
				Sodium Fluorosilicate	Sodium Fluoride
Water flow rate	Less than 500 gpm (1,900 L/min)	Less than 2,000 gpm (7,600 L/min)	More than 500 gpm (1,900 L/min)	More than 100 gpm (380 L/min)	More than 2 mgd (7.67 ML/d)
Population served by system or each well of multiple-well system	Less than 5,000	Less than 10,000	More than 10,000	More than 10,000	More than 50,000
Equipment required	Solution feeder, mixing tank, scales, mixer	Solution feeder, saturator, water meter	Solution feeder, day tank, scales, transfer pump	Volumetric dry feeder, scales, hopper, dissolving chamber	Gravimetric dry feeder, hopper, dissolving chamber
Feed accuracy	Depends on solution preparation and feeder	Depends on feeder	Depends on feeder	Usually within 3%	Usually within 1%
Chemical specifications and availability	Crystalline NaF, dust-free, in bags or drums; generally available	Downflow—coarse crystalline NaF in bags or drums; may be scarce Upflow—fine crystalline NaF	Bulk acid in tank cars or trucks; available on contract	Powder in bags, drums, or bulk; generally available	Powder in bags, drums, or bulk; generally available
Handling requirements	Weighing, mixing, measuring	Dumping whole bags only	All handling by pump	Bag loaders or bulk-handling equipment required	Bag loaders or bulk-handling equipment required
Feeding point	Injection into filter effluent line or main	Injection into filter effluent line or main	Injection into filter effluent line or main	Gravity feed from dissolving chamber into open flume or clearwell, pressure feed into filter effluent line or main	Gravity feed from dissolving chamber into open flume or clearwell, pressure feed into filter effluent line or main
Other requirements	Solution water may require softening	Solution water may require softening	Acid-proof storage tank, piping, etc.	Dry storage area, dust collectors, dissolving chamber, mixers, hopper agitators, educators, etc.	Dry storage area, dust collectors, dissolving chamber, mixers, hopper agitators, educators, etc.
Hazards	Dust, spillage, solution preparation error	Dust, spillage	Corrosion, fumes, leakage	Dust, spillage, arching, and flooding in feeder and hopper	Dust, spillage, arching, and flooding in feeder and hopper

PRELIMINARY CALCULATIONS

The first step in planning is to determine the optimal fluoride level and dosage. Then, based on the system pumping rates and chemical purity and available fluoride ions, the quantity of chemicals needed daily can be determined. The quantity in large part determines the chemical that should be used, which in turn determines the types of feeders that can be selected. Example calculations will be given after the factors have been explained.

Optimal Fluoride Level

The optimal fluoride level for a particular water system is normally determined by contacting officials in the state or provincial regulatory agency for water supplies. If there are no state or provincial regulations, Table 2-2 and Figure 2-5 may be used. The table and figure present the optimal fluoride concentrations and control ranges recommended by the US Public Health Service, Centers for Disease Control and Prevention.

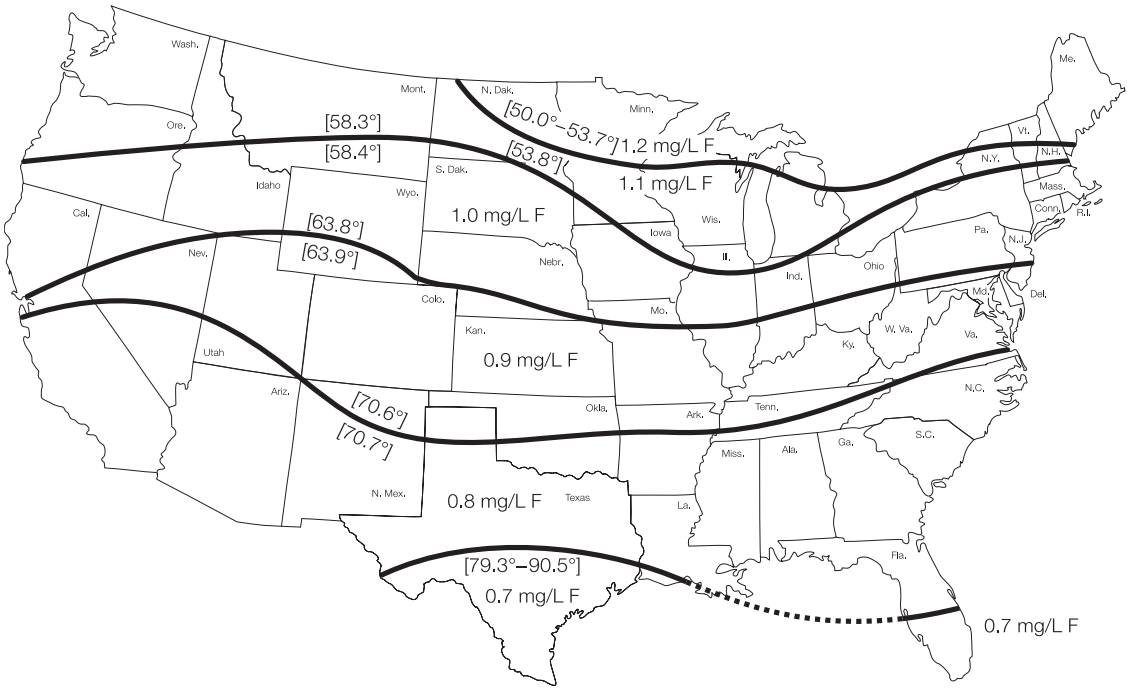
Dosage

The dosage is the amount of fluoride chemical needed to obtain the optimal fluoride level in the drinking water. The dosage, expressed as milligrams per liter (mg/L) or parts per million (ppm), is obtained by subtracting the naturally occurring fluoride level from the desired fluoride level. For example, if the desired fluoride level is 1.2 mg/L and the natural fluoride level is 0.2 mg/L, the dosage is 1.0 mg/L (1.2 – 0.2 = 1.0). The analytical procedures to measure fluoride levels in source water and finished water are described in chapter 4.

Table 2-2 Optimal fluoride levels

Annual Average of Maximum Daily Air Temperatures,*		Recommended Fluoride Concentrations,†	Recommended Control Range,†		
°F	°C	*mg/L*	*mg/L*		
			(0.1 Below)		(0.4 Above)
50.0–53.7	10.0–12.0	1.2	1.1	—	1.6
53.8–58.3	12.1–14.6	1.1	1.0	—	1.5
58.4–63.8	14.7–17.6	1.0	0.9	—	1.4
63.9–70.6	17.7–21.4	0.9	0.8	—	1.3
70.7–79.2	21.5–26.2	0.8	0.7	—	1.2
79.3–90.5	26.3–32.5	0.7	0.6	—	1.1

* Based on temperature data for a minimum of five years.
† Division of Oral Health. Centers for Disease Control and Prevention, US Public Health Service, Atlanta, Ga.



Source: Centers for Disease Control and Prevention (1993).

NOTE: Annual average of maximum daily air temperatures (°F).

Figure 2-5 Optimal fluoride levels

Maximum Pumping Rate (Capacity)

The maximum pumping rate, also called plant capacity, refers to the maximum flow of water that can be produced. The capacity may be measured in gallons per minute (gpm) or millions of gallons per day (mgd). The fluoride feed rate depends on the flow of water through the system. The maximum design feed rate will be based on the maximum pumping capacity, even if the plant does not currently reach that maximum rate. Of course, the amount of chemical needed for an average day is not based on the maximum pumping rate but rather the average daily production of water. The average daily production of water is a quantity, such as 2 mil gal, rather than a rate, such as 500 gpm. A plant may have a capacity of 2 mgd, but if it operates at that rate for an average of only 12 hours a day, then the average daily production is 1 mil gal. Of course, every plant has daily and seasonal variations, and the actual feed rate is time dependent, varying with the flow of water through the system.

Chemical Purity and Available Fluoride Ion Concentration

Only a portion of the bulk quantity of chemical contributes to the optimal fluoride level. Chemicals as delivered are not 100 percent pure, and the fluoride ions may be bound to other elements. Table 2-3 lists examples of purity and available fluoride ion (AFI). The percent available fluoride is the purity multiplied by the AFI.

Table 2-3 Typical values of purity and available fluoride ion (AFI)

Chemical	Purity, %	AFI	Available F, %
Sodium fluoride	98	0.452	44
Sodium fluorosilicate	98.5	0.607	60
Fluorosilicic acid	23	0.792	18

FEED RATE AND DOSAGE CALCULATIONS

Calculation of the chemical feed rate is necessary for proper adjustment of the fluoride feeder. In order to calculate the chemical feed rate, the following must be known:

- Desired fluoride dosage
- Plant rate or pumping rate
- Commercial purity and fluoride concentration of the fluoride chemical being fed (available fluoride ion)

With these data, the chemical feed rate (in pounds per day) can be calculated for the various methods of feeding fluorides by the following equation:

$$\text{chemical feed rate (lb/d)} = \frac{D \times PR\ (\text{mgd}) \times (8.34\ \text{lb/gal})}{AFI \times P} \tag{2-1}$$

Where:

D = dosage, in mg/L
PR = plant rate, in mgd
AFI = available fluoride ion, decimal fraction
P = chemical purity, decimal fraction

For the chemical feed rate in pounds per minute, the following equation may be used:

$$\text{chemical feed rate (lb/min)} = \frac{D \times PR\ (\text{gpm}) \times 8.34\ \text{lb/gal}}{1,000,000\ AFI \times P} \tag{2-2}$$

Where:

PR = plant rate, in gpm

Some feed rates from equipment design data sheets are given in grams per minute. In addition, the feed rate may have to be calculated in cubic feet per hour. The results from Eq 2-1 and Eq 2-2 can be converted to match these units. Many states require that records be kept of the amount of chemical used and that the theoretical concentration of the chemical in the water be determined mathematically. This number, the calculated dosage, is a safety precaution that helps ensure that an overfeed or accident does not occur. It also aids in solving troubleshooting problems. If the calculated dosage is significantly higher or lower than the measured concentration, steps should be taken to determine the reason for the discrepancy.

The following equation can be used to determine the calculated dosage (in milligrams per liter):

$$\text{calculated dosage mg/L} = \frac{(\text{pounds of chemical}) \times AFI \times P}{(\text{million gallons of } H_2O \text{ treated}) \times 8.34 \text{ lb/gal}} \quad (2\text{-}3)$$

The numerator of the equation represents pounds of fluoride ion added to the water, and the denominator represents millions of pounds of water treated.

A saturator-type feeder is unique because the strength of the solution formed is always 18,000 mg/L. This is due to the fact that sodium fluoride solubility is practically constant at 4.0 g/100 mL of water at the temperatures generally encountered in water treatment. Each liter of solution contains 18,000 mg of fluoride ion (40,000 mg/L times the percent available fluoride [45 percent] equals 18,000 mg/L). The constant strength simplifies calculations by eliminating the need for weighing the chemicals. The volume of solution added to the water is all that is needed; for a calculated dosage in milligrams per liter, a meter on the water inlet of the saturator provides this volume value. Thus, the feed rate is simply

$$\text{Feed rate} = \frac{\text{plant capacity} \times \text{dosage mg/L}}{18{,}000 \text{ mg/L}} \quad (2\text{-}4)$$

The feed rate will have the same units as the capacity. If the capacity is in gallons per minute, the feed rate will also be in gallons per minute.

The formula for the calculated dosage (in milligrams per liter) for the saturator is as follows:

$$\text{Calculated dosage mg/L} = \frac{\text{gallons in saturator} \times 18{,}000 \text{ mg/L}}{\text{gallons of } H_2O \text{ treated}} \quad (2\text{-}5)$$

EXAMPLE FEED RATE CALCULATIONS

Sodium Fluorosilicate

Example 1. The optimal fluoride level has been determined to be 1.2 mg/L, and the natural fluoride level is 0.2 mg/L. The chemical supplier has indicated that the commercial purity of the sodium fluorosilicate supplied is 98 percent and that a cubic foot of the supplied material weighs 65 lb. If the plant rate is 2,000 gpm, determine the chemical feed rate in pounds per minute and cubic feet per hour.

Given:

Optimal fluoride level	=	1.2 mg/L
Natural fluoride level	=	0.2 mg/L
Chemical purity	=	98 percent
Pumping rate	=	2,000 gpm
Chemical weight	=	65 lb/ft^3

Solution:

(a) Determine fluoride dosage:

dosage (mg/L) = optimal fluoride level (mg/L) – natural fluoride level (mg/L)

$$= 1.2 - 0.2$$
$$= 1.0 \text{ mg/L}$$

(b) Determine available F^-:
From Table 1-3, pure sodium fluorosilicate has 60.7 percent available fluoride ion.

(c) Calculate feed rate using Eq 2-2:

$$\text{chemical feed rate (lb/min)} = \frac{1.0 \text{ mg/L} \times 2{,}000 \text{ gpm} \times 8.34 \text{ lb/gal}}{10^6 \times 0.607 \times 0.98}$$
$$= 0.028 \text{ lb/min}$$

(d) Convert to ft^3/hr:

$$\text{chemical feed rate } (ft^3/hr) = \frac{0.028 \text{ lb/min} \times 60 \text{ min/hr}}{65 \text{ lb/ft}^3}$$
$$= 0.0258 \text{ ft}^3/\text{hr}$$

Example 2. The annual average of maximum daily air temperatures has been determined to be 65°F. Sodium fluorosilicate with a commercial purity of 95 percent and unit weight of 66 lb/ft^3 is to be fed. If the plant pumping rate is 695 gpm, determine the chemical feed rate in grams per minute. The natural fluoride present in the water is insignificant.

Given:
Average annual maximum

Daily air temperature	=	65°F
Chemical purity	=	95 percent
Chemical weight	=	66 lb/ft^3
Pumping rate	=	695 gpm
Natural fluoride level	=	0 mg/L

Solution:
(a) Determine optimal fluoride level:
From Table 2-2, the optimal fluoride level is 0.9 mg/L.
(b) Determine fluoride dosage:
dosage (mg/L) = optimal fluoride level (mg/L) – natural fluoride level (mg/L)
$= 0.9 \text{ mg/L} - 0.0 \text{ mg/L}$
$= 0.9 \text{ mg/L}$

(c) Determine available F^-:
From Table 1-3, pure sodium fluorosilicate has 60.7 percent available fluoride ion.

(d) Calculate feed rate using Eq 2-2:

$$\text{chemical feed rate (lb/min)} = \frac{0.90 \text{ mg/L} \times 695 \text{ gpm} \times 8.34 \text{ lb/gal}}{10^6 \times 0.607 \times 0.95}$$
$$= 0.0090 \text{ lb/min}$$

(e) Convert to grams per minute:

$$\text{chemical feed rate (g/min)} = 0.009 \text{ lb/min} \times 454 \text{ g/lb}$$
$$= 4.1 \text{ g/min}$$

Fluorosilicic Acid

Example 1. The optimal fluoride level has been determined to be 1.0 mg/L. The purity of commercial fluorosilicic acid to be fed is 23 percent (10 lb/gal). The pumping rate is 4,000 gpm, and the natural fluoride present is insignificant. Determine the feed rate in pounds per day, gallons per minute, and milliliters per minute.

Given:

Optimal fluoride level	=	1.0 mg/L
Natural fluoride level	=	0.0 mg/L
Chemical purity	=	23 percent
Pumping rate	=	4,000 gpm

Solution:
(a) Determine fluoride dosage:
dosage (mg/L) = optimal fluoride level (mg/L) – natural fluoride level (mg/L)
= 1.0 mg/L – 0.0 mg/L
= 1.0 mg/L

(b) Determine available F^-:
From Table 1-3, pure fluorosilicic acid has 79.2 percent available fluoride ion.

(c) Convert plant rate to million gallons per day:

$$\text{plant rate (mgd)} = \frac{4{,}000 \text{ gpm} \times 1 \text{ mgd}}{695 \text{ gpm}}$$
$$= 5.76 \text{ mgd}$$

(d) Calculate feed rate using Eq 2-1:

$$\text{chemical feed rate (lb/d)} = \frac{1.0 \text{ mg/L} \times 5.76 \text{ mgd} \times 8.34 \text{ lb/gal}}{0.792 \times 0.23}$$
$$= 263 \text{ lb/d}$$

(e) Convert feed rate to gallons per minute:

$$\text{chemical feed rate (lb/d)} = \frac{1.0 \text{ mg/L} \times 5.76 \text{ mgd} \times 8.34 \text{ lb/gal}}{0.792 \times 0.23}$$
$$= 263 \text{ lb/d}$$
$$\text{chemical feed rate (gpm)} = \frac{263 \text{ lb/d}}{1{,}440 \text{ min/d} \times 10 \text{ lb/gal}}$$
$$= 0.018 \text{ gpm}$$

(f) Convert feed rate to milliliters per minute:

$$\text{chemical feed rate (mL/min)} = 0.018 \text{ gpm} \times 3{,}785 \text{ mL/gal}$$
$$= 68 \text{ mL/min}$$

Sodium Fluoride

Example 1. The fluoride dosage has been determined to be 1.1 mg/L. Sodium fluoride (commercial purity of 95 percent) is to be fed using a dry chemical feeder. The plant rate is 2 mgd. Determine the chemical feed rate.

Given:

Fluoride dosage	=	1.1 mg/L
Pumping rate	=	2 mgd
Commercial purity	=	95 percent

Solution:

(a) Determine available F^-:

From Table 1-3, pure sodium fluoride has 45.25 percent available fluoride ion.

Calculate feed rate using Eq 2-1:

$$\text{chemical feed rate (lb/d)} = \frac{1.1 \text{ mg/L} \times 2 \text{ mgd} \times 8.34 \text{ lb/gal}}{0.4525 \times 0.95}$$

$$= 42.7 \text{ lb/d}$$

Example 2. The fluoride dosage has been determined to be 0.9 mg/L. A sodium fluoride saturator is to be used to treat a plant rate of 180 gpm. Determine the feed rate in gallons per minute and milliliters per minute.

Given:

Fluoride dosage	=	0.9 mg/L
Plant rate	=	180 gpm

Solution:

(a) Calculate feed rate in gallons per minute using Eq 2-4:

$$\text{chemical feed rate (gpm)} = \frac{180 \text{ gpm} \times 0.90 \text{ mg/L}}{18{,}000}$$

$$= 0.0090 \text{ gpm}$$

(b) Convert feed rate to milliliters per minute:

chemical feed rate (mL/min) = 0.009 gpm × 3,785 mL/gal

= 34 mL/min

EXAMPLE CALCULATED DOSAGE PROBLEMS

Sodium Fluorosilicate

Example 1. A plant uses 65 lb of sodium fluorosilicate in treating 5,540,000 gal of water (assume 98.5 percent chemical purity).

The solution for determining the calculated dosage (using Eq 2-3):

$$\text{calculated dosage (mg/L)} = \frac{65 \text{ lb} \times 0.607 \times 0.985}{5.54 \text{ mil gal} \times 8.34 \text{ lb/gal}}$$

$$= 0.84 \text{ mg/L}$$

Example 2. Calculate the dosage for a plant that uses 26 lb sodium fluorosilicate in treating 1,756,000 gal of water (assume 98.5 percent chemical purity).

Solution (using Eq 2-3):

$$\text{calculated dosage (mg/L)} = \frac{26 \text{ lb} \times 0.607 \times 0.985}{1.756 \text{ mil gal} \times 8.34 \text{ lb/gal}}$$
$$= 1.06 \text{ mg/L}$$

Fluorosilicic Acid

Example 1. What is the calculated dosage for a plant using 43 lb of 23 percent fluorosilicic acid to treat 1,226,000 gal of water?

Solution (using Eq 2-3):

$$\text{calculated dosage (mg/L)} = \frac{43 \text{ lb} \times 0.792 \times 0.23}{1.226 \text{ mil gal} \times 8.34 \text{ lb/gal}}$$
$$= 0.77 \text{ mg/L}$$

Example 2. Determine the dosage for a plant that uses 898 lb of 23 percent fluorosilicic acid in treating 17,058,000 gal of water.

Solution (using Eq 2-3):

$$\text{calculated dosage (mg/L)} = \frac{898 \text{ lb} \times 0.792 \times 0.23}{17.058 \text{ mil gal} \times 8.34 \text{ lb/gal}}$$
$$= 1.15 \text{ mg/L}$$

Sodium Fluoride

Example 1. What is the calculated dosage for a plant using 10 gal from its saturator to treat 200,000 gal of water.

Solution (using Eq 2-5):

$$\text{calculated dosage (mg/L)} = \frac{10 \text{ lb} \times 18,000 \text{ mg/L}}{200,000 \text{ gal}}$$
$$= 0.90 \text{ mg/L}$$

Example 2. Determine the calculated dosage for a plant using 19 gal of solution from its saturator to treat 360,000 gal of water.

Solution (using Eq 2-5):

$$\text{calculated dosage (mg/L)} = \frac{19 \text{ gal} \times 18,000 \text{ mg/L}}{360,000 \text{ gal}}$$
$$= 0.95 \text{ mg/L}$$

SIMPLIFICATION OF FEED RATE AND DOSAGE CALCULATIONS

Calculations can be simplified by using charts or tables, such as Table 2-4. The figures in the column at the extreme right of Table 2-4 can be used for calculating the amount of fluoride compound to add for quantities of water other than 1 mil gal. For example, the amount of 97 percent sodium fluoride needed for 10,000 gal would be 10,000/1,000,000, or 0.01, times the amount indicated. For 2 mil gal, the amount of fluoride compound needed would be twice as much, and so forth.

Similarly, if a concentration of F^- other than 1.0 mg/L is to be added (because of the presence of natural fluoride or an optimal concentration other than 1.0 mg/L),

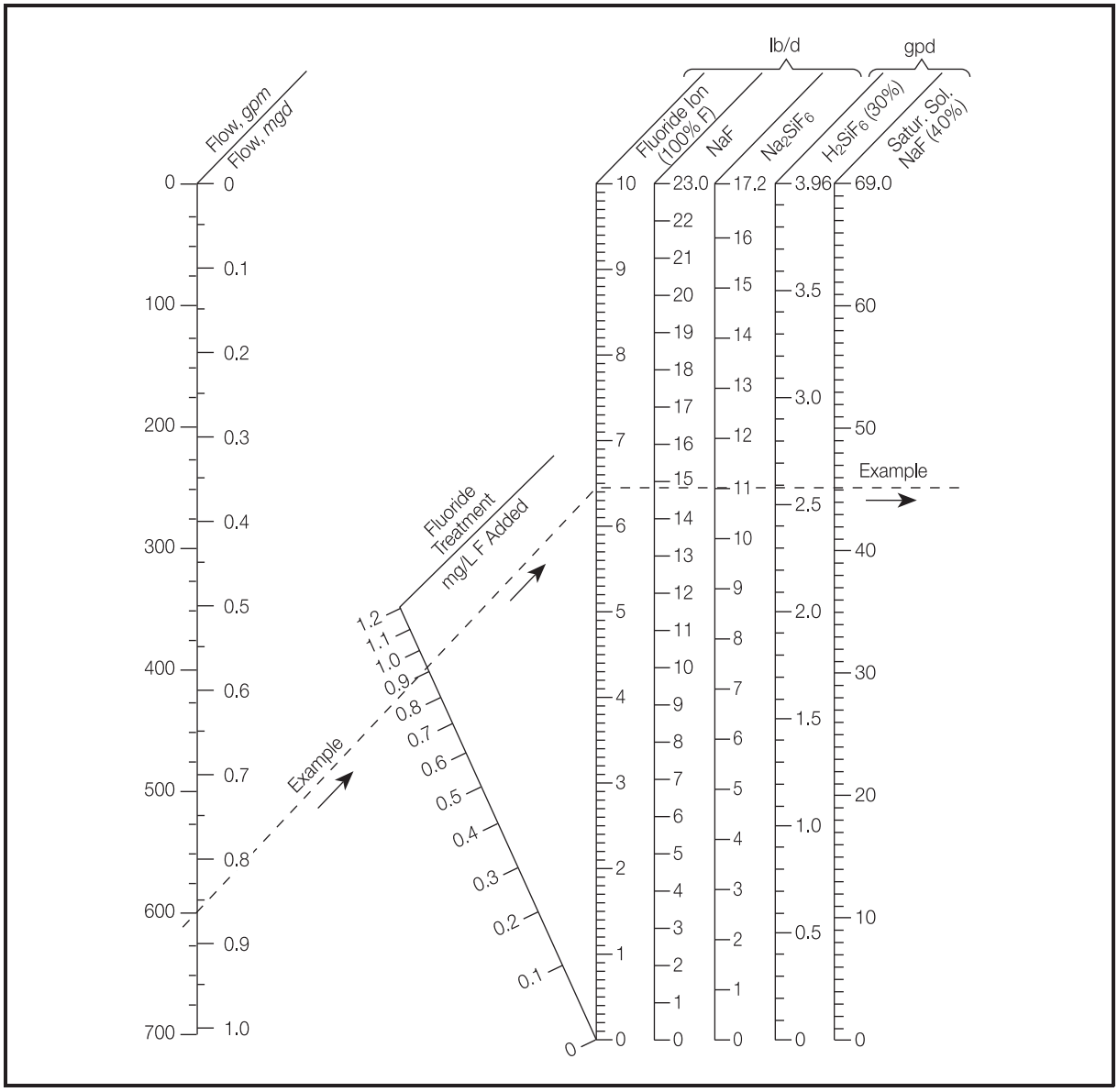
multiplying the figures in the right-hand column by the appropriate factor will give the number of pounds to use. For example, if 0.3 mg/L F^- occurs naturally and the optimal level is 0.8 mg/L, only 0.5 mg/L would have to be added, or one half as much as indicated.

Other devices often used to simplify calculations are nomographs and alignment charts (Figures 2-6 and 2-7). Nomographs have been published both for specific compounds and for several different materials, as in the illustrations. They may or may not take into account the purity of the chemical.

Tables and nomographs are generally not very accurate, but they are useful for estimating chemical requirements or, if one uses them to work backward, for estimating the theoretical fluoride concentration achieved.

Table 2-4 Fluoride calculation factors

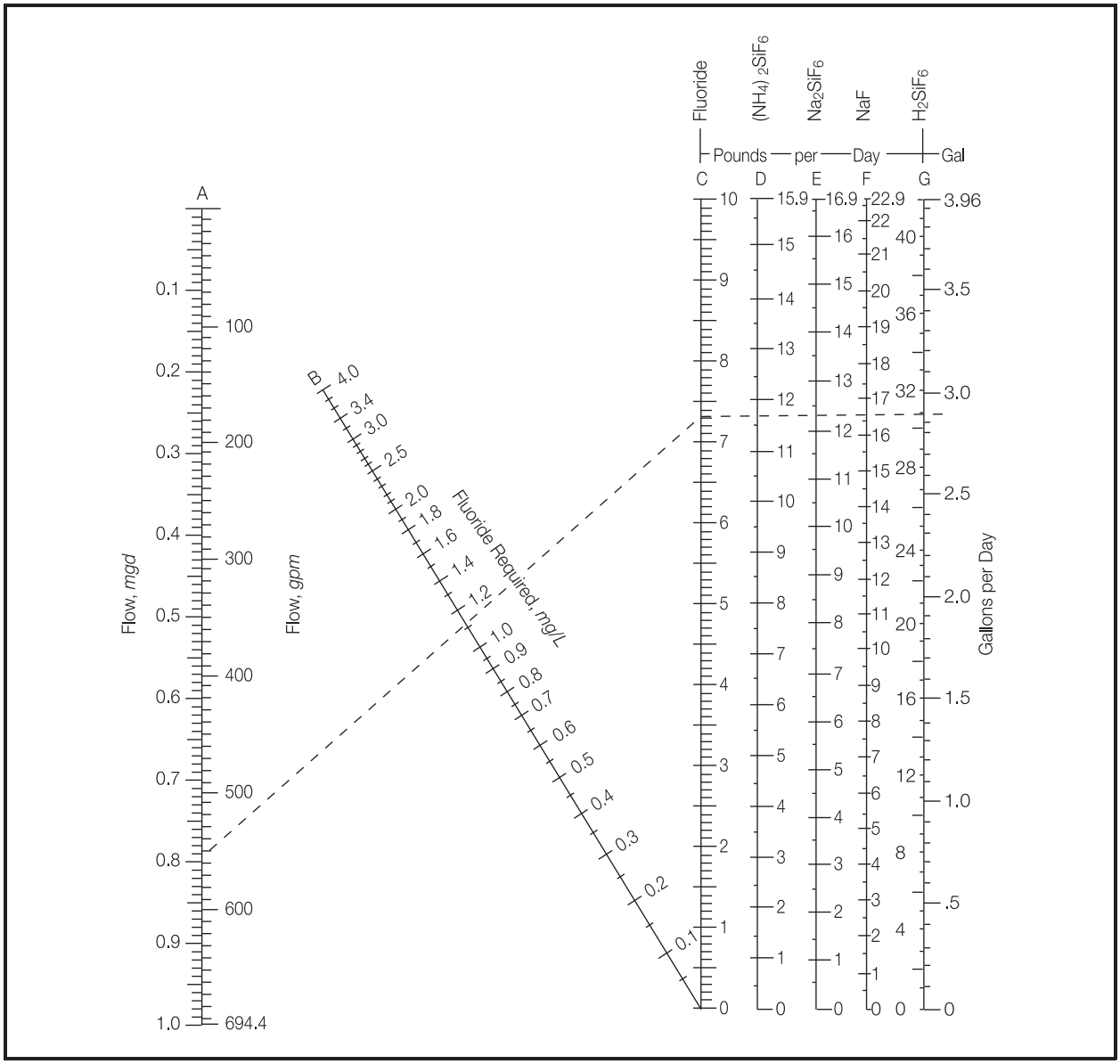
Compound	Available F^-, *lb F/lb compound*	Commercial Purity, %	Compound Required per mil gal of H_2O for 1 mg/L, *lb*
Sodium fluoride	0.4525	95	19.4
		96	19.2
		97	19.0
		98	18.8
		99	18.6
Sodium fluorosilicate	0.607	95	14.5
		96	14.5
		97	14.1
		98	14.0
		98.5	13.9
		99	13.8
Fluorosilicic acid	0.792	20	52.5
		21	50.0
		22	47.8
		23	45.7
		24	43.8
		25	42.0
		26	40.5
		27	38.9
		28	37.4
		29	36.3
		30	35.2



Instructions

1. Subtract the natural level from the desired level to get the fluoride treatment figure (mg/L fluoride ion added).
2. Draw a line from the flow figure straight through the fluoride treatment figure to the fluoride ion line. The intersection will show the required pounds of fluoride ion per day.
3. This weight of fluoride ion may be obtained from any of the chemicals listed. Starting at the required pounds of fluoride ion per day, draw a horizontal line to the right and read the weight of dry chemical or volume of liquid chemical required.
4. Thus, in the example, a flow of 600 gpm requiring 0.9 mg/L fluoride ion added requires 6.45 lb of fluoride ion per day. This can be obtained from 14.8 lb/d of sodium fluoride, 11.0 lb/d of sodium fluorosilicate, 2.55 gpd of 30 percent fluorosilicic acid, or 44.2 gpd of saturated sodium fluoride solution.

Figure 2-6 Fluoridation nomograph



Instructions

1. Decide the amount of fluoride ion required to increase fluoride content by the desired amount.
   Step 1. Align this point on line B, representing dosage, with point on line A. Read, on line C, the amount of fluoride ion required in lb/d.
   Step 2. Align straightedge at right angles to line C at this determined point. Where the straightedge crosses lines D, E, F, and G, read the amount of particular chemical to be fed.
2. For any value in excess of maximum on line A or C, introduce proper factor of 10 or multiple thereof.
3. Greatest accuracy occurs when angle of straightedge approaches 90° with line B. Use factor of 10 to obtain this objective.

Figure 2-7 Fluoridation alignment chart

PRELIMINARY PLANNING EXAMPLES

To illustrate the preliminary planning of a fluoridation installation, three examples are given.

Example 1. A small water supply consists of an unattended well pumping into an elevated storage tank. An altitude switch on the elevated tank controls the pump. The water is not treated, and the only building is a small shed at the well site. The water pumping rate is approximately 250 gpm (950 L/min).

Plan: Provided the shed is large enough and well constructed, a saturator and solution feeder can be placed inside. The solution feeder can be tied electrically to the operation of the well pump so that feeding cycles will coincide with the on–off operation of the well pump. The fluoride can be injected directly into the pump discharge line. If the shed is large enough, weather-tight, and able to be locked, a few bags of sodium fluoride can also be stored inside off the floor. A water meter must be installed in the main if there is not one already there.

Example 2. A water treatment plant is currently feeding chlorine, alum, soda ash, and carbon to a surface supply. Postfiltration chemicals are added in an open channel. The service pumping rate is 3,000 gpm (11,000 L/min), and water is pumped directly from the clearwell to the mains.

Plan: If bulk fluorosilicic acid is available nearby, the economics of using acid appear favorable. The acid storage tank can be placed outdoors, with a day tank and feed pump located at the site of postfiltration chemical feed. In addition, an alternate system for feeding sodium fluorosilicate should be provided. This system would consist of a gravimetric dry feeder with the dissolving chamber discharge falling into the postfiltration feed channel. Chemical storage would be on the floor above the feeder where there is a separate area provided for fluoride chemicals. An extension hopper installed from the feeder to the storage floor would facilitate loading. Either feed system can be controlled by electric signals from a rate-of-flow transmitter on the main.

Example 3. A city's water supply consists of eight wells, all of which pump directly into the mains. There is an elevated storage tank, but it rides on the water system, and there is no point in the system where all the water can be treated. Pumping rates vary from 200 to 500 gpm (750 to 1,900 L/min), with the operation of each well pump controlled by pressure switches on the main.

Plan: Because there is no central point where all the water can be fluoridated with a single feed system, each well pump will have to be considered an individual water supply. The most economical approach would be to use a solution feeder (metering pump) and fluorosilicic acid at each pump location. The acid would be purchased in carboys, and platform scales would be provided at each location. Operation of feeders would be controlled by well pump operation. Water meters should also be installed at each location.

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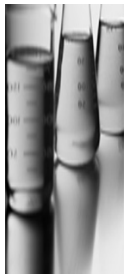


Chapter 3

Design, Equipment, and Installation

The previous chapter introduced the general types of fluoridation equipment and gave guidelines on planning a fluoridation system. This chapter presents more specific information on system design, equipment, and installation.

DESIGN

The following are important considerations in the design of a fluoridation system:

- Feeder location
- Fluoride injection point
- Chemical storage
- Cross-connections
- Automatic proportioning

This section discusses each of these concerns.

Location of Feeder

Before the type of feeder can be selected, sufficient and appropriate space must be located. At an existing water plant where other water treatment chemicals are being fed, enough space may be available for an additional feeder. If the system has no treatment plant, as is often the case with small water systems using a well supply, then a well house or some type of shelter near an elevated storage tank can be used.

The feeder must be placed in a dry, sheltered area near the point of fluoride injection and preferably in a place with storage space for chemicals. Electric power must be available. In many cases, a water line for solution preparation will be needed. The location must be accessible for chemical replenishment and maintenance. After these basic requirements are met, the prime considerations become

the isolation of stored chemicals from other materials, adequate ventilation, and general convenience.

Fluoride Injection Point

The fluoride injection point must be a point through which all the water to be treated passes. In a water treatment plant this may be a channel where other water treatment chemicals are added, a main coming from the filters, or the clearwell. In a well-pump system, this may be the discharge line of the pump if there is only one. If there is more than one pump, the point may be the line leading to the distribution system or storage facility. When facilities are combined, such as at a treatment plant for surface water plus supplemental wells, the point must be where all water from all sources passes. If there is no such common point, separate fluoride-feeding installations will have to be made for each water facility.

Another consideration in selecting a fluoride injection point is the loss of fluoride in filters. Whenever possible, fluoride should be added after filtration to avoid the substantial losses that can occur, particularly when heavy alum doses are used. (At an alum dosage rate of 100 mg/L, fluoride loss will be about 30 percent.) Adding fluoride too early in the lime–soda ash process can also result in a reduction in concentration. (Loss of fluoride in the softening process is directly proportional to the concentration of magnesium or lime in the water.) In most cases, such losses can be avoided simply by changing the fluoride addition point to a pipeline leading from the filters or to the clearwell. In rare cases, such as where the clearwell is inaccessible or so far away from the plant that transporting chemicals would be uneconomical, adding fluoride before filtering may be more practical.

When other chemicals are being fed, chemical compatibility must be considered. If any other chemicals contain calcium, the fluoride injection point should be as far away as possible from the addition point of those chemicals to minimize loss of fluoride by precipitation. For example, if lime for pH control is being added to the main leading from the filters, fluoride can be added to the same main at another point, or it can be added to one side of the clearwell. If the lime is being added to the clearwell, the fluoride should be added to the opposite side. Another factor in selecting the injection point is the necessity of having the feeder as close to the injection point as possible.

The discharge line from the feeder should be as short and straight as possible, although circumstances sometimes require a long discharge line. When this is the case, sharp curves or loops in the line must be avoided because they provide sites for precipitation buildup and subsequent blockage. If the solution is being injected into the pipeline, the injection fitting should preferably be installed near the bottom or underside of the pipe as shown in Figure 3-1. Injecting solution into the top of a pipe can cause air to collect and then work its way into the injection check valve or the discharge line and cause air binding. Locating the injection fitting in the lower portion of the pipe also prevents the fluoride chemical (particularly fluorosilicic acid) from draining out of the injection tube (and possibly the discharge line) and settling to the bottom of the pipe, causing corrosion.

The injection point should be at a higher elevation or a higher pressure than the elevation of the liquid level in the feed drum to reduce the possibility of siphonage and overfeeding. There should be an antisiphon valve at the feeder and at the injection point.

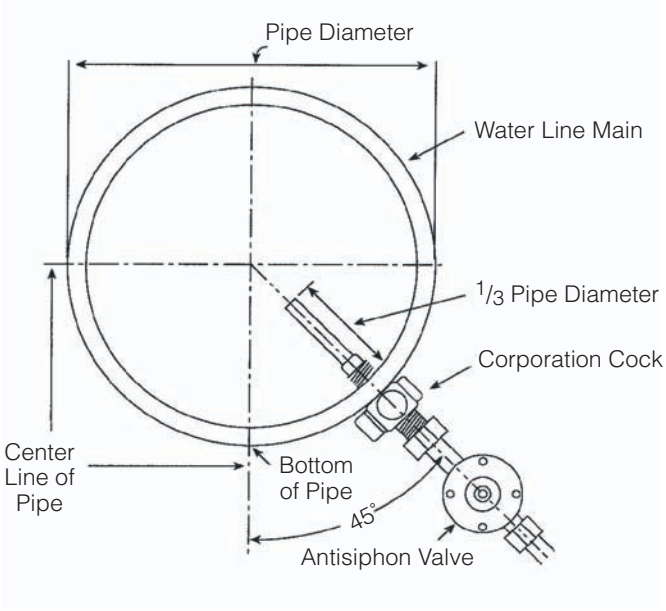


Figure 3-1 Fluoride injection point

Chemical Storage Considerations

A number of criteria govern the selection of a storage site for fluoridation chemicals. Dry chemicals must be kept dry; they must be convenient to the hopper in which they will be loaded; and they should preferably be isolated from other water treatment chemicals to avoid accidental intermixing. In addition, the storage area must be clean and well ventilated, and it should be equipped with running water and a floor drain for ease in cleaning up spills. Fluorosilicic acid presents particular problems in storage because the vapors are corrosive and will etch glass. Containers must be kept either tightly closed or vented to the outdoors. Large quantities of acid can be stored in underground or enclosed tanks equipped with outside vents.

Dry fluoride compounds (sodium fluoride and sodium fluorosilicate) have a tendency to compact or cake when exposed to moisture or when bags are stacked too high. Because similar conditions can result from long periods of storage, an oversupply of chemicals should be avoided. Dry fluorides should be stored on pallets, in stacks preferably not more than six bags high.

Cross-Connection Considerations

Water inlets to solution tanks and dissolving chambers often constitute a cross-connection when the inlet is below the level of solution. Whenever possible, the inlet line should have an air gap as a safety precaution. In cases where pressure is too high to make an air gap practical, a vacuum breaker should be installed at an elevated location between all other restrictive devices (such as valves) and the point of entry into the solution container. Possible cross-connections should be checked not only when the fluoridation installation is being designed but also when later modifications are made. AWWA Manual M14, *Recommended Practice for Backflow Prevention and Cross-Connection Control*, illustrates cross-connection prevention devices.

Automatic Proportioning (Pacing)

When the flow of water being treated is at a fixed rate, the fluoride feed rate can be maintained at the same rate after it has been adjusted to the proper ratio unless there is a change in pump delivery, feeder delivery, or chemical purity. When the flow is variable, such as when pump delivery varies with demand, a variable fluoride feed rate is necessary. Where two or three pumps are used, each with a fixed delivery rate, separate fluoride feeders may be used. Each feeder should be tied electrically to the individual pump operation, and each should be adjusted to feed fluoride in the correct ratio to the water delivered by that pump. In cases where the changes in water flow are predictable and infrequent, the feeder may be adjusted manually to a predetermined setting that corresponds to the new water flow rate. When such techniques are impossible, impractical, or inconvenient, some means for automatically adjusting the fluoride feed rate to the water flow must be provided. This automatic adjustment is called *pacing*.

For small water plants, particularly those using a solution feed system, a water-meter contactor can be used to pace the feeder. A water-meter contactor is a switch geared to the water-meter movement so that it will make contact at specified intervals of flow volume. The impulse from the water-meter contactor, when received by the feeder motor, will energize the feeder in proportion to the meter's response to flow. In cases where the impulse is too brief to activate the feeder motor, an interval timer connected between the contactor and motor can be set for appropriate time durations (as discussed later in this chapter). To avoid wide fluctuations in fluoride concentrations, the set points should be as close together as possible while at the same time preventing constant cycling off and on. If a timer is used, the durations of timed feeder operation should be as long as possible, just short of possible overlap at the maximum flow rate. Some small solution feeders, usually solenoid operated, are particularly well adapted to meter contactor operation.

Large water plants that are already equipped with flowmeters and recorders can use the signal from these devices to adjust feeder delivery electrically, pneumatically, or hydraulically. If this type of pacing is contemplated, feeders that have adjusted mechanisms compatible with the type of flowmeter signal available must be specified when ordering equipment.

Alternatives

If the plant does not have flowmeters that are readily adaptable to pacing the fluoride feeders, or if it has no flowmeters at all, various types of meters can be installed specifically for that purpose. For example, an orifice plate assembly with a differential-pressure-cell transmitter will supply an electric signal that can be used to control feeders.

Another device that provides an electric signal is a magnetic flowmeter. A signal converter will adapt the signal from such a meter to a form that can be used for adjusting some types of feeders. Other types of flowmeters require the use of recorder-controllers that modify a pneumatic or hydraulic pressure flow; the pressure modification will adjust the delivery rate of dry or solution feeders equipped for that purpose. For solution feeders, the adjustment is made to the stroke length; for dry feeders, the adjustment can be made through either a variable-speed drive or a poise-positioner. The pneumatic or hydraulic signals adjust variable-speed drives mechanically, whereas electric signals accomplish the same purpose through a silicon-controlled rectifier.

Another type of paced feed can be established through the use of a solution feeder operated hydraulically by a special water meter that diverts water under pressure to the feeder's driving piston in proportion to the rate of water flow in the main. Although

this type of paced feed does not require the use of remote flowmeter signals (and is not recommended), it is rarely used in water fluoridation.

FEEDERS

A chemical feeder measures quantities of a chemical, such as fluoride, and then adds them to the water at a preset rate. Feeders are either solution (liquid) feeders or dry feeders, depending on whether the chemical is a liquid or solid. Dry feeders are either volumetric (the chemical is measured by volume) or gravimetric (measured by weight) as illustrated in Figures 2-3 and 2-4. Dry chemical is dissolved into solution before being added to water supplies.

The three most common types of chemical feed systems for fluoridation are

- chemical solution feeder (acid feeder) with a liquid fluoride compound (fluorosilicic acid) or with a prepared solution of a dry fluoride compound
- sodium fluoride saturator
- dry chemical feeder with a dry fluoride compound (sodium fluorosilicate or sodium fluoride)

The saturator is a unique method for feeding fluoride and can be considered a special application of the chemical solution feeder method. The other two methods are commonly used to feed other water treatment chemicals. In general, most large and smaller systems use solution feeders or saturators.

Solution Feeders

A solution feeder is usually a small pump. Almost every type of pump that is used for feeding other water treatment chemicals can be adapted for feeding fluoride solutions. Minor modifications in construction may be required.

A solution feeder must deliver fluoride with accuracy and uniformity because the optimal fluoride level is prescribed between very narrow limits (see the section titled "Optimal Fluoride Level" in chapter 2). To maintain this precise level, fluoride must be added in precise proportion to the quantity of water being treated. A positive-displacement pump or feeder, which delivers a specific volume of liquid for each stroke of a piston or rotation of an impeller, meets this requirement. Figure 3-2 illustrates types of positive-displacement solution feeders that provide the accuracy essential for fluoride applications. No feeder delivers the exact volume displaced by the driving member of the pump. However, if fluoride solutions of a fixed strength are fed against a fixed pressure, the positive-displacement feeder has shown sufficient reliability for this purpose. The following paragraphs discuss specific solution feeders.

Piston and diaphragm feeders. For delivery against pressure, the two general types of solution feeders are the piston feeder and the diaphragm feeder. In the piston feeder, a reciprocating piston alternately forces solution out of a chamber and then, on the return stroke, refills the chamber by pulling the solution from a reservoir. In the diaphragm feeder, a flexible diaphragm, driven either directly or indirectly by a mechanical linkage, performs a similar function. If the mechanical drive for the feeder is an electric motor, then a gearbox or a system of belts and pulleys determines the number of strokes in a given time interval. Pneumatic or hydraulic drives are also available; these permit the use of a meter contactor to provide stroking in direct proportion to water flow instead of at a fixed rate.

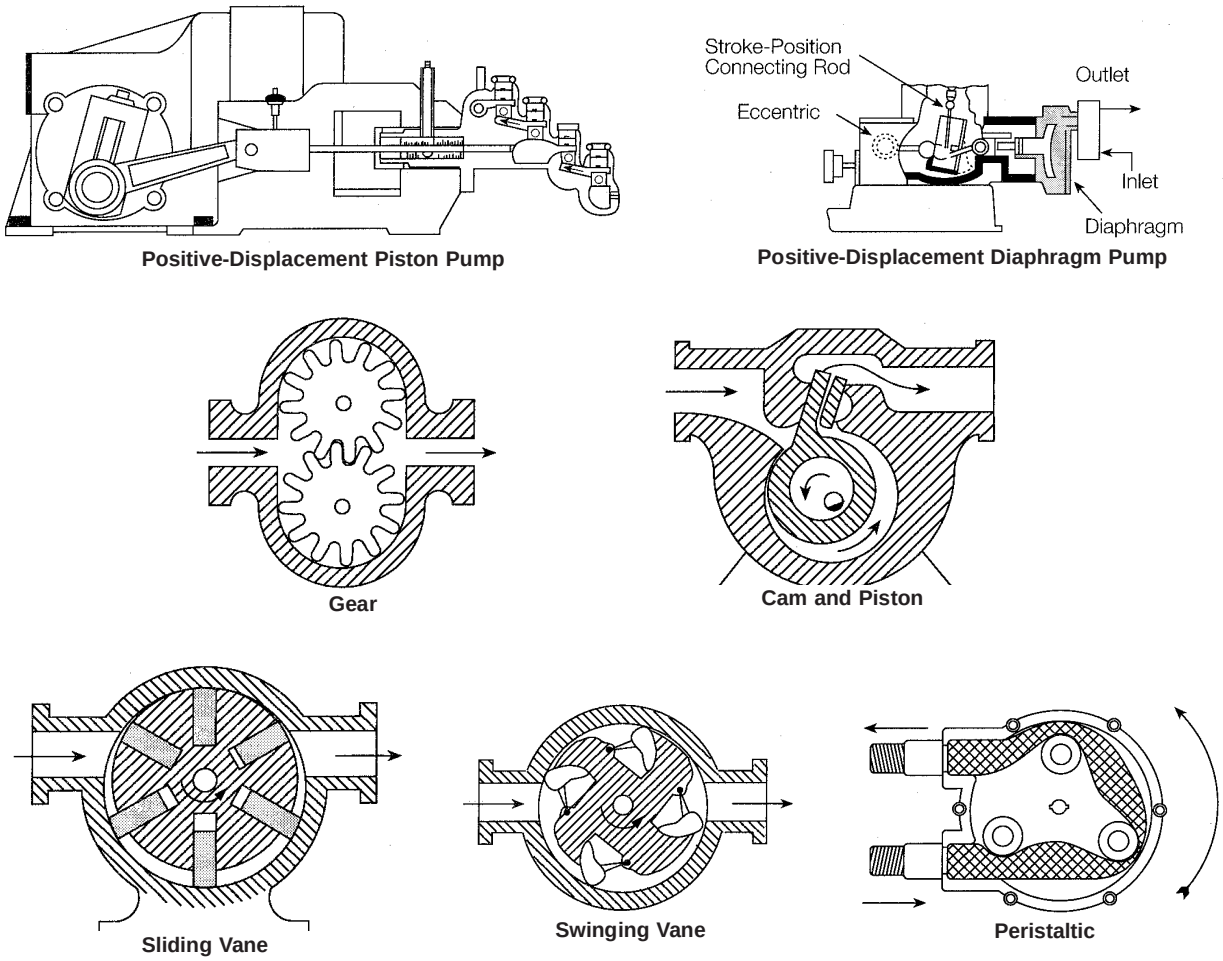


Figure 3-2 Positive-displacement solution feeders

The electronic pump is a special type of diaphragm pump and is the most common metering pump used in water fluoridation. Most diaphragm pumps used for fluoridation have a flexible diaphragm driven by a mechanical linkage. An electronic pump has a solenoid that is periodically energized to move the flexible diaphragm. It has solid-state electronics, circuit breakers, and an antisiphon valve. It can have eight manual or automatic controls and variable stroke and speed. The minimum output capacity is 0.15 gpd (0.57 L/d).

Peristaltic feeder. A peristaltic feeder is a positive-displacement pump that moves liquid (fluoride solution) through plastic tubing with alternating waves of constriction and dilation. A rotary gear rolls over the tubing, creating a suction on the solution side of the feeder. The suction draws the fluoride solution in one end of the tube and forces it out the other end.

The peristaltic feeder is self-priming and will not be damaged if the solution freezes. The range of feed is from 2 gpd up to 85 gpd (7.6 L/d up to 321.7 L/d). The tubing will generally last from one to two years, depending on use. Proper installation of the correct type of tubing is very important. Peristaltic feeders are generally used in small fluoridated systems. Although common in some parts of the country (and overseas), they are not widely used in the United States at the present time.

They have several advantages over the diaphragm pump because the check valves, diaphragm, and backsiphonage devices are all eliminated. The most frequent problem with the peristaltic pump is low durability of the tubing. Tubing is often changed at least annually.

Gravity feeders. For gravity feed, several types of solution feeders operate on the paddle-wheel principle. A rotating wheel equipped with small buckets dips solution from a constant head tank and discharges the solution into the water to be treated. The rate of feed can be varied by changing the number or size of the buckets, by changing the rate of rotation of the wheel, or by varying the proportion of the bucket contents that are emptied.

Rotary pumps. Several types of rotary pumps can also be considered positive-displacement feeders. These include gear, swinging vane, sliding vane, oscillating screw, eccentric, and cam types, as well as various modifications of these. Ordinarily, solution-feeding devices, such as centrifugal pumps, pot feeders, or a head tank and orifice, are not used for fluoridation because of their relative inaccuracy.

Selection criteria. The criteria used in selecting a feeder are

- capacity
- corrosion resistance
- pressure capability
- accuracy
- durability

Generally feeders perform most accurately near the midrange of both stroke length and stroke frequency and should be selected accordingly. At the extremely low feed rates required by small installations, the diaphragm feeders are preferable to the piston types. Most feeders come equipped with plastic heads and resilient check valves, both of which are satisfactory for fluoride solutions unless the pressure is greater than 100 psi (690 kPa). For higher pressures, corrosion-resistant alloys, such as 316 stainless steel or Carpenter 20 alloy, are required for feeder-head construction.

Because most solution feeders are adjustable both for stroke length, which determines the volume of liquid delivered per stroke, and stroke frequency, usually expressed in strokes per minute (spm), both factors should be considered when the feeder size is being selected for a particular application.

Saturators

Because sodium fluoride has a maximum solubility of approximately 4 percent (18,000 mg/L as F^-) regardless of substantial variations in water temperature, devices that automatically prepare saturated solutions can be used. These devices eliminate the need for weighing sodium fluoride, measuring the volume of solution water, and stirring to dissolve the chemical.

If water is allowed to trickle through a bed containing excess sodium fluoride, the solution will become saturated. The two general types of saturators are upflow and downflow. The upflow saturator is the most common type; it is preferred because it requires less maintenance than the downflow saturator. Downflow saturators are not generally available.

Upflow saturator. In an upflow saturator, undissolved sodium fluoride forms a bed through which water is forced upward under pressure (Figure 3-3). A spider-type water distributor located at the bottom of the tank contains hundreds of very small slits. Water, forced under pressure through these slits, flows upward through

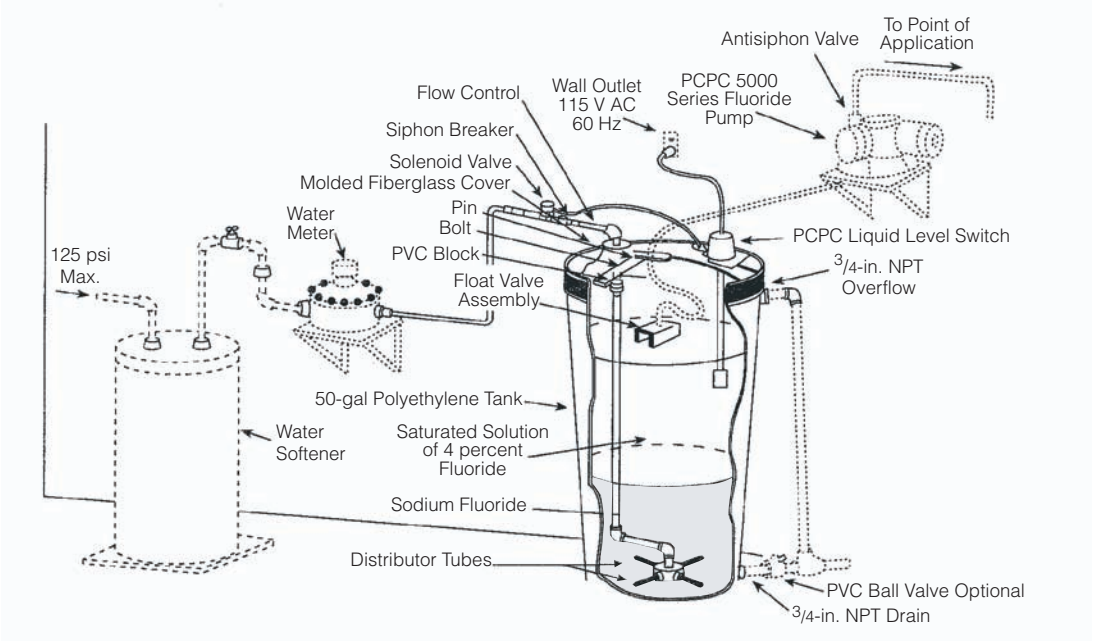


Figure 3-3 Upflow saturator

the sodium fluoride bed at a controlled rate to ensure the optimal 4 percent solution. As the water flows up through the bed of sodium fluoride, the solid material's specific gravity keeps the material from rising into the area of the clear solution above. The feeder pump intake line floats on top of the solution to prevent withdrawal of undissolved sodium fluoride. Because piping of water to the bottom of the saturator constitutes a cross-connection, a mechanical siphon breaker must be incorporated into the water line.

Because of the thicker bed of sodium fluoride attainable in an upflow saturator, higher withdrawal rates are possible. With 300 lb (140 kg) of sodium fluoride in the saturator tank, more than 15 gph (57 L/hr) of saturated solution can be fed—a rate sufficient to treat about 5,000 gpm (19,000 L/min) of water to a fluoride level of 1.0 mg/L. If the water supplied to the saturator is hard (more than 50 mg/L hardness), a household-type water softener installed in the supply line will minimize the amount of insoluble material accumulating in the saturator and increase the interval between cleanings.

To illustrate better how an upflow saturator works, the following procedure outlines the general steps necessary to prepare one for use:

1. With the distributor tubes in place and the floating suction device removed, add 200–300 lb (90–140 kg) of sodium fluoride directly to the tank. Any type of sodium fluoride can be used, from coarse to fine crystal. Powdered sodium fluoride is less desirable than the crystal form.
2. Connect the solenoid water valve to an electric outlet and turn on the water supply. The water level should be slightly below the overflow; if it is not, the liquid level switch should be adjusted.
3. Replace the intake float and connect it to the feeder intake line. The saturator is now ready to use.

4. The level of undissolved sodium fluoride should be visible through the translucent wall of the saturator tank. Whenever the level is low (one-half to one-third dissolved), add another 100 lb (45 kg) of fluoride.

The water distributor slits are essentially self-cleaning, and the accumulation of insolubles and precipitates does not constitute as serious a problem as it does in a downflow saturator. Periodic cleaning, however, is still required. Frequency of cleaning is dictated by the frequency of use, the rate of debris accumulation, and the hardness of the incoming water.

Downflow saturator. In downflow saturators, the solid sodium fluoride is held in a plastic drum or barrel and isolated from the prepared solution by a plastic cone or a pipe manifold (Figure 3-4). A filtration barrier of layers of sand and gravel prevents particles of undissolved sodium fluoride from entering the solution under the cone or within the pipe manifold. The feeder pump draws the solution from within the cone or manifold at the bottom of the plastic drum.

When a downflow saturator is in operation, water flows into the top of the saturator tank, with the level regulated by a float-operated controller. An air gap prevents a cross-connection. The water then trickles down through the bed of sodium fluoride. The solution is clarified in the sand-and-gravel filter bed and ends up as a clear, saturated solution at the bottom of the tank. A pump takes up the solution and adds it to the water supply.

Dry Feeders

A dry feeder meters a chemical at a predetermined rate. Generally, volumetric dry feeders are simpler to operate, are less expensive, deliver smaller quantities, and are slightly less accurate. Gravimetric dry feeders are capable of delivering extremely large quantities in a given time period, are extremely accurate, are more expensive, and are readily adapted to recording and automatic control. Attaching a weighing and controlling mechanism to a volumetric feeder enables it to be converted to a gravimetric feeder.

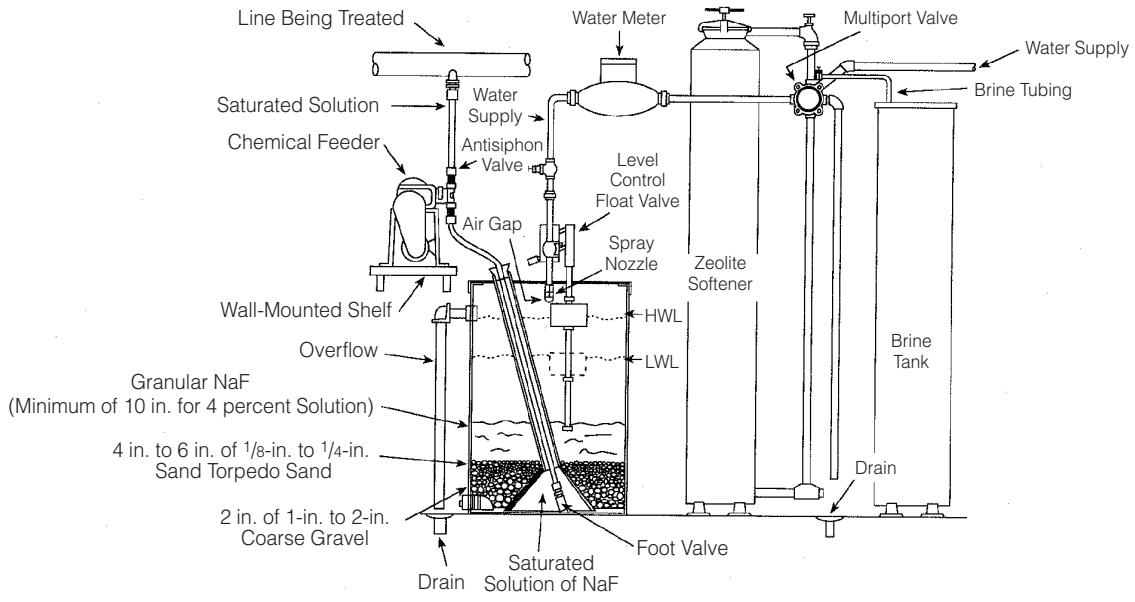


Figure 3-4 Downflow saturator

The choice between a volumetric or gravimetric feeder is governed largely by size and economics. In general, the accuracy of volumetric feeders is sufficient for feeding fluorides, thereby eliminating the need for the more expensive gravimetric feeders in many installations. The selection of one of the types of volumetric feeders involves several factors, such as size, cost, accuracy, and personal preference.

Volumetric dry feeders are available in several types that differ in terms of the method of measuring and delivering the dry chemical. Figures 3-5 and 3-6 show two types of volumetric dry feeders. Various types include the following:

- Rotating roller
- Rotating disc
- Rotation or reciprocating screw
- Star wheel
- Moving belt
- Vibratory pan
- Oscillating hopper
- Combinations of these types

The two general types of gravimetric dry feeders are those based on loss in weight of the feeder hopper and those based on the weight of material on a section of moving belt (Figures 3-7 and 3-8). Many gravimetric dry feeders also incorporate some of the features of volumetric feeders, such as a rotary feed mechanism between the hopper and the weighing section or a mechanical vibrator for moving chemicals out of the hopper. Because it is the weight of material per unit of time that is measured and regulated, such variables as material density or consistency have no effect on feed rate. This accounts for the extreme accuracy of these feeders. The stream or ribbon of dry material discharged from a dry feeder falls into a dissolving chamber where the dry chemical is mixed with water. The solution either drains into an open flume or clearwell or is pumped or injected into a pressure main.

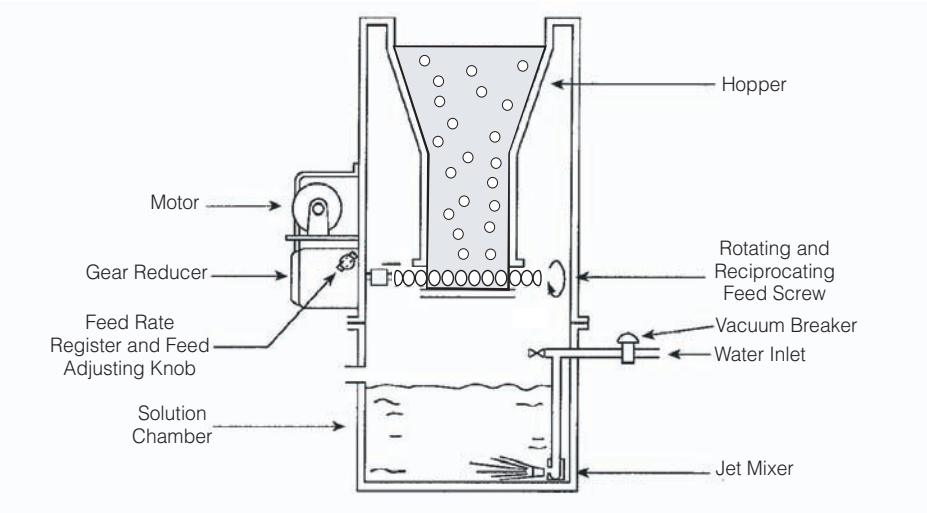


Figure 3-5 Screw-type volumetric dry feeder

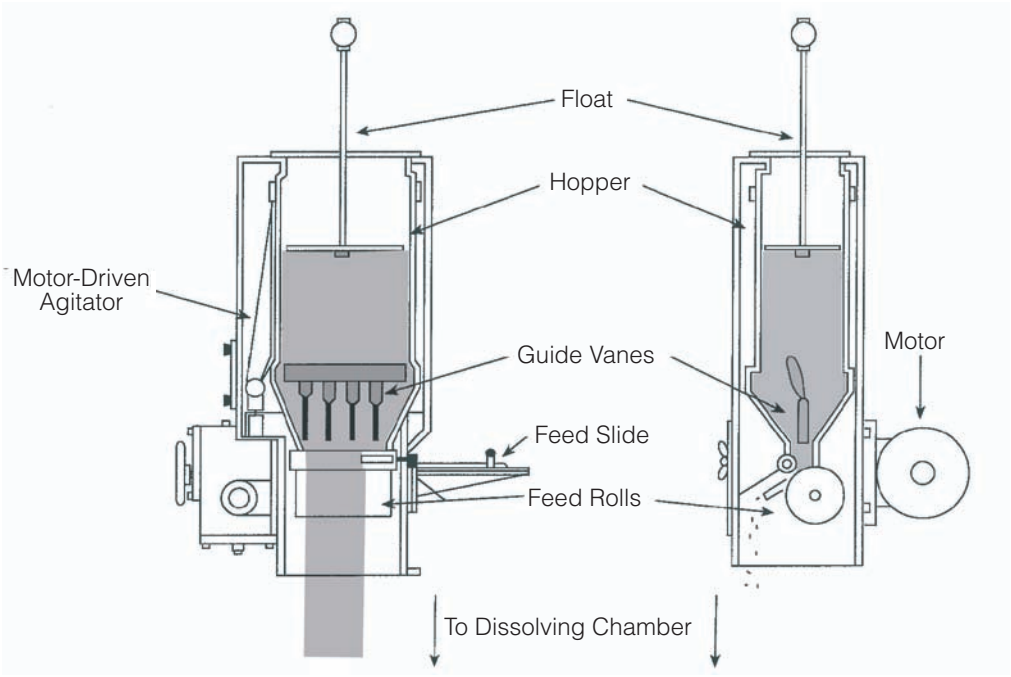


Figure 3-6 Roll-type volumetric dry feeder

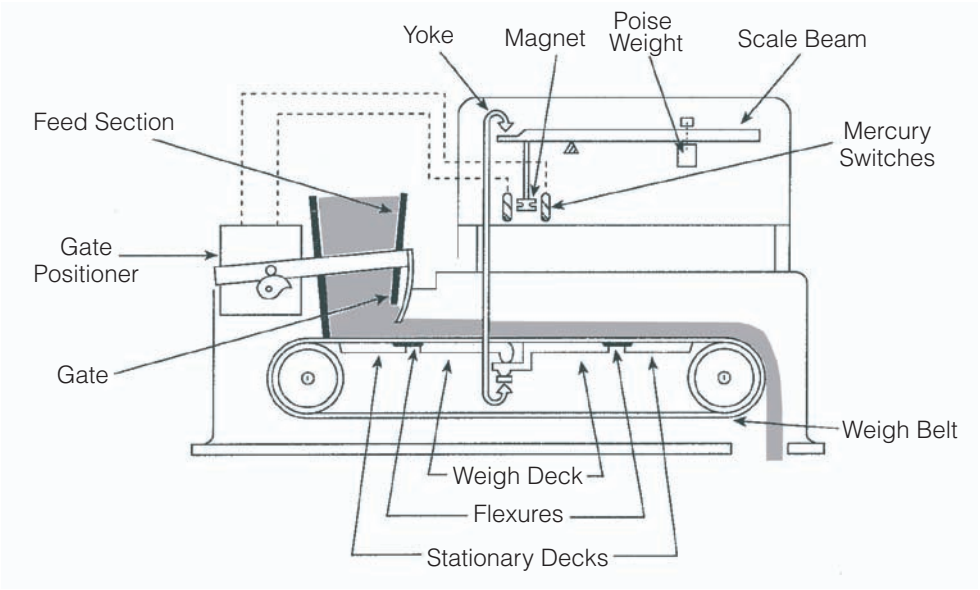


Figure 3-7 Belt-type gravimetric feeder

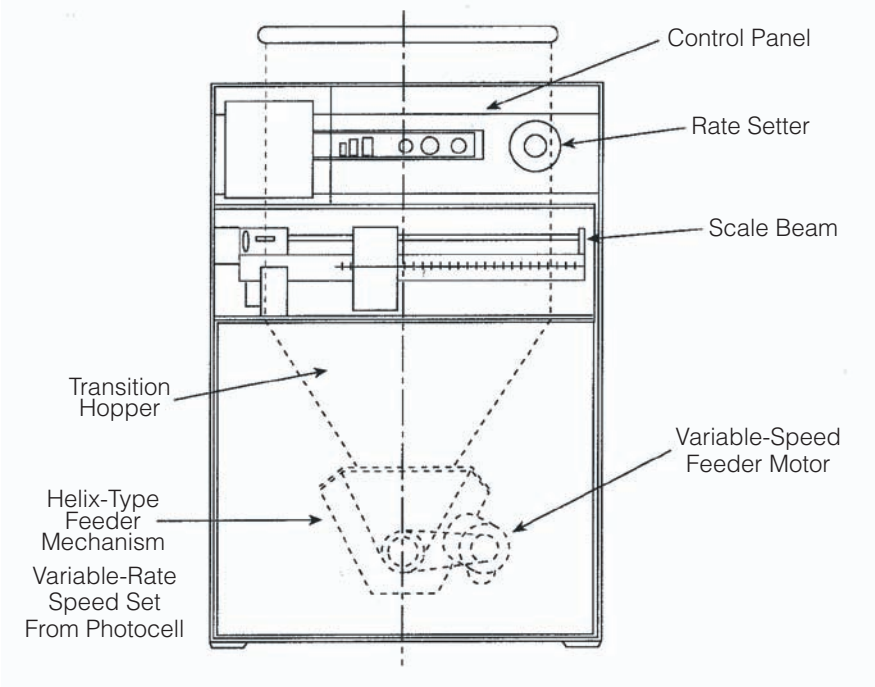


Figure 3-8 Gravimetric feeder—loss-in-weight type

Material quality. Dry feeders are designed to handle powdered materials, but not all such materials are handled with equal ease. Material that is too fine can flow like a liquid through the measuring mechanism and cause flooding. Some materials can form an arch in the hopper and, when the arch collapses, emit a cloud of dust that can flood the feeder. Other powders, either hygroscopic (water attracters) by nature or produced with a significant moisture content, tend to form lumps that can reduce the feed rate or prevent the powder from being fed at all. For most consistent feeding, a narrow size distribution and a low moisture content are best.

The AWWA standards for sodium fluorosilicate (sodium silicofluoride) and sodium fluoride limit the moisture content of these materials. Also, the materials should be suitable for feeding with a conventional dry feed machine used in water treatment. In many cases, individual water plants have devised chemical size specifications that can be handled adequately by the feeders on hand. Chemicals that meet AWWA standards usually produce minimal feeding problems.

Feeder size. As with solution feeders, manufacturers' bulletins and direct technical assistance should be used in the selection of appropriate equipment for a particular application. The criterion used in selecting the size of a dry feeder is similar to that used in selecting a solution feeder—they both operate most reliably when the delivery rate is near midrange. All too often, dry feeders are used on water supplies that are so small that the feeder is operating at dead minimum or even below this rate. The feeders are often operated below the minimum rate through the use of a cycle timer. Accurate and uniform fluoride feed rates cannot be expected under these conditions.

Calibrating dry feeders. Determining the accuracy and reliability of a dry feeder requires a small scale and a stopwatch (or a watch with a sweep second hand). Insert a shallow pan or sheet of cardboard between the measuring mechanism and

the dissolving chamber of the feeder while the feeder is operating, making sure that all the chemical that feeds through will be collected. Collect the chemical that is fed in several short periods (e.g., five periods of 5 min each). Weigh each of the amounts collected and the total. Provided the weighings and timings are accurate, the individual samples will indicate the uniformity of feed, and the total will indicate the accuracy of the feed rate.

Example. Weights of sodium fluorosilicate, in grams, collected in 5-min periods: 35, 35, 34, 36, and 35.

$$\begin{aligned} \text{total} &= 175 \\ \text{average} &= 35 \text{ g/5 min} \\ \text{uniformity} &= 35 \text{ g} \pm 1 \text{ g in 5 min (approximately 3 percent variation)} \\ \text{feed rate} &= \frac{35 \text{ g}}{5 \text{ min}} \times 60 \text{ min/hr} \\ &= 420 \text{ g/hr, or } 0.0926 \text{ lb/hr} \end{aligned}$$

The uniformity of feed in this case would be acceptable. If fluoride levels are to be maintained within 10 percent, the feeder delivery rate should be maintained at the highest accuracy possible. Repeating a test with longer sampling periods should show a smaller percentage of variations if the feeder is in proper working condition.

AUXILIARY EQUIPMENT

Auxiliary equipment is usually necessary for the proper operation of a fluoride chemical feed system. The type and complexity of the equipment required depend on the size and complexity of the fluoridation system. For the simplest system, one using only a carboy of acid and a pump, the requirements for auxiliary equipment are minimal. A platform scale and the feeder are all the equipment needed. An auxiliary piece of equipment might be a vacuum breaker to prevent pulling unmetered quantities of fluoride solution into the system in the event of a low-pressure situation.

For more complex systems, additional auxiliary equipment may include an alarm system for detecting and reporting low solution levels, a softener for removing hardness from the solution water, and a small meter for measuring the amount of water used in the solution preparation. The following paragraphs briefly describe common auxiliary equipment.

Meters

A water meter is required for accurate fluoride feeding. If a supply is unmetered, calculation of the fluoride feed rate as well as the selection of an appropriate feeder will be guesswork. The type of meter used for water flow depends largely on the flow rate. Disk or piston meters are used for low flow rates, and compound, propeller, or magnetic meters are used for higher flow rates. Unfortunately, meters are usually sold by pipe size, not flow rate, and all too often the water meter being used is seriously oversized for the rate of flow going through it. Because most meters are least accurate at the low end of their measurement range, the result of this oversizing is that water flow is not accurately measured. A meter no larger than that necessary to handle the maximum flow rates expected should be used, even if the pipe and meter sizes do not match. In some cases this may involve the use of pipe reducers to adapt the water main to the meter. This practice is acceptable so long as pressure loss is not excessive.

Another application for water meters is on the supply lines for solution makeup water. When a sodium fluoride saturator is being used, a water meter is a necessity; without one, calculating the fluoride feed rate is impossible. Because water usage in a saturator installation is minimal, the meter must be the smallest type available (usually ½ in. [13 mm]).

Scales

In any fluoridation installation, except one based on a sodium fluoride saturator, scales are necessary for weighing the quantity of dry material to be used in preparing the solution, the quantity of solution fed, or the quantity of fluoride compound or fluorosilicic acid delivered by the appropriate feeder.

The type of scale can vary from a small household type that weighs the 1–2 lb (0.5-0.9 kg) of sodium fluoride used in solution preparation to the complex built-in mechanism of a gravimetric dry feeder. The most generally applicable type is the platform scale, on which a solution tank, a carboy of acid, or an entire volumetric dry feeder can be placed. Although the scales can be specifically designed for the application, such as those supplied by manufacturers of volumetric dry feeders, in many cases an ordinary hardware-store scale will be satisfactory. Some minor modifications, such as removing the wheels or rotating the beam, may be necessary; but as long as the scales have sufficient capacity and sensitivity, there is no reason they cannot be used. The scale must be capable of weighing to the nearest pound either the full tank or the full volumetric feeder and hopper. Sensitivity to the nearest ounce should be sufficient for small scales used for measuring sodium fluoride in the manual preparation of solutions.

No particular problems should be encountered when equipment is being mounted on platform scales unless the equipment is already connected to a water line or the discharge line from the dissolving chamber of a volumetric dry feeder is fixed in place. In these situations the dissolving chamber (solution pot) will also need to be mounted on the scale platform, and all connections to it must be flexible enough to permit the scale to operate.

Softeners

Although sodium fluoride is quite soluble, the fluorides of calcium and magnesium are not. Fluoride ions in solution will combine with calcium and magnesium ions in the makeup water and form a precipitate that can clog the feeder, the injection port, the feeder suction line, or the saturator bed. Water used for sodium fluoride dissolution should be softened whenever the hardness exceeds 50 mg/L; hardness values greater than this will result in an excessive amount of work in clearing stoppages or removing scale. The entire water supply does not need to be softened, only the water used for solution preparation.

The volume of water to be softened is usually quite small, and a household type of zeolite water softener is usually adequate. This type of softener operates on the ion exchange principle and can be installed directly in the pipeline used for solution makeup. When the softening capacity is exhausted, the zeolite (or synthetic resin) can be regenerated with brine made from common salt.

As an alternative to softening, polyphosphates can be used for keeping calcium and magnesium in solution. The amount required is usually 7–15 mg/L. The polyphosphate can be added directly into the solution tank. If an eductor is used, both the eductor water and the dissolving water should be treated, and some type of feeder will be required to add polyphosphate to the eductor water.

Mixers

Fluoride solutions must be homogeneous, no matter which method is used to prepare them. Slurries should not be tolerated in the feeding of fluorides because undissolved fluoride compound can dissolve and cause a higher than optimal concentration. Undissolved material can also clog feeders and other devices that have small openings. Considerable waste can result because of the accumulation of undissolved materials.

Manually prepared solutions must be mixed thoroughly. Liquids of differing specific gravities tend to stratify, and such stratification could result in feeding a solution that is either too concentrated or nothing more than plain water. Although sodium fluoride is quite soluble, the preparation of even the most dilute solutions requires sufficient agitation to avoid having undissolved material settle in the bottom of the dissolving tank. Even as the bottom material gradually dissolves, the strong solution formed at the bottom of the tank will tend to remain in its own stratum.

Although manual mixing with a paddle is usually sufficient for the preparation of a dilute solution, a mechanical mixer is preferred. Mixers are available in various sizes, with shafts and propellers made of various materials. A fractional horsepower mixer with a stainless-steel shaft and propeller is satisfactory for sodium fluoride solutions.

A jet mixer can accomplish the dissolution of sodium fluorosilicate in the solution tank of a dry feeder, but a mechanical mixer is still preferred. Because of the low solubility of sodium fluorosilicate (particularly in cold water) and the limited retention time available for dissolution, violent agitation must be provided to prevent the discharge of a slurry. Preferred materials for construction of a mechanical mixer are 316 stainless steel or plastic-coated steel.

Dissolving Tanks

The dry material discharged from a volumetric or gravimetric feeder is continuously dissolved in a chamber to the side of the feeder. From there the clear solution drains or is pumped into the water to be treated. This chamber, referred to as the solution pot, dissolver tank, solution tank, or dissolving chamber, may be a part of the feeder or a separate device. Fluorides should not be fed directly into flumes or basins without a dissolving tank being used. Use of a dissolving tank prevents the buildup of undissolved dry chemical and makes it possible to maintain accurate feed rates.

Dissolving tanks are available in sizes ranging from 5 gal (19 L) and up; the size is usually determined by the size of the feeder under which the tank is mounted. If there is a choice, the largest size available should be used for fluoride compounds. Chemicals mix with water through a system of baffles. A paddle driven by jets of water or by a mechanical mixer can provide agitation. As mentioned earlier, experience has shown that the jet mixer is not nearly as dependable as the mechanical mixer, even under ideal conditions.

The failure to produce a clear, homogeneous solution discharge from the dissolving tank of a dry feeder indicates one of the following problems:

- The dissolving chamber is too small.
- The detention time is too short.
- Too little solution water is being provided.
- Agitation is insufficient.

- The dry chemical is short-circuiting the tank's designed route and is not being adequately mixed with the water.

Experiments show that the fluoride compound should remain in the dissolving tank a minimum of 5 min. This provides a concentration of one-fourth the maximum solubility if the water temperature is greater than 60°F (16°C) and the chemical is a fine powder. If the chemical is in crystal form or the water temperature is less than 60°F (16°C), the dissolving time should be doubled; if both, the time should be tripled to 15 min. Table 3-1 shows relationships between detention time, dissolving chamber capacity, and water flow rate for sodium fluorosilicate dry feed rates.

Short-circuiting occurs when the travel time through a tank is less than the designed time. This reduced detention time is essentially a function of the dissolving tank design and is more likely to occur in smaller tanks. If short-circuiting does occur, baffles should be added to the tank so that the path of the chemical to the outlet of the chamber is sufficiently winding to provide the necessary detention time for the solution.

A water inlet to the dissolving tank, which is below the outlet, may create a cross-connection that requires adequate safety measures. If the dissolving tank is not already equipped with a correctly placed vacuum breaker, one should be installed on the water inlet as near as possible to the point of entry. If the water line has a solenoid or manually operated valve, a vacuum breaker must be installed between the valve and the tank for adequate cross-connection protection.

Table 3-1 Detention time of sodium fluorosilicate in dissolving tanks

Feed Rate, *lb/hr*	Minimum Water Flow Rate Required for Solution, *gpm*	Dissolving Tank Size, *gal*				
		5	10	25	50	100
		Detention Time, *min*				
1	1	5	10	25	50	100
2	2		5	12.5	25	50
3	3			8.3	16.7	33.3
4	4			6.2	12.5	25
5	5			5	10	20
6	6				8.3	16.7
7	7				7.1	14.3
8	8				6.2	12.5
9	9				5.5	11.1
10	10				5	10
20	20					5

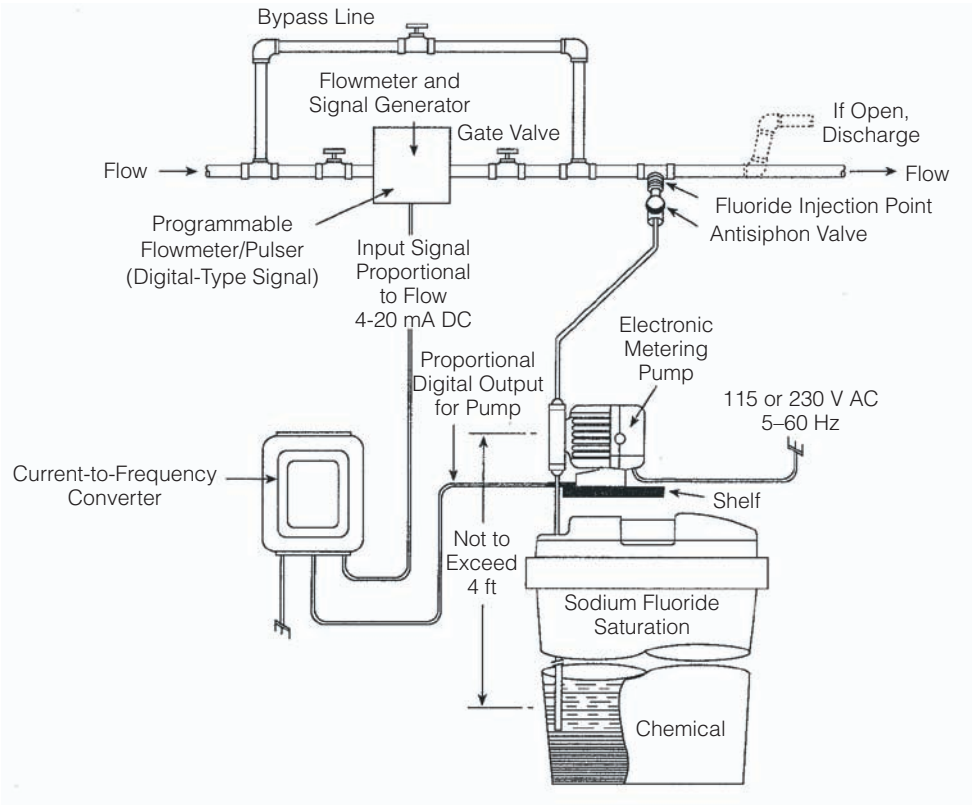
NOTE: To use the table, read across from the feed rate that comes closest to your specific application. The figure in the next column will be the *minimum* water flow rate required for dissolving the chemical. The next figure, or figures, will be the detention time for each given size of dissolving tank. Where no figure is given, the detention time for the particular tank size would be less than 5 min and would therefore be inadequate. Remember, if the water flow rate is increased to more than the specified minimum, the detention time is decreased proportionately, and a larger tank may be required. Metric conversions: lb/hr × 0.4536 = kg/hr, gpm × 0.06309 = L/sec, gal × 3.785 = L.

Flowmeters

A flowmeter, in contrast to an ordinary water meter, measures rate of flow rather than volume of flow. In large pipelines, flowmeters operate on various differential pressure principles. Flowmeters for small flows are usually based on the lifting of a spherical or cylindrical float by the hydraulic action of a fluid flowing through a vertical tube.

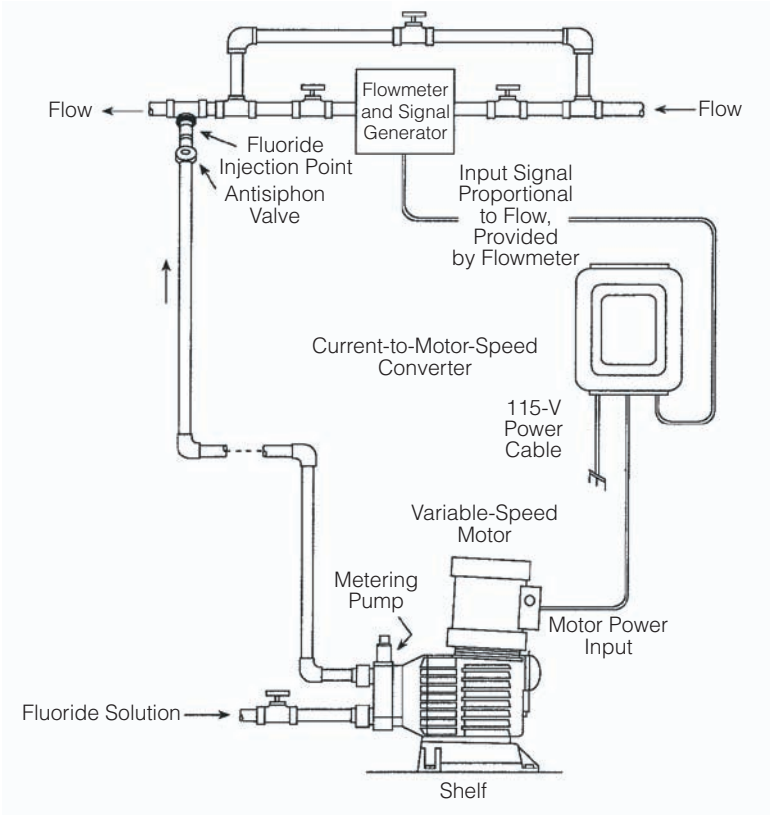
In a water plant where the water output is variable, such as in cases where more than one pump is used, a flowmeter on the main line serves two purposes. First, the flowmeter indicates the flow rates for which the fluoride feeder or feeders must operate. Second, if so designed, flowmeters provide an electrical, pneumatic, or hydraulic signal that adjusts the feeder output to correspond to changes in water flow rate. Two different types of pacing meters are illustrated in Figures 3-9 and 3-10. The electronic metering pump shown in Figure 3-9, usually available with programmable signal, is found under relatively constant flow conditions. The pacing meter shown linked to a variable speed motor control in Figure 3-10 is useful under variable flow conditions.

The type of flowmeter used in small pipelines, often known as a rotameter, can be located in the water supply line leading to the dissolving chamber of a dry feeder. Because detention time is a function of water flow rate, the flow must be regulated and maintained at the prescribed value. In general, a flowmeter must be selected on the basis of pipe size and, in particular, the range of flows expected. For greatest accuracy, the range of the flowmeter should coincide with the range of flows that will be encountered in each particular installation.



Source: Water Fluoridation: A Manual for Engineers and Technicians (1986).

Figure 3-9 Pacing meter—electronic metering pump



Source: Water Fluoridation: A Manual for Engineers and Technicians (1986).

Figure 3-10 Pacing meter—variable-speed motor control

Day Tanks

Although called a day tank, it can hold up to 3 days' supply of a water treatment chemical. It is a convenient, and often necessary, means for isolating the supply of fluoride solution that will be fed during one day or shift at a water plant. The day tank is a necessity when fluorosilicic acid is being fed, particularly if the acid is received and stored in a large tank. In order to provide a record of the weight of acid fed, a small quantity of the acid is pumped or siphoned into the day tank (mounted on a platform scale) and is then fed into the water system from there. A similar arrangement can be used for sodium fluoride solutions.

The day tank (or carboy) containing the acid must be vented to the outside atmosphere, and all connections *must be sealed* to prevent corrosion of the equipment in the room, "clouding" of any windows, and damage to any electrical panels. The chemical being used determines construction materials for the day tanks; however, plastics such as polyethylene are generally applicable. The tank can be provided with graduations or a type of gauge so that approximate volume measurements can be used. Commercial mixing tanks available with the day tank mounted on the cover provide a convenient means for preparing fluorosilicic acid dilutions. However, this arrangement does not permit weighing the acid, and so the operator must rely on volume measurements.

Bag Loaders

When the hopper of a dry feeder is located directly above the feeder—that is, when the operator has to lift the chemical to a considerable height in order to fill the hopper—a bag loader is more a necessity than a convenience. A bag loader is essentially a hopper extension large enough to hold a single 100-lb (45-kg) bag of chemical. The front of the loader is hinged so that it will swing downward to a more accessible height. The operator places a bag in the hinged section, opens the bag, and then swings the section back into position. This device not only lessens the labor required to empty a bag but also eliminates part of the dust created from emptying bags.

Dust Collectors and Wet Scrubbers

The handling of powdered, dry chemicals can raise dust. When the quantities of fluoride compounds are small, ordinary care will minimize the dust problem. Good housekeeping plus an exhaust fan will keep the storage and loading area relatively dust-free. However, when larger quantities (more than one bag at a time) are handled, dust prevention and collection facilities should be provided. A dust canopy completely enclosing the hopper-filling area and provided with an exhaust fan will prevent the spread of dust throughout the loading area. To prevent the escape of dust into the atmosphere and the area surrounding the water plant, dust filters can be incorporated into the exhaust system. Dust collectors and exhaust fans are sometimes incorporated into the hoppers of large dry feeders.

Wet scrubbers are a means of removing dust from exhausted air. The air flows through a chamber continuously sprayed with water. The air is "scrubbed" clean, and the dust particles are dissolved or carried down the drain by water.

Alarms

To prevent underfeeding or loss of feed, alarm systems can be included in either solution feed or dry feed systems. The alarm alerts the operator when the level of solution in the day tank is low or when it is time to add another bag of dry chemical to the hopper. An alarm can also notify the operator that the water supply to a saturator or a dissolving tank has either stopped or diminished. The alarms are attached to level switches, flow switches, or pressure switches.

Backflow Prevention Devices

Any time potable water is connected to a chemical solution tank, the possibility of a cross-connection exists. This can occur in the supply line to a saturator or dissolving tank or in the discharge from either of these or any solution feeder.

The simplest method for preventing potential siphonage is to provide an air gap in the line. When pressure is high enough to make an air gap impractical, a reduced-pressure backflow valve or a double-check valve should be used. For the highest level of safety, the device should be installed as close to the chemical solution tank as possible. The use of mechanical vacuum breakers is not recommended because of the potential siphonage hazards that can exist during an instantaneous pressure loss. Refer to AWWA Manual M14, *Recommended Practice for Backflow Prevention and Cross-Connection Control*, for additional guidance.

Hoppers

Most dry feeders are equipped with a hopper, but for large installations, additional hopper capacity may be necessary. This often requires extension of the existing hopper to the floor above, which not only increases the hopper capacity but makes it easier to

fill the hopper. If at all feasible, the chemical storage should be on the floor above the feeder. If the extension hopper reaches to approximately 12 in. (300 mm) above the floor of the storage room, the edge of the hopper can serve as a fulcrum point for upending drums or barrels.

In small plants, the chemical hopper should be large enough to hold slightly more than one entire shipping container of a chemical. This will allow the contents of another bag or drum to be added before the hopper becomes completely empty. If an entire container is loaded in this manner, there will be less handling of the chemical, less dust, a savings of time, and less chance of spillage and loss of the chemical. Not allowing the hopper to become completely empty means that there will be less chance of arching and flooding and less chance for an interruption in feed.

Hoppers, whether equipped with a feeder made by a factory or one constructed at the plant, may require vibrators to ensure uniform feed. A rotary valve can be installed between the hopper and the feeder to prevent flooding, and a gate can be installed in the extension hopper to limit the amount of material going to the feeder hopper at any given time.

Weight Recorders

Whenever a platform scale is used to measure the amount of dry chemical or solution fed during a given period, a recorder can be attached to obtain a record of the weight of the chemical fed. Many volumetric dry feeders have recorders available as an accessory with the scales, so that the loss-of-weight feature makes the feeder somewhat equivalent to a gravimetric dry feeder.

Controllers

The feed rate of a dry feeder or metering pump can be adjusted automatically to be proportional to the water flow, a feature that is almost indispensable when the water flow rate is extremely variable. When there is only one service pump operating at a fixed rate, the feeders can be tied electrically to the pump operation, and the fluoride feed will remain in the predetermined proportion. When two pumps are used, two separate feeders can be used, or one feeder can be adjusted manually each time the second pump cuts on or off. For more than two pumps or where there is not a fixed delivery rate, manual adjustment becomes impractical.

Controllers are based on the use of some type of primary flow-measuring device, such as an orifice plate, venturi meter, or magnetic meter. The controller adapts the indication of flow rate to an electrical, pneumatic, or hydraulic impulse that in turn activates an adjusting mechanism on the feeder.

Eductors

An eductor uses water pressure and flow for transporting other fluids. In fluoridation, an eductor carries the solution from the dissolving chamber of a dry feeder and injects it into a pressure main. Water at a pressure substantially higher than that of the fluoride injection point is required to operate an eductor. Although the solution from the dissolving chamber is diluted by the action of the eductor, there will be no effect on the fluoride concentration in the treated water because the water to operate the eductor is taken from the flow that is being treated. To prevent the introduction of air into the main, the eductor should draw fluoride solution from a solution well that is supplied continuously with water through a float-controlled valve.

Transfer Pumps

Transfer pumps are useful in situations similar to those where an eductor is used, and they are also used for transferring fluorosilicic acid from storage to the day tank and for transferring other fluoride solutions. Centrifugal pumps are most commonly used because they can run continuously and can be throttled without damage.

The choice of construction materials for pumps is as critical as for solution feeders. Pump heads and impellers, as well as pipelines, must be resistant to the material being handled to ensure that leaks and pump failures do not occur. Pumping of slurries must be avoided because slurries tend to be abrasive and can damage pump heads, impellers, and packing.

Timers

An interval timer is basically a clock mechanism, usually electric, that closes or opens an electric switch upon receiving a signal, holds the switch in position for the preset time interval, and then reverses the switch position. Timers are frequently used in conjunction with water-meter contactors to operate solution feeders. When the contact is made in the water meter, the timer is energized, and the feeder runs for the time selected. The momentary contact made by the meter contactor is sufficient to produce a stroke of a solenoid-operated feeder, but it is too short to operate an electric-motor-operated feeder. The timer serves to extend the impulse received from the contactor.

CAUTION: Using a proportional timer at low percentages, and particularly for long interval settings, can result in cyclic fluoride levels. Insufficient detention time in clearwells or pipelines before water reaches the consumers will cause fluoride readings that are alternately too high and too low. Other than using a smaller feeder, the remedy is to make the proportioned time interval as short as possible.

Hopper Agitators

To promote the smooth and even flow of dry material in a hopper, some type of agitation is helpful. The hopper agitator may be a device that imparts vibration magnetically or mechanically to the outside of the hopper, or it may be a rotating device inside the hopper. Many dry feeders incorporate a hopper agitator into their construction. The rotating type of agitator is preferred because vibrators sometimes cause caking or packing problems.

Fans

Exhaust fans should be used in confined areas, like well houses, that feed fluorosilicic acid. The acid fumes are lighter than air so exhaust fans should be mounted near the ceiling, unlike the fans for chlorine. Inspect fans annually for wear and corrosion.

EQUIPMENT INSTALLATION

The descriptions that follow illustrate the general arrangement of equipment in typical fluoridation installations. Factors to consider in design include proximity to the fluoride application point, proximity to chemical storage, availability of solution water, and accessibility for operation and maintenance.

Solution Feeder Installations

If possible, the solution feeder should be placed above the solution tank to lessen the chances for siphonage from the solution tank into the water line. The suction line should be as short and straight as possible and should include a foot valve and strainer. If the suction line tends to curl or float in the solution, it may be weighed down. Weights usually supplied with solution feeders are made of porcelain, but any heavy material sufficiently resistant to the solution can be used.

Most solution feeders come equipped with an antisiphon discharge valve or have one available as an accessory. These valves should be mounted directly on the feeder head and at the injection point. In addition, particularly if solution is to be fed into an open channel or a low-pressure pipeline, a loaded discharge valve should be used—a spring-loaded check or diaphragm valve that will not open until the feeder discharge pressure exceeds a fixed value. A common setting is approximately 15 psi (100 kPa).

When a solution feeder is being mounted on a shelf or platform above the solution container, it should be offset sufficiently to allow access to the container (or saturator) for filling and cleaning.

Dry Feeder Installations

A dry feeder should be placed so that the solution from the dissolving chamber can fall directly into the chemical feed channel next to the feeder. If other considerations dictate that the feeder be placed some distance from the application point, the drain line should be as direct as possible, with adequate slope and sufficient size to avoid the buildup of precipitates and subsequent stoppage.

The dry feeder installation must be on a firm, level foundation if the scales are to perform satisfactorily. If a small hopper is attached to the feeder, the hopper must be readily accessible for filling. If an extension hopper is used, it should extend vertically upward to the filling area without angles that could trap material. The water supply line to a volumetric feeder must contain a section of flexible hose between the dissolving chamber and the water pipe to permit free movement of the feeder and scale platform.

The water supply line to a dry feeder must be equipped with an air gap, mechanical vacuum breaker, or some other type of antisiphon device. The air gap is the simplest and most positive protection against the dangers of cross-connection. If water pressure is too high to permit the use of an air gap, one of the other devices may be used, but in any case the antisiphon device must be placed between the points of entry to the feeder dissolving chamber and any restrictive device in the pipeline, and it must be installed in an elevated location.

Valves and Meters

Shutoff valves are sometimes installed where solution is fed under pressure. Their use permits repairs to the feeder or discharge line, but they can also present a possible hazard. Attempting to feed solution when the valve is closed can rupture diaphragms or discharge lines or severely damage the feeders. If a shutoff valve is located at the injection point, it must be in the fully open position.

If a sodium fluoride saturator is used, a water meter must be placed in the water supply line. A shutoff valve in this line is a necessity for dismantling and cleaning the saturator. The valve must be placed between the water meter and the saturator inlet so that the meter chamber will remain filled with water and will register properly.

No water supply can be properly fluoridated unless the water flow rate in the main is known, and fluoride levels cannot be calculated unless a record of total flow is available. A master meter on the main is therefore a prerequisite for fluoridation.

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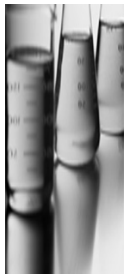

Chapter 4

Operation and Maintenance

For the benefits of fluoridation to be realized, the fluoride concentration must be maintained at or near the optimal level. Experience has shown that the basic reason for low or erratic fluoride levels is poor operation and maintenance.

CONTROL SCHEME

Adjusting the fluoride level in a water supply to an optimal level is accomplished by adding the proper concentration of a fluoride chemical at a constant rate. Figure 4-1 summarizes the process monitoring and control scheme for fluoridation. The proper concentration of fluoride chemical to be added is calculated based on the difference between the fluoride level required and the naturally occurring fluoride level present in the water supply. Once the concentration to be added is known, the chemical feeders can be adjusted to deliver the proper dosage. Routine sampling, analysis, and adjustment of the fluoride dosage will ensure that the optimal fluoride level is consistently maintained (within 0.1 mg/L).

Sampling, analytical procedures, determination of the optimal fluoride level, calculation of the fluoride dose, and troubleshooting are discussed in this section. Refer to the appropriate manufacturers' instructions for the steps necessary to adjust fluoride chemical feeders and solution pumps.

Chemical Impurities

Trace amounts of impurities, especially arsenic, lead, and zinc, may be introduced into fluoride chemicals during production. Normally, the low levels of these impurities do not necessitate the establishment of maximum impurity limits. As with all direct additives for water treatment, chemical purchasers must ensure impurities are not present at levels that would cause deterioration of the quality of the water being treated.

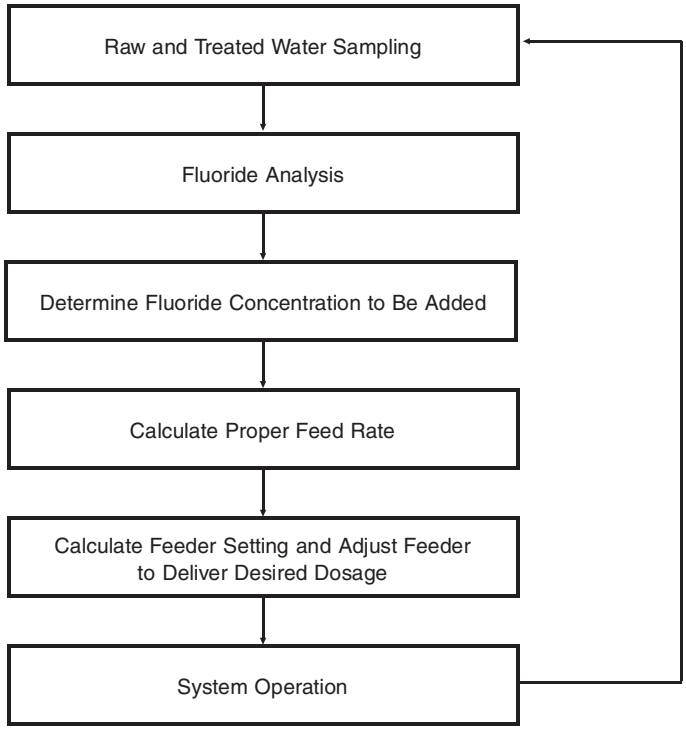

Figure 4-1 Simplified process control scheme

AWWA standards address impurity limits and tests for determining levels. All chemicals used for fluoridation should meet the requirements of these standards.

Chemical Availability

Fluoride chemicals are plentiful, but having the right one in the right place at the right time may not always be the case. The availability of the compounds derived from phosphate fertilizer production—fluorosilicic acid and sodium fluorosilicate—is related to fertilizer sales. A decline in such sales means a corresponding decline in recovery of fluoride compounds. During the summer of 1986, a moderately severe decline in phosphate fertilizer production resulted in several municipalities depleting their supplies of fluorosilicic acid. The best way to reduce the possibility of running out of these fluoride chemicals is to purchase them on a long-term (two to three years) contract basis. Most suppliers will deliver preferentially to contract customers.

The availability of fluoride chemicals through a local supplier should be determined before the chemical is selected for use. Usually, stocks of chemicals on hand at local distributors' warehouses are sufficient for small water plants even during a temporary shortage. Users of large quantities of fluorosilicic acid, however, should be assured of an ample supply before committing to an installation designed around the use of the acid.

If possible, a reserve supply of fluoride chemical should be maintained at the treatment facility. The amount of reserve will depend on system size, type of chemical, storage space availability, and available funding. The Centers for Disease Control and Prevention (CDC) recommends that a minimum of three months' supply be kept on hand (except for very large water systems). If a shortage is anticipated, seek

assistance from the state health agency or the Division of Oral Health, Centers for Disease Control and Prevention, Atlanta, Ga.

Sampling

Although state health agencies may require only occasional tests, a minimum sampling of once per day is recommended. Samples should be taken at locations in the water distribution system where the water will be representative of the whole system, and sampling points should be rotated throughout the distribution system.

When fluoridation is first started, sampling should be done more often and should include several points in the distribution system. Distribution system analyses on startup will show how long it takes for fluoridated water to reach the ends of the mains and whether untreated water is entering the system. The fluoride ion, being a stable and persistent substance, is an excellent indicator of flow patterns.

Analytical Procedures

The ability to detect and accurately measure trace amounts of the fluoride ion in water is essential in obtaining the benefits of fluoride. Not only must the fluoride concentration of the untreated water be determined, but the fluoride concentration of the treated water must also be determined to make sure that the correct amount of chemical is being added.

Because the quantity of fluoride being measured is quite small (usually about 1 mg/L F^-), the analytical method used must be sensitive, and the accuracy of measurement must be well within the limits established for the maximum permissible variation from the optimal concentration. If a concentration of 0.9–1.1 (1.0 ± 0.1) mg/L is considered optimal for a certain area, the analysis must be accurate to 0.1 mg/L or less to ensure that the actual concentration falls within these limits.

The generally accepted analytical methods for determining fluoride concentration are outlined in detail in the latest edition of *Standard Methods for the Examination of Water and Wastewater* (or *Standard Methods*). Additional methods are available, most of which are based on colorimetric principles. Several methods have been approved by the US Environmental Protection Agency for regulatory purposes, including the electrode method and the colorimetric SPADNS method with distillation.

Electrode method. The electrode method is based on the use of a specific ion electrode, resembling the electrodes used for pH determinations. In the case of the fluoride electrode, the key element is a single crystal through which only fluoride ions can move. When the electrode is immersed in a solution containing fluoride ions, an electric potential is set up between the solution and a standard fluoride solution within the electrode. This potential, expressed in millivolts, can be either positive or negative depending on whether the fluoride concentration of the sample is lower or higher than that of the standard solution. Because only fluoride ions can move through the crystal, the electrode is essentially specific for fluoride. A buffer is added to the sample to eliminate potential interferences and to ensure uniform electrode response despite variations in total ionic concentrations in the sample.

The electrode method is the most accurate way to determine the fluoride content of a water supply system. Unfortunately, many water plant operators are unsure of how the electrode equipment works. If the electrode method is to be used, time must be spent to ensure that the operator not only understands how it is operated but also has confidence in the results.

SPADNS method. The SPADNS method is based on the zirconium-SPADNS dye reaction that produces a red lake (a deep color). Any fluoride present has the effect of decreasing the intensity of color. However, the colors produced by different concentrations of fluoride are all shades of red, making it almost impossible to detect these differences with the naked eye and making the use of a photometer necessary.

In general, the determination consists of adding a measured volume of reagent to a measured volume of sample, placing a portion of the mixture in a cell or cuvette, placing the cell in a photometer, and taking the absorbance reading. The absorbance reading is then converted to fluoride concentration by consulting a calibration curve for the absorbance of known standard solutions against their concentrations. The SPADNS method involves an instantaneous reaction, permitting analysis within seconds of the reagent addition.

Interferences. Both the electrode method and the SPADNS method can be subject to error caused by other substances in the water. Common interferences are given in Table 4-1. For most drinking waters the levels of the constituents listed in Table 4-1 will be low enough so that the electrode method will be generally free of interferences. Constituents that may cause interferences with the SPADNS method are more common in drinking waters but may be eliminated by distillation of the sample before analysis. (The distillation procedure should be conducted by a trained laboratory technician.) The electrode method is the preferred method of analysis, although the SPADNS colorimeter can be used if there are no serious interferences.

Ion chromatography. Ion chromatography is a highly accurate and versatile analytical method combining ion exchange and chromatography. One of the advantages of ion chromatography is that many anions can be simultaneously analyzed, thus eliminating the need for separate procedures for each. Fluoride concentrations between 0.1 mg/L and 3.0 mg/L can be analyzed from a filtered, unacidified sample with good precision.

Typically, a water sample is injected into a stream of carbonate-bicarbonate eluent and passed through a series of ion exchangers. The ions are separated because of their differing affinities for the ion exchangers. The separated ions are converted to the conductive acid form. A conductivity sensor is used to produce a chromatogram. Comparing the retention time to standards identifies the ions. The concentration is determined by peak height or area.

Table 4-1 Interfering substances

Substance	SPADNS	Electrode
Alkalinity	5,000 (–)	7,000 (+)
Aluminum	0.1 (–)*	2.0 (–)
Chloride	7,000 (+)	20,000 (–)
Iron	10 (–)	200 (–)
Hexametaphosphate	1.0 (+)	50,000
Phosphate	16 (+)	50,000
Sulfate	200 (+)	50,000 (–)
Chlorine	Must be completely removed with arsenite	5,000
Color and turbidity	Must be removed or compensated for	—

NOTES: Concentration of substance, in milligrams per litre, required to cause error of plus or minus 0.1 mg at 1.0 mg/L fluoride.
(+) causes a higher fluoride reading than actually exists, (–) causes a lower fluoride reading than actually exists.
*Figure is for immediate reading (the figure will change with time).

Interferences. A compound that has the same retention time will interfere. Some organic acids, in particular, can confuse the analysis for fluoride. A high concentration on one ion can interfere with others by overlapping peak retention times. Fluoride is difficult to analyze in low concentrations because of the contribution of the "water dip" that typically occurs near the fluoride retention time. It is important to determine the precision and bias before using ion chromatography for the analysis of fluoride. Testing techniques that use, for example, gradient elution and preconcentration may reduce interferences in certain samples. See *Standard Methods* for a complete description of this test method.

Test kits. Test kits based on the procedures in *Standard Methods* are available commercially and include portable colorimeters and portable ion meters. The portable colorimeters, used with the SPADNS method, are small photometers that are precalibrated so that the fluoride concentration in a reagent-treated sample can be read directly from a scale or chart without the need for preparing standards or a standard curve. Similarly, the portable electrode meter substitutes a precalibrated scale for the millivolt readings of the electrode method.

Continuous monitors. A continuous monitor is a device that automatically monitors the fluoride ion concentration and provides a continuous record of the fluoride level. The advantage of a continuous record over a spot check, such as a daily fluoride analysis, is that the continuous record will show the fluoride concentration at any given time rather than only at the time the daily sample is taken. This type of record could prove helpful in answering complaints regarding under- or overfeeding, as well as in detecting variations in fluoride concentration for unexplained reasons. If the monitor is equipped with an alarm system, it can alert the operator to feeder malfunctions or other problems affecting fluoride level.

TROUBLESHOOTING

The problems commonly encountered in the operation of a fluoridation system are related to low, high, or variable fluoride readings. Although slight over- or underfeeding of fluoride for short periods (for example, a variation of 0.2–0.3 mg/L for two or three days) is actually of no serious consequence, such variations should be investigated because they may be indications of potential problems of a more serious nature.

Low Fluoride Readings

When the fluoride concentration determined by analysis is consistently lower than that determined by calculation, a number of problems may be indicated. If the calculations are correct and are based on accurate weight and flow figures, the problem may be interference in the laboratory test procedure. If alum is used for flocculation, traces of aluminum in the finished water can interfere with colorimetric analysis by influencing the readings negatively. A high iron content can also cause low readings if the SPADNS method is used. In rare cases, chloride and alkalinity can also interfere, but their concentrations must be extremely high. Distilling the sample to remove interfering substances before analysis or switching to the electrode analytical method can confirm or rule out this potential error.

A common cause of low readings is underdosing caused by inadequate chemical depth in a saturator or incomplete mixing in a dissolving tank. Deposits of undissolved chemical in the dissolving tank of a dry feeder indicate incomplete mixing. This problem can be caused by inadequate baffling or an inadequate flow rate of the makeup water. As the fluoride is dissolved a high reading may eventually result.

Low chemical purity is another possible cause of low fluoride readings. Fluorosilicic acid has the most variable purity and can be anywhere from 20 to 30 percent pure. The manufacturer usually specifies the purity of a given batch, but if there is some doubt, the acid should be analyzed according to directions given in AWWA B703, Standard for Fluorosilicic Acid. Sodium fluoride and sodium fluorosilicate usually exhibit less variation in purity, but occasionally a relatively impure lot is produced. AWWA B701, Standard for Sodium Fluoride, and AWWA B702, Standard for Sodium Fluorosilicate, give procedures for determining the purity of these materials.

If the fluoride level is low in a sample from the distribution system, check for unfluoridated water entering at some point in the distribution system and diluting the water fluoridated at the plant.

High Fluoride Readings

If laboratory testing indicates a fluoride concentration consistently higher than that determined by calculation, different problems may be indicated.

Polyphosphates can cause analytical error in the positive direction when the SPADNS method is being used. An operator can check for this type of error by using the electrode method or comparing results with the local or state health department. Failure to eliminate chlorine from the water sample can also lead to high results in colorimetric analysis.

Failure to take into account the natural fluoride content of the source water can result in the addition of more fluoride than is needed; surface supplies, which can show considerable variability, should be analyzed daily so that the correct dosage can be calculated. If the water supply comes from wells, the variability is much less, but in the case of a higher-than-calculated fluoride concentration, the possibility of a contribution from a high-fluoride well should be investigated.

Varying Fluoride Readings

The most difficult type of problem to solve is that of variable fluoride concentration when calculations show that the fluoride feed rate is of the required proportion. One possibility that can be easily checked is the fluoride feeder. Verification of the delivery rate with weight measurements at short intervals will reveal whether the feeder delivery rate is constant.

Almost all of the factors that can produce consistently low or high fluoride analyses can also produce variable errors if the analytical interference, chemical purity, source water fluoride, or completeness of chemical solution is variable. In the last case, undissolved sodium fluorosilicate can eventually go into solution after a quantity of undissolved material accumulates at some point, and a solution feeder can begin drawing from a concentrated stratum after feeding from a dilute stratum in an improperly mixed solution tank.

One of the causes of a varying fluoride content in a treated water system is the intermittent intrusion of unfluoridated water into the system. This situation usually occurs when fluoridation measures are first instituted and no attempt has been made to fluoridate the reservoir separately. When no water is being pumped or the pumping rate is less than the demand, water flows into the system from the reservoir. Because this water has not yet been fluoridated, low fluoride readings will result, particularly at the sampling points nearest the reservoir. Eventually, with flow pattern reversals as the pumps operate intermittently, the reservoir contents will become displaced by fluoridated water. However, there have been cases involving large reservoirs, located at the end of a water system, where it has taken years before there was a complete turnover of the reservoir contents. The obvious solution to this type of

problem is to fluoridate the reservoir separately at the time fluoridation of the system begins, if possible.

A similar situation occurs when an elevated tank or other storage facility merely rides on the system and its contents rarely enter the system or at best only a slight intermixing occurs. Sampling points near the tank will have varying fluoride concentrations—normal during pumping and low when water is being drawn from the tank. In such cases, allow the tank contents to drain into the system before fluoridation begins, and then do not refill the tank until the entire system is up to the optimal fluoride level.

Cyclic fluoride levels can result when the feeder is operated intermittently, such as when capacity is reduced by the use of a cycle timer and when there is insufficient storage capacity between the feeder and the consumers. Detention time in mains or a storage facility between the feed point and the first consumer are important factors in providing homogeneous fluoridated water.

Other Problems

Undoubtedly many other possible causes exist for fluoride levels that are less than optimal, but fluoride certainly does not disappear in the pipelines, nor will fluoride concentrate at points or become leached out of incrustations in the mains. Unlike chlorine, fluoride does not have the ability to dissipate. Even though trace amounts are incorporated into tubercles in pipelines, the extreme insolubility of these formations prevents subsequent dissolution. When there is an unexplained difference between the calculated and observed fluoride concentrations, the calculations are usually at fault. If calculations prove to be accurate and none of the previous possibilities apply or can be eliminated, common sense and a knowledge of the individual system should enable the operator to locate and correct the cause of the trouble.

RECORDS

Comprehensive record keeping is necessary for the efficient operation and maintenance of the water supply system. Because the sizes and designs of water supply systems vary, record-keeping methods should be tailored to each system. Without permanent records describing the system, a community becomes dependent on the memories of long-time employees. Valuable information can be lost with the retirement of each employee. A well-kept system of records demonstrates that the operator is attempting to maintain system reliability.

Most states require that certain records be kept. Generally, this includes the daily determination of fluoride concentration, daily weights (or volumes) of chemicals fed, and the volume of water treated. Some states also require the daily calculated chemical dosage. Additional information, such as when the equipment was checked, repaired, and lubricated and when chemicals were added, should also be maintained. The state health department should be contacted to ascertain specific record-keeping requirements.

MAINTENANCE

To ensure uninterrupted and consistent fluoride feed, proper maintenance of equipment is required. This includes maintaining not only the fluoride feeder but also all the appurtenances, feed lines, and laboratory testing equipment.

Fluoride Feeder

Some specific maintenance concerns that apply to fluoride feeders are cleaning and lubrication, spare parts, and inspection and recalibration.

Cleaning and lubrication. Like any other mechanical device, fluoride feeders must be kept clean and lubricated if they are to perform their function efficiently. A regular maintenance program will also minimize costly breakdowns and ensure long life for the equipment. Electric motors have a prescribed schedule for lubrication—the right type, amount, and frequency of lubrication are important. Gearboxes must be kept filled to the prescribed level with the proper lubricant, and all moving parts and unpainted metal surfaces should be kept clean and rust-free. If there are grease fittings, the proper grade, quantity, and frequency of lubrication should be observed.

Spare parts. Fluoride feeders and related equipment should be accompanied by an instruction book and parts list when purchased. The instruction book will contain information on maintenance and repairs, and the parts list will enable the operator to select replacement parts when needed. If this information is lost, call or write the manufacturer or the manufacturer's representative for replacement. A list of spare parts should be kept on hand; having parts available can minimize the length of shutdowns as a result of equipment failure. In large water plants, an entire spare feeder should be available.

Inspection and recalibration. Fluoride feeders will feed as intended only if the measuring mechanism is kept clean and operative. The diaphragms or pistons of solution feeders; the rolls, belts, disks, or screws of dry feeders; and associated mechanisms of both types should be inspected regularly for signs of wear or damage. Repairs or replacements should be made before the machine breaks down. Even with all parts in the best mechanical condition, fluoride delivery can be affected by leaks, spillage, buildup of precipitates from solutions, or accumulation of dry chemicals on or around measuring mechanisms. Occasional recalibration of the feeder can reveal evidence of potential malfunction.

Leaks. Leaks in and around the discharge line of a solution feeder can affect the quantity of solution delivered and result in low fluoride levels. Leaks are an annoyance and are always somewhat corrosive, ranging from the salt effect of sodium fluoride solutions to the acid corrosion of fluorosilicic acid. Even the smallest leak can result in damage to the feeder, appurtenances, or surroundings if left unattended. Leaks of strong solutions result in the formation of crystalline deposits, which, if allowed to build up, make subsequent cleaning difficult. A leak in the suction line of a solution feeder, though not immediately apparent, will adversely affect delivery and can eventually lead to air binding and cessation of feed. Air binding can also be caused if fluoride solution is injected at the top of a main where air can collect.

Leaks in a dry feeder installation cause a dust problem, and if the feeding mechanism (for example, around the rollers of a volumetric feeder) leaks, the feed rate will be in error. In addition to an economic loss, the dust is a hazard to equipment and personnel.

Leaks in equipment not related to fluoride feed can also present problems. For example, a water leak can result in dampness and subsequent caking of dry chemicals. A leak in a chlorine gas system can result in damage to feeders and associated equipment. Leaks in other dry feed equipment can result in dust contamination of the fluoridation installation.

Precipitates. When strong solutions are used, the possibility of precipitation buildup is always present. In a solution feed system, precipitates in the feeder pumping chamber or on the check valves can affect delivery rate or stop the feeder entirely. Deposits in suction or feed lines can build up until flow stops. A coating of insoluble matter on a saturator bed can prevent water from percolating through. If

the deposits are the result of water hardness, then softening the makeup water will eliminate the problem. If softening is impractical, frequent inspection and removal of the deposits is a necessity. Even when the water is soft, impurities in the chemical used and other mineral constituents in the water can build up to the point where small openings are clogged and feed is impaired or stopped. Dissolving chambers or dry feed installations is a vulnerable point for precipitation buildup. Frequent inspection and cleaning are the best solutions to this problem.

Tanks in which fluoride solutions are prepared invariably show precipitates of the insoluble impurities from the chemical used or of insoluble compounds formed by the reaction of the chemical with mineral constituents of the water. If a separate tank is used for fluoride solution preparation and the clear supernatant layer is then transferred to a day tank, then problems will be minimized but not necessarily completely eliminated.

A regular schedule for cleaning a saturator should be established. The time interval between cleanings will depend on the amount of use and the accumulation of impurities in the saturator.

Storage Areas

Storage areas, although not necessarily a major factor in maintaining accurate feed of fluoride, need to be kept clean and orderly. Bags of dry chemicals should be piled neatly on pallets. Whenever possible, whole bags should be emptied into hoppers. Partially emptied bags present a spillage hazard and are a nuisance to store. Empty bags should be rinsed out and disposed of promptly. Metal drums should be kept off the floor and tightly closed. The storage area for fluoride chemicals should be isolated from areas used to store other chemicals to avoid mix-ups. All other types of materials, such as lubricating oil and cleaning equipment, should be kept out of the area. Both the stored chemicals and the general area should be kept free of dust, not only from the chemicals used in fluoridation, but also from other chemicals stored or used nearby.

Laboratory

The laboratory or fluoride testing area requires special precautions in cleanliness. Fluoride dust on glassware can result in extreme analytical errors. Dirty pipettes or other measuring glassware can produce errors in volume measurements and hinder proper drainage, resulting in carryover of solutions from one sample to the next. In colorimetric analyses, dirty glassware prevents accurate color determination whether the method is visual or photometric. Permanent standards for colorimetric test kits should be kept covered when not in use because they are difficult to clean and may fade when exposed to light. Reagent bottles, buffers, and standard solutions should all be kept tightly closed when not in use. Evaporation ruins the reagents, and the acid fumes can damage nearby objects. Analytical instruments should always be covered when not in use, because fumes and dust can corrode electrical connections, cloud mirrors, and result in expensive repairs or replacement.

The use of phosphate-based detergents for cleaning glassware presents a hazard because of the potential interference of phosphates in colorimetric analysis. Because tap water contains fluoride, it is imperative that all glassware be thoroughly rinsed with distilled water. The quality of distilled water should be verified by conductivity measurements. When equipment for this procedure is lacking, help can often be obtained from state health departments. State health officials can sometimes check a water plant's distilled water or provide a sample of quality distilled water for comparison. Comparing fluoride analyses of a plant's distilled water with that supplied by the state can reveal possible contamination. Many state health department

laboratories will also provide a standard fluoride solution for purposes of checking accuracy.

SAFETY

Although potable water fluoride levels at the recommended concentration of 1.0 mg/L have been very safe, the fluoride levels to which the water plant operator can be exposed are potentially much higher. If safety precautions are not taken, the operator may be overexposed to fluoride chemicals, especially in the form of dust.

The information contained in this section is drawn from sources believed to be reliable. The safety suggestions are based on the injury prevention experience of professional safety engineers, water utility superintendents, and others. Not every acceptable safety procedure is necessarily discussed here, nor are abnormal or unusual circumstances. These safety suggestions should be cross-referenced with approved local, state, or national regulations. For more detailed information refer to AWWA Manual M3, *Safety Practices for Water Utilities*.

Chemical Handling

The best safety measure for prevention of overexposure is the proper handling of fluoride chemicals. Proper handling implies adequate knowledge of the material, the use of correct procedures, and the use of proper safety equipment.

When bags of fluoride are handled carelessly or when bags are emptied too quickly, airborne fluoride dust levels can become dangerously high. Bags should not be tossed or thrown. When the bags are opened, an even slit should be cut across the top to avoid tearing the sides. The contents of the bag should be poured gently into the feed hopper. The empty bag should not be bellowed. Good ventilation is a necessity in work areas, even when there is no visible dust production.

The disposal of empty fluoride containers is usually a problem. The temptation to reuse fiber drums is difficult to overcome because the drums are convenient and sturdy. Paper bags are dusty and could cause a hazard if burned, and empty acid drums could still contain enough acid to cause contamination. The best approach is to rinse all empty containers with plenty of water—paper bags are strong enough to withstand several rinses. After all traces of fluoride are removed, the bags should be disposed of properly. Supposedly well-rinsed drums should never be used where traces of fluoride could present a hazard. The solid waste division of the state environmental protection program should be consulted for the correct procedures regarding bag and drum disposal. If possible, the storage area should be kept locked and not used for any other purpose. An eyewash station should be easily accessible. In particular, workers should be warned against eating in a fluoride storage area.

Fluorosilicic acid requires special precautions. The 23 percent acid has a freezing point of approximately 4°F (−16°C). Fluorosilicic acid containers should not be stored in the hot sun where they can build up hydrostatic pressure or in open areas where they are subject to winter freezing. The fumes from the acid are highly corrosive and will etch glass. Store fluorosilicic acid in well-ventilated areas, away from switches, contacts, and control panels. Although the acid is available in all-polyethylene drums, some suppliers continue to ship in lined steel drums that may suffer leakage problems. Wash down all spills immediately.

Always wear protective safety gear when handling fluoride chemicals. In particular, full-face shield, splash-proof goggles, rubber gloves and boots, and acid-proof aprons should be worn when fluorosilicic acid is being handled.

The greatest chance for overexposure to dry fluoride chemicals comes from the inhalation of dust generated when feeder hoppers are being filled. During the filling

operation, the operator should wear an effective respirator approved by the National Institute for Occupational Safety and Health, splash-proof safety goggles, an apron, and rubber gloves. The respirator should have a rubber face-to-mask seal with replaceable cartridges. Cartridges are available for either dust or acid vapor. The maximum allowable concentration of fluoride dust in the area should be 7.1–10.6 mg/ft^3 (0.2–0.3 mg/m^3) of fluoride dust in air.

Toxic Exposure

This section describes the difference between chronic and acute toxic exposure.

Chronic toxic exposure. Chronic toxic exposure occurs when exposure to large doses of fluoride takes place over a number of years. This type of exposure could occur as a result of repeated dust inhalation when feeder hoppers are being filled.

The body's assimilation capacity for fluoride is limited. The body begins retaining fluoride at an exposure rate of about 1.5 mg/d. It is estimated that low poisoning may start at 0.2–0.35 mg/kg of body weight (for 175 lb [80 kg], that corresponds to 15.9–27.8 mg). With chronic toxic exposure, there may be a general lack of appetite, slight nausea, some shortness of breath, constipation, pain in the region of the liver, and anemia. See chapter 1 for additional discussion on health effects.

Acute toxic exposure. Acute toxic exposure results from a single massive dose. Acute fluoride poisoning may result from ingestion, inhalation, or bodily contact with concentrated fluoride compounds. Knowledge is limited concerning acute fluoride poisoning caused by ingestion or inhalation because it is very rare. Accidental ingestion is quite unlikely but could occur through contamination of food or drink either by mistaking the compound for sugar or salt or through carelessness in allowing areas where food is consumed to become contaminated by dust or spillage.

The symptoms of acute poisoning by inhalation of dust or vapor include sharp biting pains in the nose followed by nasal discharge or nosebleed and possibly coughing or respiratory distress. Acid spill or splash may cause a tingling or burning sensation of the skin; if the eyes are involved, severe eye irritation may result.

Ingested toxic dosages generally cause vomiting, stomach cramps, and diarrhea. If the poisoning involves ingestion of large amounts of fluorides, the vomitus may be white, and the victim may experience weakness, disturbed color vision, thirst, and difficulty in speaking. Ingestion of 4–5 g per 175 lb (80 kg) of body weight may be fatal.

First aid for acute toxic exposure. Once fluoride poisoning is determined, first aid treatment should be started while waiting for medical help. Emergency treatment for an ingested fluoride overdose from fluorosilicic acid is described in Table 4-2 and for dry fluoride chemicals in Table 4-3.

Fluoride Overfeed

When a community fluoridates its drinking water, the possibility for a fluoride overfeed exists. Most overfeeds have no serious consequence, but all overfeeds should be taken seriously and corrected immediately. If an overfeed remains uncorrected, serious health consequences can occur. Fluoride overfeeds that have resulted in illness or death are rare, but a few instances have occurred. Table 4-4 describes some of the known instances.

The CDC recommends the actions listed in Table 4-5 for fluoride overfeed instances. When a fluoride test result is near the end of the analyzer scale, the water sample must be diluted and retested to measure high fluoride levels accurately.

Table 4-2 Emergency treatment for ingested fluoride overdose of fluorosilicic acid H_2SiF_6

Milligrams of Fluoride Ion Injested/Body Weight	Treatment
Less than 5.0 mg F^-/kg*	1. Give calcium (milk) orally to relieve gastrointestinal symptoms. Observe for a few hours. (NOTE: Keep a can of evaporated milk accessible.)
	2. It is not necessary to induce vomiting.
Over 5.0 mg F^-/kg	1. Move the victim away from any contact with fluoride and keep victim warm.
	2. Call poison control center.
	3. If the poison control center advises and if the victim is conscious, induce vomiting by rubbing the back of the throat with a spoon or your finger, or use syrup of Ipecac. While the patient is vomiting, the head should be lower than the body with face downward to prevent inhalation of the vomitus.
	4. Give the victim a glass of milk or any source of soluble calcium (5 percent calcium gluconate or calcium lactate solution).
	5. Take the victim to the hospital as quickly as possible. **Notify physicians that there may be a late onset of pulmonary edema for up to 48 hours.**

Source: Engineering and Administrative Recommendations for Water Fluoridation (1995).

NOTE: 5 mg of fluoride (F^-) is equivalent to 27 mg of 23 percent fluorisilicic acid. Ingesting 5 mg F^-/kg is equivalent to a 154 lb (70 kg) person consuming 2 g of fluorosilicic acid.
*Average weight per age: 33 lb (15 kg)/1-2 years; 44 lb (20 kg)/4-5 years; 50 lb (23 kg)/6-8 years; 154 lb (70 kg)/21 years.

Table 4-3 Emergency treatment for ingested fluoride overdose of dry fluoride chemicals NaF and Na_2SiF_6

Milligrams of Fluoride Ion Injested/Body Weight	Treatment
Less than 5.0 mg F^-/kg*	1. Give calcium (milk) orally to relieve gastrointestinal symptoms. Observe for a few hours. (NOTE: Keep a can of evaporated milk accessible.)
	2. It is not necessary to induce vomiting.
5.0 mg F^-/kg and over	1. Move the victim away from any contact with fluoride and keep victim warm.
	2. Call poison control center.
	3. If the victim is conscious, induce vomiting by rubbing the back of the throat with a spoon or your finger, or use syrup of Ipecac. While the patient is vomiting, the head should be lower than the body with face downward to prevent inhalation of the vomitus.
	4. Give the victim a glass of milk or any source of soluble calcium (5 percent calcium gluconate or calcium lactate solution).
	5. Take the victim to the hospital as quickly as possible.

Source: Engineering and Administrative Recommendations for Water Fluoridation (1995).

NOTE: 5 mg of fluoride (F^-) is equivalent to 11 mg of sodium fluoride or 8 mg of sodium fluorisilicate. Ingesting 5 mg F^-/kg is equivalent to a 154 lb (70 kg) person consuming 0.8 g of sodium fluoride or 0.6 g of sodium fluorosilicate.
*Average weight per age: 33 lb (15 kg)/1-2 years; 44 lb (20 kg)/4-5 years; 50 lb (23 kg)/6-8 years; 154 lb (70 kg)/21 years.

Table 4-4 Summary of reported fluoride overfeed incidents in public water systems

Location	Total Population at Risk	Number of Illnesses/ Deaths	Fluoride Concentrations, *mg/L*	Data (Duration)	Comments
Annapolis, Md.	8	2 illnesses 1 death	35	Nov. 11, 1979 (30 hours)	Following renal dialysis at clinic where water F was 35 ppm, 8 patients became ill. Two became very ill, one of whom refused hospitalization for observation and died 16 hours after the onset of illness. Immediate cause of death was hypertension and arteriocardiovascular disease. Acute F intoxication during hemodialysis was contributing cause of death. A valve to H_2SiF_6 acid at water plant had been left open all night.
Crown Point, N.M.	Unknown	35 to 40 illnesses	60 to 208	May 23, 1983 (unknown)	Navajo Indian Reservation. Nausea, vomiting, dizziness, diarrhea, skin rash, eye irritations. No hospitalizations. Survey taken after incident. Two theories how the large "slug" of F acid entered water line.
Dublin, CA	1,000	23 illnesses	250	June 3, 2002 (unknown)	Workers (23) at a manufacturing plant were sickened after a valve serving the facility was reopened following maintenance. Fluoride feed may have continued during the outage and entered the facility at a high concentration when service was resumed.
Harbor Springs, Mich.	1,700	4 illnesses	42.6 maximum	Nov. 22, 1977 (unknown)	Four persons became ill with nausea and vomiting after drinking municipal water. One person sought medical care and was hospitalized overnight. Mechanical control of F metering pump malfunctioned.
Hooper Bay, Alaska	470	262 illnesses (estimated 1 death)	2 to 150	May 1992 (unknown)	Multiple deficiencies attributed to outbreak. System failed to report fluoride levels; high levels found previously. Fluoride pump wired in parallel, rather than in series, with the well pump, allowing it to run without water flow. Fluoride pump malfunctioned, causing overfeed. Operator lacked proper training.
Island Falls, Maine	1,010	6 illnesses	250 maximum	May 2, 1979 (24 hours)	Interview and telephone survey identified six possible cases. Acute gastrointestinal symptoms found. No other reported illnesses and no hospitalizations. Two gal of F acid inadvertently injected into water system while changing a flowmeter in large water pipe.
New Haven, Conn.	150 homes	1 illness	50 maximum	March 12, 1986 (2 hours)	One case of illness was reported. Incident occurred during plant operation switch between 2:00 a.m. and 4:00 a.m.: several water lines were switched and a fluoride injection point relocated.

Table continued next page.

Table 4-4 Summary of reported fluoride overfeed incidents in public water systems (continued)

Location	Total Population at Risk	Number of Illnesses/ Deaths	Fluoride Concentrations, *mg/L*	Data (Duration)	Comments
Portage, Mich.	50	7 illnesses	92	July 1991	Students at a school became ill due to fluoride feed electrical malfunction.
Rice Lake, Wis.	150	4 to 5 illnesses	Unknown	Feb. 22, 1992 (2 days)	On survey 10 persons noted something unusual with the water, but only 4 to 5 persons became ill. No hospitalizations were reported. Mechanical failure of equipment caused the problem.

Source: Adapted from Pontius (1993).

Table 4-5 Recommended fluoride overfeed action

If Fluoride Content in Drinking Water Is:	Perform the Following Recommended Actions:
0.1 mg/L above control range to 2.0 mg/L	1. Leave the fluoridation system on. 2. Determine what has malfunctioned and repair it.
2.1 mg/L to 4.0 mg/L	1. Leave the fluoridation system on. 2. Determine what has malfunctioned and repair it. 3. Notify your supervisor and report the incident to the appropriate county or state agencies.
4.1 mg/L to 10.0 mg/L	1. Determine what has malfunctioned and immediately try to repair it. 2. If the problem is not found and corrected quickly, then turn off the fluoridation system. 3. Notify your supervisor and report the incident to the appropriate county or state agencies. 4. Take water samples at several points in the distribution system and test the fluoride content. Retest if results are still high. 5. Determine what has malfunctioned and repair it. Then, with supervisor's permission, restart the fluoridation system.
10.1 mg/L or higher	1. Turn off the fluoridation system immediately. 2. Notify your supervisor and report the incident immediately to the appropriate county or state agencies and follow their instructions. 3. Take water samples at several points in the distribution system and test the fluoride content. Retest if results are still high. Save part of each sample for the state lab to test. 4. Public notification may be required by the state to prevent consumption of high levels of fluoridated water. 5. Determine what has malfunctioned and repair it. Then, with supervisor's and the state's permission, restart the fluoridation system.

Source: Centers for Disease Control and Prevention.

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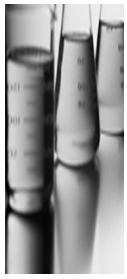


Chapter 5

Defluoridation

In some areas, fluoride concentration levels exceed the optimum level. The United States Environmental Protection Agency (USEPA) has established the maximum contaminant level (MCL) for fluoride at 4 mg/L. The secondary level for fluoride has been established at 2 mg/L. Approximately two million people in the United States are served by water systems that exceed the secondary limit. Treatment systems for removal of excess fluoride (defluoridation) are implemented to protect the health of the consumer as well as achieve regulatory compliance.

The USEPA has established "the best technology generally available" (BTGA) for the removal of fluoride as activated alumina (AA) and reverse osmosis (RO). Additionally, point-of-use RO (POU-RO) treatment has been listed as an acceptable compliance technology for small systems. For water systems that require only the removal of excess fluoride from raw water, the AA treatment method is preferred. For water systems that need to lower the total dissolved solids (TDS) or to remove other contaminants that are not removed by AA in addition to fluoride, RO is the recommended treatment solution.

The AA method has several advantages over the RO method. They include much smaller amounts of wastewater requiring disposal, lower installed equipment cost, lower operating cost, and lower energy consumption. Other technologies, although not listed as a BTGA, might be useful for fluoride reduction in certain situations. Examples include the following: enhanced lime softening, optimized aluminum-based coagulation, electrodialysis, bone char adsorption, and distillation. Although these technologies might be applicable for fluoride reduction because of special conditions, the possibility is remote. Therefore, this chapter will limit the discussion to the two BTGA treatment methods listed above: AA and RO. Because the RO process is described in detail in AWWA Manual M46, *Reverse Osmosis and Nanofiltration*, the discussion in this manual is abbreviated.

ACTIVATED ALUMINA (AA) TREATMENT PROCESS

Activated alumina is a highly porous granular material that possesses a very large surface area per unit weight. AA is a by-product of the manufacture of aluminum. It is primarily aluminum oxide (Al_2O_3) that has been activated by exposure to high

temperature and caustic soda. The material is ground into a granular form that is available in several mesh sizes. The optimum mesh size for fluoride removal water treatment systems is –28, +48. Coarser mesh sizes have been utilized; they work, but the adsorptive capacity is significantly lower because the adsorptive surfaces are less accessible in larger grains. Finer mesh sizes have not been used in other than laboratory bench-scale work because the finer mesh material presents pressure-drop and backwash problems. Because the physical and process characteristics may vary between AA product manufacturers, the information provided herein is represented as typical. Therefore, the characteristics of a given AA product should be verified by experience, special knowledge, or field pilot testing on the actual water to be treated.

Fluoride removal by means of AA is an adsorption process in which the fluoride ions in the source water are attracted to and held by the surfaces of the AA. The fluoride removal adsorption process is extremely pH sensitive. The AA attraction for the fluoride ion is the strongest at pH 5.5, the pH at which the AA capacity for fluoride is the greatest. At this optimum pH, the fluoride concentration in the treated water is below 0.5 mg/L. The AA fluoride capacity varies depending on the concentration of the fluoride in the raw water. For example, when the raw water fluoride concentration is 4 mg/L, the AA fluoride capacity is 4,500 g/m^3 (2,000 grains/ft^3); and when the raw water fluoride concentration is 12 mg/L, the AA capacity for fluoride is 9,000 g/m^3 (4,000 grains/ft^3). As the pH of the water deviates either higher or lower from the optimum 5.5, the attractive forces (and the fluoride capacity) are reduced. At very high and very low pH levels, the attractive forces become zero. At those pH levels, the previously adsorbed fluoride ions can be flushed from the AA treatment media in a wastewater stream that requires disposal. Wastewater disposal must comply with regulatory agency rules. The removal of the adsorbed fluoride ions from the AA is termed *regeneration*, the part of the treatment process in which the original capacity for fluoride removal is restored to the AA treatment media for reuse in the fluoride removal treatment cycle. Therefore, the AA treatment media is used continuously by alternately removing fluoride from the water until the capacity of the media is saturated and then regenerating the fluoride from the AA in a separate stream directed to wastewater disposal. It should be pointed out that although the AA attraction for fluoride can be eliminated at low pH as well as high pH, the low pH level required for regeneration is too aggressive, resulting in the dissolution of the AA granular material. Therefore, the AA regeneration is accomplished with dilute caustic soda (or caustic potash) solution without loss of treatment media.

Arsenic (arsenate and arsenite) is also removed from water by the same AA treatment process. The AA arsenic removal process is also very pH sensitive. The optimum treatment pH is also 5.5. In addition, if arsenic is present with fluoride in the water, the arsenic is removed preferentially to the fluoride. Therefore, arsenic removal will continue long after the AA capacity for fluoride has been saturated. However, when arsenic is present in the water, its concentration is normally in the low parts per billion range while the fluoride is in the parts per million range. Therefore, except in cases where the level of the arsenic is very high, it does not impact the AA fluoride capacity. In those exceptions, a variation of the normal fluoride removal treatment process is implemented (see USEPA 600/2-80-100). Another factor that requires process knowledge is that arsenic clings to the AA surfaces more tenaciously than does fluoride. Therefore, removal of the arsenic from the AA surfaces requires a higher concentration regeneration caustic soda solution.

There are other ions that are also removed from water by the AA adsorption process with optimum removal characteristics at pH 5.5. These ions can be either organic or inorganic and do compete with fluoride for adsorption sites. However, they rarely

occur in drinking water. If they are present, they are able to be totally regenerated by the same process as that used for fluoride. Finally, there are other ions, which are adsorbed by AA at pH ranges other than that which is applicable to fluoride removal; those ions are also easily regenerated with applicable pH adjustments. A typical example is silica (SiO_2), which is adsorbed in a pH range between 6 and 10. Silica is also completely regenerated by means of an appropriate concentration caustic soda solution.

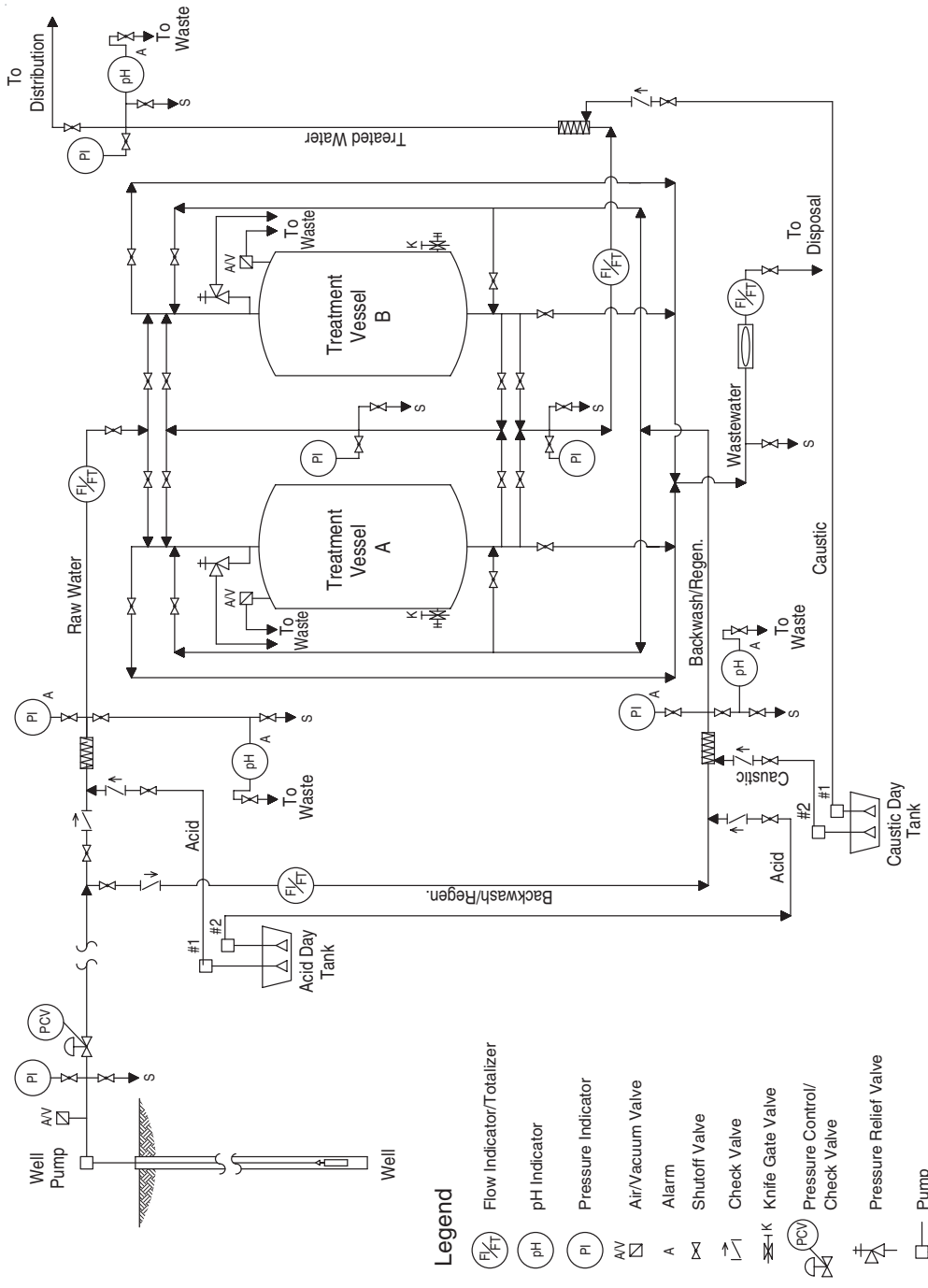
The most efficient treatment process concept consists of two downflow treatment pressure vessels in a series in which the fluoride removal treatment takes place completely in the first (lead) vessel. For the process schematic flow diagram see Figure 5-1. The water flows through both vessels. The fluoride removal takes place in a treatment band, which moves downward in the lead vessel as the media in initial contact with the water becomes saturated with fluoride. As the treatment band extends through the outlet of the first vessel, the treatment is completed in the second (lag) vessel. Eventually, the treatment band is totally contained in the second vessel. At that time, the first vessel can be removed from service and regenerated. The second vessel then is placed in the lead position. When the first vessel regeneration has been completed, it is returned into service in the lag position. Therefore, the use of a two vessel train with the vessels alternating positions constitutes a continuous treatment operation that can perform indefinitely.

The treatment plant described herein is for a central treatment that is provided for a well water supply. Though not normally encountered, the treatment process is also applicable for surface water supplies. Components, other than the treatment system, are assumed to be provided separately; included are: well, well pump, storage reservoir(s), pressurization subsystem(s), distribution subsystem, and disinfection subsystem. Because chlorine degrades the AA, it is applied after the fluoride removal treatment.

The AA fluoride removal water treatment plant can be operated manually, semiautomatically, or automatically. The features of each of these operational modes are beyond the information provided in this chapter.

An AA fluoride removal water treatment plant based on the concept described above includes, but is not limited to, the following basic items:

1. Two identical treatment vessels are required.
   a. Each treatment unit is a vertical cylindrical pressure vessel. Skid-mounted supports are recommended to minimize foundation requirements.
   b. Each vessel is sized to contain the volume of AA treatment media to treat the required flow rate. (NOTE: For flow rates that exceed the size available in standard pressure vessels, the feed water should be proportionately divided into multiple dual vessel trains that operate in parallel.) Each treatment vessel will contain the volume of AA treatment media that will provide a minimum empty bed contact time (EBCT) of five minutes. The depth of the AA treatment media ranges between 3 ft and 6 ft. The vertical straight side height of the treatment vessel provides 50 percent AA treatment media expansion during backwash plus 6-in. freeboard. Therefore, a typical treatment vessel that employs an 8-ft straight side will include 5-ft AA treatment media depth plus 2 ft 6 in. for media expansion and 6 in. freeboard.
   c. The treatment vessel will include internal piping, which uniformly distributes and collects the various process streams that flow through the



Courtesy of Rubel Engineering, Inc., Tucson Arizona

Figure 5-1 Activated alumina with pH adjustment fluoride removal water treatment plant schematic flow diagram

AA treatment media. Most important, the internal piping will include provisions to prevent AA grains from exiting the treatment vessel.

d. All materials of construction must be suitable for exposure to acid and caustic in the pH range 2 to 13. The materials of construction or their protective linings must also have abrasion resistant qualities. It should be noted that both sulfuric acid and hydrochloric acid are used successfully for lowering pH while both caustic soda and caustic potash are used successfully for raising pH. The sulfuric acid and caustic soda are usually less costly. Other pH adjusting chemicals may be applicable, but each chemical requires evaluation of its characteristics.

2. Process water pipe, fitting, valve, and accessory materials shall also be suitable for exposure to pH in the range of 2 to 13.

3. Chemical bulk storage tanks for acid (usually H_2SO_4 66°Bé) and caustic (usually 50 percent NaOH) shall be sized to comply with the volume of the container by which the commodity is delivered to the treatment plant. For example, chemicals are the least costly when procured in bulk quantities, such as tank trucks or railroad tank cars. For example, storage tanks shall be designed with a minimum capacity sufficient for the full transportation vehicle load plus the maximum volume that can be consumed during a maximum time period required for delivery. Where fluoride removal water treatment systems are not large enough to justify purchases of chemicals in bulk quantities (cost of bulk storage equipment, space requirements), the commodities are purchased and stored at a premium cost in small containers, such as drums, carboys, etc. Regardless of the size or type of storage vessel, the materials of construction must be resistant to the chemicals to which they are exposed, and the storage containers must be set in secondary containment structures to prevent chemical leaks and spills from escaping into the environment.

4. Chemical feed pumps, feed systems, etc., must be sized to accurately supply all feed rate requirements up to at least 110 percent of the maximum. Chemical feed equipment may be operated and controlled either manually or automatically. All chemical feed equipment and miscellaneous items exposed to treatment chemicals must be constructed of materials that are resistant to the chemicals for which they are employed. All feed equipment for treatment chemicals must either be double contained or shielded to provide complete operator safety. Emergency shower and eyewash equipment shall be provided at all locations where operators might be exposed to treatment chemicals.

5. Instruments and accessories are required to monitor or control pH, flow rate, total flow, pressure, and liquid level. As previously mentioned, the instruments and control components may be operated manually or automatically. Operation of an AA fluoride removal water treatment plant may be fully automated under the control of a programmable logic controller, or individual operational features may be operated under the control of an individual controller. All instrument and accessory materials of construction must be recommended for all of the chemicals to which they might be exposed.

The treatment for removal of the fluoride takes place at pH 5.5. The treatment may be continuous or intermittent. The pH of the treated water must be readjusted

to a level that is acceptable for distribution, approximately 7.5. This can be accomplished by various methods, such as addition of caustic soda, blending with raw water, or stripping of free carbon dioxide by means of aeration equipment.

The initial startup of the treatment operation requires careful placement of the AA in each treatment vessel. Prior to AA application, each vessel should be half filled with water. This procedure separates the fine particles (powder) from the granular material, prevents cementing of the AA particles, stratifies the particles by grain size, and protects the internal piping from impact loads. Prior to placing the treatment vessels into operation, the AA treatment media should be backwashed until the backwash water is clear. At this point, the vessel should be drained, and the top 1/4 in. of fine media should be carefully skimmed off the surface.

After completion of a treatment cycle (fluoride concentration of influent and effluent are the same), the treatment vessel is removed from service while treatment continues in the other vessel. The AA must then go through a regeneration, which continuously employs raw water for all steps. The regeneration consists of the following steps:

1. Backwash AA treatment media at a flow rate of 7–9 gpm/ft^2 (depending on the density of AA and water temperature) for a minimum of 10 min, or until backwash water effluent is clear.
2. Drain treatment vessel.
3. Perform upflow regeneration using 15 gal of 1 percent NaOH solution per cubic foot of AA treatment media. Flow rate shall be established to provide 30 min minimum for this step. For example, if the AA treatment bed is 8 ft in diameter and 5 ft deep, the bed volume is 250 ft^3. Then 3,750 gal of 1 percent NaOH will be used during the upflow regeneration step. Then, the flow will take place at 125 gpm for 30 min. This equates to a flow rate of 2.5 gpm/ft^2 (50 ft^2 AA treatment media surface area).
4. Perform upflow rinse. At completion of the upflow regeneration, the NaOH feed pump is turned off, but the water continues flushing the fluoride from the AA upflow at the same flow rate for 60 min.
5. At the completion of the upflow rinse, drain the treatment vessel to the top of the AA treatment media.
6. Perform the downflow regeneration using the same procedure as the upflow regeneration (15 gal of 1 percent NaOH per cubic foot of AA treatment media for a minimum period of 30 min).
7. Perform the downflow rinse for 30 min at a flow rate that provides a minimum EBCT of 5 min. Using the example, AA volume is 250 ft^3 (1,875 gal) which results in a maximum flow rate of 375 gpm (1,875 gal/5 min). If an EBCT of 7.5 min is used, the maximum flow rate would be 250 gpm.
8. Neutralization of the AA treatment media with pH elevated to greater than 12 by the 1 percent NaOH regenerant solution takes place in three steps using the same raw water flow rate with pH adjusted by the feed of (sulfuric) acid. The first step takes place at pH 2.5. This step continues until the pH of the effluent leaving the AA treatment media drops to 8.5. The second step takes place at pH 4.0. This step continues until the pH of the effluent leaving the AA treatment media drops to 6.5. The third step

takes place at pH 5.5, which occurs by placing the regenerated AA treatment vessel back into the treatment mode in the lag position.

The wastewater, which contains the fluoride removed from the AA along with the chemicals (acid and caustic) employed during the regeneration, may be disposed in one of several ways depending on local regulations and conditions. The most desirable disposal method is reuse for a beneficial purpose, such as irrigation, industrial application, etc. Frequently, those opportunities are not available. Therefore, other disposal methods, such as evaporation ponds, sewer discharge, etc., must be evaluated. The cost of disposal in addition to potential environmental impact require careful consideration. Fortunately, the volume of wastewater is small (approximately 3 percent) compared to the treated water produced.

REVERSE OSMOSIS TREATMENT

A complete description of reverse osmosis (RO) membrane system design, equipment and installation, and operation and maintenance is the subject of AWWA Manual M46. Therefore, only a brief overview will be presented here.

A typical RO system (figure 5-2) consists of three subsystems: pretreatment, the membrane process, and posttreatment. The feed water is forced through the membranes under pressure, and the product is called permeate. A waste stream that includes all of the rejected ions and a fraction of the feed water is produced and called the concentrate (or reject stream).

Pretreatment may include acid addition and antiscalant to prevent precipitation of salts on the membranes. Pretreatment for removal of membrane fouling compounds of the feed water may also be required. The feed water is filtered prior to entering the membrane stage. Polishing filtration is performed using low micron cartridge filters. When rough filters are required prior to polishing filtration, multimedia pressure filters are used.

The membrane system consists of a membrane array. Several elements are included in each array. The size of the elements can vary (from 4 to 16 in. in diameter) depending on the production requirements. The number of membrane stages used depends on the percent recovery needed and the fouling characteristics of the feed water. A three stage array, for example, may produce a throughput of 85–90 percent. However, when high concentrations of silica exist in the feed water, the throughput can be greatly reduced, resulting in a very high volume of wastewater, which requires disposal.

Posttreatment might include aeration to remove hydrogen sulfide, carbon dioxide or other dissolved gases. This is followed by disinfection and corrosion control. Some RO plants are designed for split flow treatment. This is sometimes the case for fluoride removal installations. The RO system can remove as much as 90 percent of the fluoride (the AA system can remove as much as 99 percent). This concept is utilized for both the RO and the AA processes in cases where the fluoride in the treated water is sufficiently below the regulatory treated water requirement. In those cases, part of the raw water can bypass treatment and be blended with the treated water, raising the fluoride level of the treated water, and remaining in compliance. This strategy reduces the size of the RO system and lowers treatment cost.

Proper disposal of concentrate from the RO treatment process can be very costly. In some states it is regulated as an industrial waste. Permits for concentrate disposal must be obtained from the applicable regulatory agency.

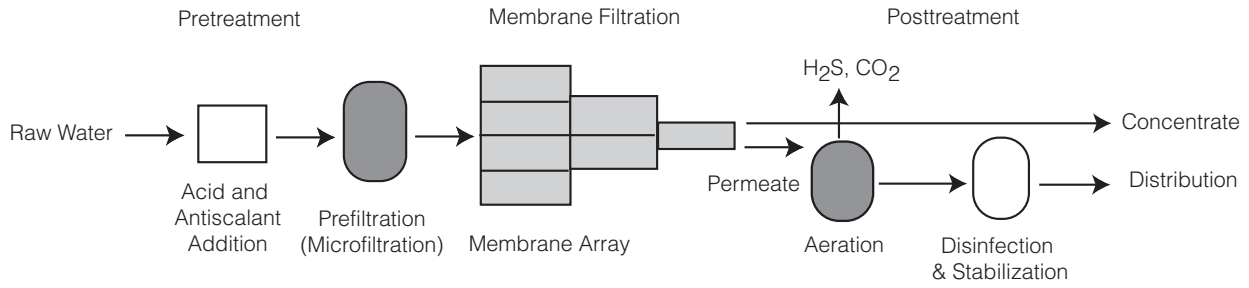


Figure 5-2 Conventional RO/NF membrane process

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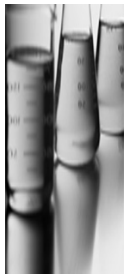

Additional Sources of Information

In addition to the references at the end of each chapter, the following may be helpful. Also, the 1993 National Research Council (NRC) report *The Health Effects of Ingested Fluoride* has an extensive list of references. It is available from National Academy Press, Washington, D.C.

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