WATER FLUORIDATION

A MANUAL FOR ENGINEERS AND TECHNICIANS

U.S. DEPARTMENT OF HEALTH & HUMAN SERVICES
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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
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CENTERS FOR DISEASE CONTROL
DENTAL DISEASE PREVENTION ACTIVITY
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ABSTRACT

This manual provides technical information which will enable State fluoridation engineers or technicians to provide instruction and technical assistance to the water plant operator in the operation and maintenance of proper fluoride levels in drinking water. The fluoridation of public water supplies requires strict control of dosage rates for maximum dental health benefits. Accurate analytical determination of the fluoride level in the water is also essential and is included in this manual.

DISCLAIMER

The use of trade names and commercial sources is for identification purposes only and does not constitute endorsement by the Public Health Service or by the U.S. Department of Health and Human Services.

NOTE

Please note that in this manual the terms ppm (parts per million) and mg/l (milligram per liter) are used interchangeably. While mg/l is preferred, ppm is used in many instances in the interest of clarity.

The term ''ppm'' is a ratio which measures the concentration of a mineral or other ingredient in a liquid, gas, or solid. One part per million fluoride in water, for example, means one part by weight of fluoride ion in one million parts by weight of water. One part per million fluoride is equivalent to 8.34 lb fluoride ion per million gallons of water because 1 gallon of water weighs approximately 8.34 lb. In metric units, one part per million is identical to one milligram per liter (the weight of a liter of pure water being one kilogram).

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CHAPTER ONE

FLUORIDATION AND PUBLIC HEALTH

1.1 Definition

Fluoridation is the deliberate upward adjustment of the natural trace element, fluoride, in accordance with scientific and dental guidelines, for the purpose of promoting the public's health through the prevention of tooth decay. Fluoride is present in small but widely varying amounts in practically all soils, water supplies, plants, and animals, and thus is a normal constituent of all diets.[1] The highest concentrations in mammals are found in the bones and teeth. All public water supplies in this country contain at least small amounts of natural fluoride.

Few public health measures have been accorded greater clinical and laboratory research, epidemiologic study, clinical trial, and public attention—both favorable and adverse—than the fluoridation of public water supplies.

1.2 History

The discovery of the role of waterborne fluoride in preventing tooth decay is an interesting and intriguing story. One of the most brilliant investigations ever carried out in the epidemiology of chronic disease was the series of studies that led to demonstration that fluoridated water had caries-inhibitory properties.

It started when a young dentist, Frederick S. McKay set up his practice in Colorado Springs, Colorado. He noticed that many of his patients' teeth exhibited a condition he called ''Colorado Brown Stain.'' As it wasn't described in any scientific literature, he was determined to find out more about it. In 1908, he initiated a study and found that the condition we now know as fluorosis (mottled enamel) was prevalent throughout the surrounding El Paso County. Dr. McKay, along with another major figure in the dental world, Dr. G. V. Black, wrote detailed descriptions of mottled enamel.[2,3]

In the 1920's, Dr. McKay, along with others, concluded that something either in or missing from the drinking water was causing the mottled enamel. Also, in the late 1920's, Dr. McKay made another major discovery. The teeth with mottled enamel were essentially free of dental caries. In 1931, fluoride was identified as the element in drinking water that caused mottled enamel and also inhibited dental caries.

In the 1930's, Dr. H. Trendley Dean, of the U.S. Public Health Service and Dr. McKay corroborated to determine if fluoride could be added to the drinking water to prevent cavities. Dr. Dean and his associates conducted several classic studies to established a community fluorosis index.[4,5,6] This led to further studies which predicted the cause-and-effect relationship between fluoridation and the reduction of dental caries and determined what the optimal levels of fluorides should be in a community's drinking water. Dr. G. J. Cox was the first person to propose adding fluoride to the drinking water for the prevention of dental caries.[7]

The studies on fluorides were interrupted by World War II, but in 1945 and 1947, four classic studies were begun which finally proved the benefits of water fluoridation by adding fluoride to a community's drinking water of several communities.[8,9,10,11] The most important study, under the direction of Dr. Dean, was started in 1945 in Grand Rapids, Michigan. (Fluoridation began in January 1945, in Grand Rapids; in May 1945, in Newburgh, New York; in June 1945, in Brantford, Ontario; and in February 1947, in Evanston, Illinois.) These studies firmly established fluoridation as a practical and effective public health measure that would prevent dental caries.

In the 1950's and 1960's, two more individuals emerged on the fluoridation scene. It had already been determined that fluoridation was safe and effective, but the engineering aspects needed to be developed before community water fluoridation could be implemented. Franz J. Maier, a sanitary engineer, and Ervin Bellack, a chemist, both with the U.S. Public Health Service, made major contributions to the engineering aspects of water fluoridation.

Maier and Bellack helped determine which fluoride chemicals were the most practical to use in water fluoridation, the best mechanical equipment to use; and the best process controls. Bellack helped make major advances in testing for fluorides. In 1963, Maier published the first comprehensive book on the technical aspects of fluoridation: the "Manual of Water Fluoridation Practice." In 1972, Bellack, then with the U.S. Environmental Protection Agency, published the "Fluoridation Engineering Manual." It still is widely used today.

Over the past 40 years continuous studies have been conducted on fluorides and fluoridation by the U.S. Public Health Service, State health departments, and nongovernmental research organizations. Since 1970 alone, there have been over 3,700 studies on fluoride. For a more comprehensive review of many of these studies, we refer you to the "Michigan Department of Public Health Policy Statement on Fluoridation of Community Water Supplies and Synopsis of Fundamentals of Relation of Fluorides and Fluoridation to Human Health."[12] This synopsis contains an extensive list of references. Also, an excellent book that contains a comprehensive chapter on fluoridation is "Dentistry, Dental Practice, and the Community" by Striffler, Young, and Burt.[13] Many other very good reference books and booklets on fluoridation are available. Please write to the Centers for Disease Control in Atlanta, Georgia for additional information.

1.3 Effectiveness of Fluoridation

1.3.1 Causes of Dental Caries

Dental caries (tooth decay) is a complex process and all of the causative factors involved are not entirely understood. It is usually characterized by the loss of tooth structure (enamel, dentin, and cementum) as a result of destruction of these tissues by acids. Evidence shows that these acids are produced by the action of oral bacteria and enzymes on sugars and carbohydrates that are taken into 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. The bacteria are capable of converting some of the simpler sugars into acids, and the bacteria and enzymes acting in combination are capable of converting carbohydrates and more complex sugars into acids. The production of these acids is a result of the natural existence of bacteria and enzymes in the mouth.

The acids dissolve tooth enamel and initiate the process of tooth decay. As the enamel is dissolved, a cavity forms which usually becomes larger as the decay process continues. The dentin underneath the enamel may also be damaged by acid. As the protective covering of enamel and dentin are destroyed the pulp will be exposed to infection by bacteria.

The highest rate of tooth decay activity is found in schoolchildren. It begins in early childhood, reaches a peak in adolescence, and diminishes during adulthood.

1.3.2 Dental Benefits

Nearly everyone in the United States is attacked by dental caries, the most prevalent chronic disease of man.[14] It is truly universal. Almost 98 out of 100 Americans experience some tooth decay by the time they reach adulthood. By age 17, the average American will have 6.3 decayed, missing or filled teeth.[15] Much of the pain and expense of dental decay can be prevented through fluoridation. No other public health measure is as effective in building decay-resistant teeth and this measure is available to all, without regard to education or socio-economic status.

The effect of fluoridated water ingested during the years of tooth development has been amply demonstrated. The evidence is irrefutable that fluoride, at the optimal concentration in potable water, will reduce dental caries up to 65 percent among children who ingest this water from birth.[16] It is not as well known by the general public that these benefits continue into adult life. Even early studies documented that the benefits of fluorides extended to adults.[17] Fewer caries results in stronger teeth, requiring fewer and less extensive fillings, fewer extractions and fewer artificial teeth.

Several studies in fluoridated communities over the last forty years have shown a dramatic increase in the number of teenagers who were completely caries-free.[18] It has been demonstrated that even teenagers without lifetime exposure have realized benefits from adjusted fluoridation and that the benefits increase among those with life-time exposure. Conservative estimates indicate that 20 percent of the teenagers in a fluoridated community will be caries-free.[19] This is about six times as many as are caries-free in a fluoride-deficient community.

There is now strong evidence that water fluoridation not only makes the tooth more resistant to bacterial acids but also actually inhibits the growth of certain kinds of bacteria that produce these acids. Also, it has now been shown that fluorides actually aid in the remineralization of the tooth, thus actually reversing the decay process after it has already begun.

Fluoridation thus enhances the appearance of the teeth, makes them more impervious to bacterial acids, and substantially reduces bills for restorative dentistry. For every dollar spent on water fluoridation, up to 50 dollars in dental bills may be saved.[20,21] The cost of fluoridation is about 35 cents person per year.[22] The benefits of fluoridation last for a life-time if one continues to consume fluoridated water. There is also some evidence to show that higher levels of fluoride strengthen the bones of older people, thus reducing the incidence of bone fractures.[23,24,25]

1.3.3 Systemic and Topical Effects of Fluorides in Drinking Water

Generally, when water containing fluoride is drunk, a small amount (20 percent) is retained by fluids in the mouth and will be incorporated onto the tooth by surface uptake (topical effects). The greater part (80 percent) of the fluoride utilized goes into the stomach and is rapidly absorbed by simple diffusion through the walls of the stomach and gut. It enters the blood plasma and is rapidly distributed throughout the body, including the teeth (systemic effect). Because of the systemic effect, the fluoride ion is able to pass freely through all cell walls and thus is available to all organs and tissues of the body. Distributed in this fashion, the fluoride ion is available to all the skeletal structures of the body in which it may be retained and stored in proportions which, generally speaking, increase with age and with intake.

The bones, teeth, and other parts of the skeleton tend to attract and retain fluoride. The soft tissues do not retain fluorides. It is correctly stated that fluoride is a "bone seeker." About 96 percent of the fluoride found in the body is deposited in the skeleton.[26]

As the teeth are part of the skeleton, the incorporation of fluoride in the teeth is basically similar to that in other bones. Incorporation of fluoride is most rapid during the time of the child's formation and growth. This time period is roughly from the 4th month of pregnancy to the 10th year. The 8th year probably marks the end of the maximum rate of incorporation of fluoride in the teeth. Erupted teeth differ from other parts of the skeleton in that once they are formed, with the exception of the dentin (inner part of the tooth) and the root, there is little cellular activity. Thus, there is not as much change in the fluoride levels in the teeth after they are formed. It is important that children drink the proper amount of fluoridated water during the early development of the permanent teeth, starting at birth.

As is true with bones, fluoride concentrated in the teeth has a direct relationship with the level of fluoride in the drinking water and with the age of the subject. But, not being subject to internal repair by the body, the teeth do not tend to lose fluoride by reabsorption except in the root structure. The amount of fluoride in the teeth varies as widely as the fluoride in the other parts of the skeleton, from several hundred to several thousand parts per million (ppm).

Note that the fluoride incorporated in the tooth is in a soluble form. Insoluble fluorides, such as calcium fluoride (CaF_2) particulates, will pass through the body and will not be utilized. Also, fluorides in the organic form are not utilized by the body. The actual mechanism for the incorporation of the fluoride ion in the tooth and bones is not well-known. But it is known that the fluoride ion replaces the hydroxyl ion (OH^-) in the crystal lattice in the enamel, resulting in a stronger tooth.

1.3.4 Alternatives to Water Fluoridation

While there are other ways to provide the benefits of fluoride besides the fluoridation of municipal water supply systems, one point must be kept clearly in mind. Municipal water fluoridation is by far the most cost-effective and practical means available for reducing the incidence of caries in the community. This conclusion is based on the mass of evidence demonstrating the efficacy of the measure, and on the most current information on costs of implementing fluoridation. School fluoridation is another way to provide the benefits of water fluoridation, and should not be considered as an *alternative* to water fluoridation. This is because with both school fluoridation and community fluoridation, the fluoride level of the drinking water is being adjusted upward.

In general, there are five alternatives to water fluoridation which use either topical or systemic fluorides:

A. Topical Fluorides
  1. Fluoride gels (professionally applied)
  2. Fluoride mouthrinses
  3. Fluoride dentifrices

B. Systemic Fluorides
  1. Fluoride tablets
  2. Fluoride drops

C. Combination of Topical and Systemic Fluorides:

While topical fluorides can be used in conjunction with water fluoridation (optimally fluoridated water in community or school water systems or naturally fluoridated water), systemic fluorides should not. Utilization of only one type of systemic fluoride is sufficient to prevent tooth decay. The cost and the effectiveness of these alternatives vary as shown in Table 1-1 below.

Topical fluorides may be professionally applied or self-applied. Table 1-2 on page 5 lists these methods and shows the percent reduction in DMFT (decayed, missing and filled permanent teeth).[27] In the Table, note that only those toothpastes containing fluoride that are accepted by the Council on Dental Therapeutics of the American Dental Association assure effectiveness.

Systemic fluoride supplements require daily administration and may be in the form of either tablets or drops. Fluoride supplements may be combined with vitamins, and the amount of fluoride recommended in the tablet or drop depends on the fluoride concentration in the water and the age of the child. The current recommendations of the American Dental Association (ADA) and the American Academy of Pediatrics (AAP) on fluoride supplements are shown in Table 1-3, on page 5.[28]

TABLE 1-1

COMPARISON OF EFFECTIVENESS OF DIFFERENT TYPES OF FLUORIDES*

Procedures	Number of Cavities Prevented**	Cost/Cavity Prevented
1. Water Fluoridation		
A. Municipal	500,000	$ 0.20
B. School	111,100	0.90
2. Topical Fluorides		
A. Supervised Application of Paste or Rinse in School	55,555	1.82
B. Professional Application of Topical Fluoride	25,600	3.90
3. Systemic Fluorides		
A. Supervised Distribution of Fluoride Tablets in School	16,542	6.06
B. Individually Prescribed Fluoride Tablets or Drops	10,000	10.00

*Estimates from Dr. Charles Gish, Director, Division of Dental Health, Indiana State Board of Health which were published in June 1978 in the Proceedings of a workshop at the University of Michigan.
**Number of cavities prevented per $100,000 spent.

TABLE 1-2

TOPICAL FLUORIDE APPLICATIONS*

Applications	No. of Applications	Percent Reduction in Number of Cavities
1. Professionally Applied		35
2. Self-Applied		
a. 0.2% NaF Rinse	Weekly	25
b. Supervised brushing with 9.0% Stannous Fluoride	2/yr	25
c. Toothbrushing at home with 0.1% fluoride dentifrice	Daily	20

*Heifetz, Stanley B. "Cost-Effectiveness of Topically Applied Fluorides." Workshop on Preventive Methods in Dental Public Health. Ann Arbor, Mich., June 5-8, 1978.

TABLE 1-3

DAILY SUPPLEMENTAL FLUORIDE DOSAGE SCHEDULE*

AGE (years)	Concentration of Fluoride in Water		
	Less than 0.3 ppm	0.3 ppm to 0.7 ppm	Greater than 0.7 ppm
6 mon – 3 yr ~~Birth to 2~~	0.25 mgF/day**	0.0 mgF/day	0.0 mgF/day
~~2-3~~ 3-6	0.50 mgF/day	0.25 mgF/day	0.0 mgF/day
~~3-13~~ 6-16	1.00 mgF/day	0.50 mgF/day	0.0 mgF/day

*American Dental Assoc., Council on Dental Therapeutics, Accepted Dental Therapeutics, 39th Ed. Chicago, American Dental Assoc. 1982

**2.2 mg of Sodium Fluoride contains 1 mg of Fluoride (F)

1.4 Dental Fluorosis

Dental fluorosis is defined as the whitish to brownish spots seen on teeth in high fluoride areas. It has been clearly established that high levels of fluoride in the drinking water will cause fluorosis (or "mottled enamel" as it is sometimes called).

As mentioned in section 1-2, in the 1930's, Dr. H. Trendley Dean, the first director of the National Institute of Dental Research, was assigned to research the relationship between mottled teeth and low incidence of dental caries. From this research came the recommendation for water fluoridation at the various optimal levels. The relationship between mottled teeth and the incidence of dental caries was documented in the "Dean's Index of Dental Fluorosis." This index established a method for comparing various stages of fluorosis.

Dr. Dean's Index and his 21 city study were used to determine the optimal levels of fluoride in the drinking water.[6] Dr. Dean's Index shows that there is very little mottling at fluoride levels of 2.0 ppm or lower. Even the mottling, which causes formation of whitish opaque areas, is not unattractive and is generally detectable only by a trained observer. At over 3.0 ppm of fluoride, the brown strain effect becomes noticeable in a very small percentage of the population. (Figures 1-1 and 1-2 on page 6.)[6,29,44]

FIGURE 1-1
DEGREE OF MOTTLED ENAMEL AND FLUORIDE CONCENTRATION IN WATER

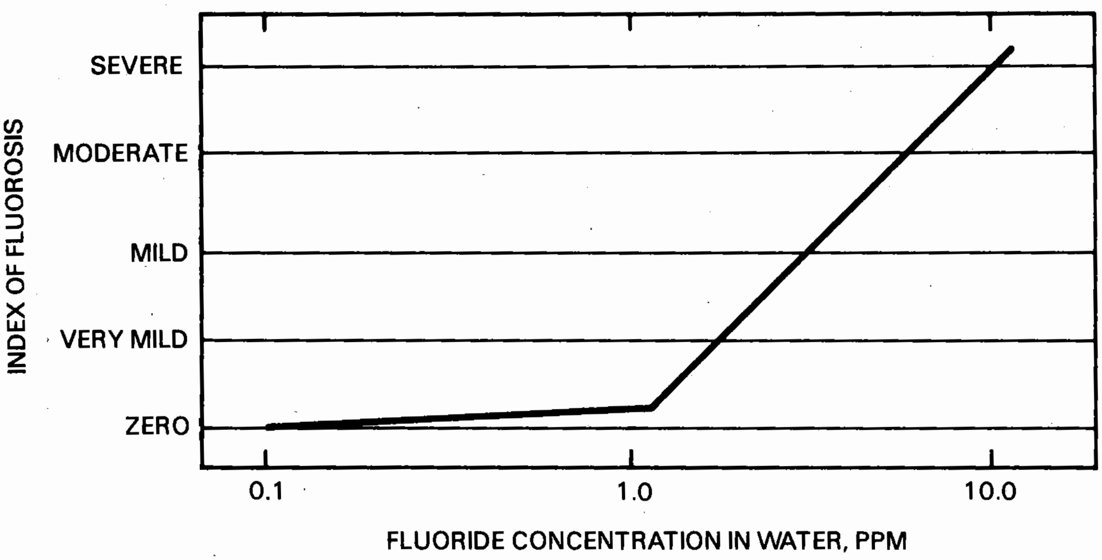
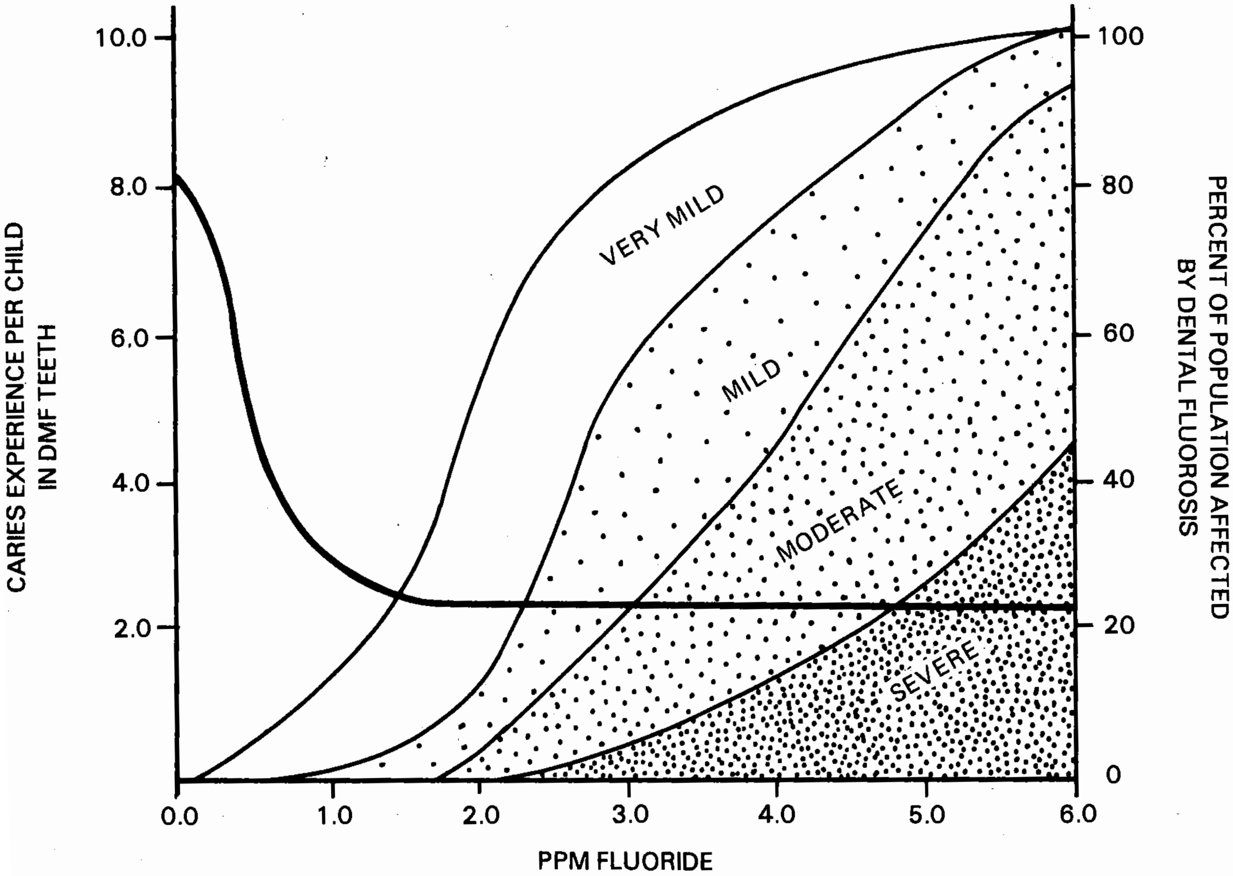


FIGURE 1-2
DENTAL CARIES AND DENTAL FLUOROSIS IN RELATION TO FLUORIDE IN PUBLIC WATER SUPPLIES



1.5 The Opponents of Fluoridation

Although community water fluoridation has been proven to be both safe and the most cost-effective method to prevent dental caries, a small percentage of the population continues to oppose its introduction into community water systems. When fluoridation is being considered for adoption by a community, persons opposed to fluoridation often introduce charges or allegations that attempt to refute the benefits, safety, and efficacy of this proven public health measure. Since many of these charges will have to be answered by the State fluoridation engineer, samples of the charges are presented in this chapter. They are divided into two groups: 1) engineering charges; and 2) medical/legal charges:

Here are the charges and the facts that relate to the engineering aspects of fluoridation:

1. **THE CHARGE:**
   Natural fluoridation is different from adjusted fluoridation.

   THE FACT:
   There is absolutely no difference. No matter where the fluoride comes from, the fluoride ion in the drinking water is the same. The element fluorine is made up of atoms that have a definite structure. When fluorine combines with another element, each fluorine atom gains one electron and the new substance is called fluoride. In a *water solution*, these fluoride particles tend to dissociate as separate charged particles called ions. The fluoride ions have completely different properties from fluorine. But, no matter which group of minerals the fluoride comes from, the fluoride ion is the same.

2. **THE CHARGE:**
   Fluoridation is wasteful. Less than one-tenth of 1 percent of the water is drunk by children. The remaining 99.9 percent is used for sanitary and industrial purposes, fighting fires, washing streets, sprinkling lawns, etc.

   THE FACT:
   True. But based on this argument, chlorination and all other water treatment processes are also wasteful. Obviously, we cannot fluoridate only that part of the water drunk by children. Fluorides must be added to the whole supply. Even with this admitted ''waste,'' fluoridation remains by for the most cost-effective and equitable method of preventing tooth decay.

3. **THE CHARGE:**
   There is a danger that a whole town will be over-fluoridated.

   THE FACT:
   Such a danger is non-existent. In this country, the apparatus, chemicals and mode of operation are so arranged that it would be very difficult to administer a dangerous dose to a whole community. The type of pump used, operating near its maximum capacity, would add fluoride solution at the rate of only 2 ppm. Moreover, the pump is frequently calibrated, and the fluoride content of the water is checked routinely, so that any deviation from the desired level is seen immediately.

   Nevertheless, it is suggested by some that either by accident or design it is possible to mass poison a community. Though such ideas are unrealistic, they are entertained by some community members and, therefore, the logistics of the suggestion need to be examined. The minimum fatal dose for a human adult is approximately 2 grams of fluoride. It takes about 19 lbs. of sodium fluoride or 14 lbs. of sodium silicofluoride to fluoridate 1 million gallons of water at 1 ppm. To fluoridate 10 million gallons of water would require 190 lbs. or 140 lbs., respectively. To raise the fluoride concentration to a level where the minimum fatal dose (2 grams) could be consumed in say, a 10 oz. glass of water, it would be necessary to add to the same water supple approximately 700 tons of sodium fluoride or 500 tons of sodium silicofluoride at one time. The danger would probably be greatest in larger systems that use dry feeders. The hopper capacity of the fluoridator (dry feeder) is designed to be limited to a 2 days' supply (about 50 lbs.), but even if one week's supply was added at one time, it would still be about one five-hundredth of the quantity required for the minimal fatal dose. Obviously, under the circumstances, it is impossible for 700 tons of fluoride chemical to be fed into the water at one time.

4. **THE CHARGE:**
An accident in the water plant might cause a harmful overdosage of fluorides.

THE FACT:
Fluoride feeders are designed to stop operating if there is an accident or malfunction. Besides, a year's supply of fluoride would have to be added in a single day to produce harmful effects. That is many times the amount of fluoride the water plant usually has available for fluoridation.

5. **THE CHARGE:**
Fluoridation causes corrosion in the water lines.

THE FACT:
Allegations that fluoridation is the cause of corrosion in water systems continue to be circulated despite refutations by competent authorities such as the U.S. Environmental Protection Agency[30] and the National Association of Corrosion Engineers.[31] Corrosion by potable water is related primarily to dissolved oxygen concentration, pH, water tmperature, alkalinity, hardness, salt concentration, hydrogen sulfide content, and the presence of certain bacteria. The fluoride ion itself is unrelated to corrosion at concentrations found in potable water at or near the optimal level. Under special water quality conditions, a small increase in the corrosivity of potable water that is *already* corrosive may be observed after treatment with alum, chlorine, hydrofluosilicic acid, or sodium silicofluoride. The very slight increase in corrosivity by depression of pH resulting from these treatments occurs in potable waters with little buffering capacity (alkalinity less than about 10 mg/l as calcium carbonate). In such cases, further water treatment to adjust the pH upward is indicated.

6. **THE CHARGE:**
Fluoride adds taste, color, or smell to the water supply.

THE FACT:
This is not true. Color, taste (palatability), and smell are not affected by the addition of fluoride at a concentration of 1 ppm. Water supplies, of course, vary in regard to their content and there is no such thing as pure water in the absolute sense. Also, other materials can add taste and/or smells to a water supply system, especially total dissolved solids.

Using distilled water as a test medium is not an exact substitute for water in which there may be anywhere from 100 to 1,500 ppm of dissolved solids. However, an experiment using distilled water showed that 50 percent of 280 subjects tested failed to distinguish any difference between distilled water and distilled water fluoridated at 133 ppm.[32] In another experiment, out of 187 male dental students, only 8 said they could detect the fluoride in distilled water with 10 ppm fluoride.[33] It was thus concluded that a fluoride concentration of 1.8 ppm would be tasteless in distilled water and that the average person would be unable to detect any taste at 10 ppm. It is strongly suggested that the taste threshold would be even higher in normal (i.e., undistilled) water.

7. **THE CHARGE:**
Fluoridation is promoted by the big chemical companies which make huge profits from it.

THE FACT:
This is a false statement. Fluoridation represents only one ten-thousandth of the chemical industry business.

8. **THE CHARGE:**
The hardness of water makes the introduction of fluoridation difficult.

THE FACT:
There is no truth to this charge. Calcium and magnesium can reduce the solubility of fluorides but this effect is negligible with the concentration present in natural waters. It may be necessary to soften water used to make a fluoride solution to enable it to be added homogeneously to the supply, but this presents no difficulty.

9. **THE CHARGE:**
Although fluoride may be added at a uniform rate at the source of the water supply, there is a likelihood of the fluoride tending to form pockets in water pipes which would give rise to uneven concentrations.

THE FACT:
This is not true. At the concentration of 1 ppm fluoride, the fluoride is completely soluble and will not be precipitated out of solution, even in hard water. The concentration of fluoride at the plant tap will be carried throughout the distribution system, but if a change in the concentration occurs at the plant there will be a time lag before the change reaches outlying parts of the distribution system. The time lag depends on the length of pipe through which the water has to pass. But, "pockets of fluoride" do not occur in the distribution system.

10. **THE CHARGE:**
There are alternative, inexpensive methods which can be used by families who believe in the value of fluoridation, such as a home fluoridation unit.

THE FACT:
There is no reasonable alternative to community fluoridation. It is impractical and much more expensive for each home to have its own fluoridation system. Operation and maintenance problems are difficult for the average home owner to handle. Community water fluoridation remains by far the most cost effective and equitable method of providing for benefits of fluoridated water.

11. **THE CHARGE:**
It is impossible to control the amount of fluoride every person gets from food and by drinking fluoridated water.

THE FACT:
There are variations of fluoride consumption due to differences in eating and drinking habits, but this is not a cause for concern. The recommended level of 1 ppm for fluoridation was made realizing these variations exist. Comparatively, there has been only a slight change in people's eating and drinking habits since the recommended level was set.

12. **THE CHARGE:**
The U.S. Environmental Protection Agency (EPA) says fluoridation contaminates and pollutes water.

THE FACT:
While the U.S. EPA controls the amount of natural fluoride in drinking water at 4 mg/l, it also strongly supports water fluoridation.[45,46]

13. **THE CHARGE:**
Fluoridation has caused deaths. For example, a young boy in New York City and an Annapolis resident.

THE FACT:
There has never been a death attributable to water fluoridation whereas there are deaths annually from both tooth decay and conditions associated with osteoporosis.

The death in New York City of the boy was not from fluoridation but from an extremely concentrated fluoride rinse solution which the child swallowed while unsupervised in a dental office. To compound the situation, he did not receive emergency treatment for three to four hours after the ingestion.

In the Annapolis, MD, situation, a spill of approximately 1,000 gallons of concentrated hydrofluosilicic acid, into the water system led to high fluoride levels. The water system was not purged and the spill went unreported to public health officials. (This was not an overfeed because no feed control equipment was involved.)

The high fluoride content of the water came to light eight days later during an investigation of illness of eight chronic renal failure patients who were being dialyzed on the day of the spill. (The dialysis was being carried out with tap water rather than deioned water as recommended by health officials. Mineral-free water should be always used for dialysis since normally harmless substances naturally found in water such as aluminum, copper, magnesium, calcium and fluoride could potentially cause problems during dialysis.) One dialysis patient died about 16 hours later of severe atherosclerotic heart disease with acute fluoride intoxication as a contributing factor. Although this patient had become acutely ill during dialysis, he declined hospitalization and went home without professional treatment.

14. **THE CHARGE:**
Pure water is better.

THE FACT:
There is no such thing as pure water. All water has a variety of substances held in suspension or dissolved in it including some level of fluoride. (Other substances may include iron, calcium, and/or silica.) Actually there are over 40 different chemicals that can be used to treat water in the United States, such as copper sulfate, calcium hydroxide, and chlorine (see Table 5-2). Most are added for aesthetic or convenience purposes such as to improve the odor or taste, prevent natural cloudiness or prevent staining of clothes or porcelain. At improper concentrations, many can be hazardous.

15. **THE CHARGE:**
Fluoridating the water would contaminate the environment and cause adverse ecological effects.

THE FACT:
Fluoride in the ion form is the thirteenth most common element present in the earth's crust and twelfth in ocean waters. It is found in all water except falling rain. The fluoride content of sea water is 1.2 ppm. Fluoridation is the adjustment of the fluoride content in fluoride deficient supplies. A minor increase in the fluoride content of municipal water supplies will have no effect on the environment.

Here are some of the medical/legal charges made by those opposed to the fluoridation of community water supply systems.

16. **THE CHARGE:**
Fluoridation causes cancer.

THE FACT:
Early in 1975, the National Health Federation issued information alleging a relationship between fluoridation and cancer. Their allegations have been repeatedly refuted, both by separate reviews of their work and by independent studies, not only in the United States but

in several other countries. Reviews have been conducted by the National Cancer Institute of the National Institutes of Health. Independent studies conducted in the U.S. by the National Cancer Institute, the National Heart, Lung, and Blood Institute, and the Centers for Disease Control found no relationship between fluoridation and cancer mortality.[34] Recent studies reported on populations in Australia, England, and Canada, encompassed 79 groups of municipalities and covered approximately 20 years (1954-1973).[35,36,37] These studies concluded that no appreciable differences in death rates from all types of cancer or any specific tumor site were indicated between fluoridated and non-fluoridated municipalities over this period. Nor were any significant differences apparent between death rates from all types of cancer when compared within the same group of municipalities prior to and after fluoridation.

17. **THE CHARGE:**
Fluoridation causes heart diseases, diabetes, and liver and kidney ailments.

THE FACT:
Studies made in 64 cities (32 of which have used naturally fluoridated water for generations, and 32 without fluoridation) show no significant difference in the mortality rates from these diseases.[38] These findings have been confirmed by other studies in Illinois, New England, Texas, and New York.[39,40,41,42]

18. **THE CHARGE:**
Fluoridation is mass medication.

THE FACT:
Fluoridation is not a medicine. It does not treat or cure anything. It is a nutrient which prevents dental decay. Like other minerals in the diet, fluoride helps the body to resist disease. And dental decay is a serious disease.

19. **THE CHARGE:**
Fluoridation is unconstitutional and an illegal invasion of individual rights.

THE FACT:
Over the years the legality of fluoridation has been tested repeatedly. Courts in over one-half of the States have heard fluoridation cases, and the constitutionality of fluoridation has been upheld by State Supreme Courts in over a dozen States. In addition, at least eight times, cases have been taken to the United States Supreme Court, where the court has declined to hear these cases because no substantial Federal constitutional question was involved. To date, no final decision has ever been made that was unfavorable toward fluoridation regardless of the charges presented.

20. **THE CHARGE:**
Fluorides in drinking water can produce an allergic reaction.

THE FACT:
Fluoride at the concentration recommended for dental health, does not cause such reactions. The American Academy of Allergy conducted a review of clinical reports of possible allergic responses to fluoride. The Academy found no evidence of allergy or intolerance. Following completion of the study, the Executive Committee of the Academy unanimously adopted the following statement: "There is no evidence of allergy or intolerance to fluorides as used in the fluoridation of community water supplies."[43]

21. **THE CHARGE:**
The cumulative effect of drinking water a fluoridated water supply will damage irreparably the tissues and bones of the body.

THE FACT:
The effect of drinking fluoridated water is non-cumulative. A minute part is deposited in the bones and teeth; the remainder is rapidly excreted through the kidneys. It is true that the bones and teeth will accumulate fluoride over long periods of time. This is not a problem, but rather a beneficial result.

22. **THE CHARGE:**
Fluoride is used as rat poison.

THE FACT:
This fact used to be true. Fluoride was used as a rat poison in the past. It no longer is used as such because it was not very effective. But no one has ever questioned that large doses of fluoride are toxic. However, it is essential to emphasize two completely different aspects of fluorides. One aspect concerns the serious toxic effects from massive doses of extremely high levels of fluorides. The other aspect concerns evaluation of the effects of trace amounts of fluoride in the drinking water. The implication that fluorides in large doses and in trace amounts have the same effect is completely incorrect. Many substances in common use are very beneficial in small amounts, but may be harmful in large doses, for example, table salt (sodium chloride) or chlorine.

The list of charges, whether they relate to engineering, medical, legal, or other questions, could go on indefinitely. Some of the more common questions that may arise have been presented for the State fluoridation engineer/technician or the water treatment plant operator. There are several studies and reports on the charges against fluoridation that are very complete. If additional information is desired on any charge or information on a charge not covered in this manual, please refer to *Fluoridation Facts*, (a publication of the American Dental Association), or other similar publications.

It is unfortunate that irrelevant, unreplicated, or refuted research is purposefully presented to the detriment of the public's health. It is also unfortunate that misinterpretation of actions in foreign countries and out-of-context statements continue to circulate and create unnecessary fears. For every report which casts doubts about fluoridation, there are innumerable reports attesting to its safety and efficacy. It is not surprising that some differences of opinion among scientists and professionals in research and medicine may occur. What is surprising, however, is their almost universal agreement on the safety and effectiveness of fluoridation. Fluoridation is not a controversy in any scientific sense. There are few public health measures which have had the scientific endorsement and broad base of research which supports its use as does fluoridation.

Community fluoridation is supported by government officials, the U.S. Public Health Service, the American Dental Association, the American Medical Association, the World Health Organization, the American Water Works Association, and virtually every scientific and professional organization in the health field. In the more than forty years of fluoridation, there has never been any clinically substantiated evidence of harm to anyone from drinking optimally fluoridated water.

Fluoridation is safe. It's economical. It's effective. It's practical. There is no substitute which can prevent up to two out of every three cavities.

The effectiveness of fluoridation depends on how consistently the water treatment operator maintains the optimal fluoride concentration. He holds the key to better dental health. As has been stated by Dr. Joseph M. Doherty, Director, Division of Dental Health, Virginia Department of Health: "We must recognize the operator as being part of that professional team. He should be recognized, because I think he does more to prevent decay than all the dentists in that community can do in their lifetimes."[47]

CHAPTER TWO
FLUORIDE CHEMICALS

2.1 Introduction

Fluorine, a gaseous halogen, is the thirteenth most abundant element found in the earth's crust. It is a pale yellow noxious gas that is highly reactive. It is the most electronegative of all the elements. It can not be oxidized to a positive state. Fluorine is never found in a free state in nature, but is always in combination with chemical radicals or other elements as fluoride compounds. When dissolved in water, these compounds dissociate into ions. It is the fluoride ions at the optimal level in drinking water that are responsible for dental caries reduction. There are only three basic compounds commonly used for fluoridating drinking water supplies in the United States: Sodium fluoride, sodium silicofluoride, and hydrofluosilicic acid.

2.2 Chemical Sources

Fluoride can be found in a solid form in minerals such as fluorspar, cryolite and apatite. Fluorspar is a mineral containing from 30 to 98 percent calcium fluoride (CaF_2). Fluorspar (also called fluorite) is found in most parts of the world, with Kentucky and Illinois having the largest deposits in the United States. There are also small deposits in Nevada and Texas. Most of the U.S.-produced fluorspar comes from two mining companies in southern Illinois. In recent years, the U.S. has produced only about 10 percent of its fluorspar consumption. The rest has been imported, generally from Mexico (about 85 percent), because of low cost and high purity.

Cryolite (Na_3 Al F_6) is a compound of aluminum, sodium, and fluoride. It is preferred for industrial use because of its low melting point. Large deposits are in Greenland. Cryolite is not a major source of fluoride in this country.

Apatite [Ca_{10} $(PO_4, CO_3)_6$, $(F, Cl, OH)_2$] is a deposit of a mixture of calcium compounds. (The comma in the chemical equation means a mixture.) These calcium compounds include primarily calcium phosphates, calcium fluorides, and calcium carbonates. Also, there are usually trace amounts of sulfates as impurities. Apatite contains from 3 to 7 percent fluoride and is the main source of fluorides used in water fluoridation at the present time. It is also the raw material used for phosphate fertilizers. Large deposits of apatite are found in Tennessee, Florida, and South Carolina. Three-fourths of the U.S. annual production of apatite comes from central Florida. There are also deposits in North Carolina, Montana, Idaho, Utah, and Wyoming.

Due to the dissolving power of water and the movement of water in the hydrologic cycle, fluoride is found naurally in all waters. As water moves through the earth as groundwater, it contacts fluoride-containing minerals and carries fluoride ions away from them. Because all water eventually goes to the ocean, sea water also contains fluoride (approximately 1.2 ppm). The concentration of fluoride found in fresh waters varies according to such factors as the depth at which the water is found and the quantity of fluoride bearing minerals in the area. Generally speaking, the deeper the groundwater, the greater the concentration of fluoride in the water.

2.3 Fluoride Compounds in General

Theoretically, any compound which forms fluoride ions in water solution can be used for adjusting the fluoride content of a water supply. However, there are several practical considerations involved in selecting compounds. First, the compound must have sufficient solubility to permit its use in routine water plant practice. Second, the cation to which the fluoride ion is attached must not have any undesirable characteristics. Third, the material should be relatively inexpensive and readily available in grades of size and purity suitable for their intended use. Fluoride chemicals, like chlorine, caustic soda, and many other chemicals used in water treatment can constitute a safety hazard for the water plant operator unless proper precautions in handling are observed. It is essential that the operator be aware of the hazards associated with each individual chemical prior to its use.

The three commonly used fluoride chemicals—sodium fluoride, sodium silicofluoride, and hydrofluosilicic acid—should meet the American Water Works Associations (AWWA) standards for use in water fluoridation.[1,2,3] Imported chemicals especially should be checked for compliance with these standards.

2.4 Sodium Fluoride

The first fluoride compound used in water fluoridation was sodium fluoride. It was selected on the basis of the above criteria and also because its toxicity and physiological effects had been so thoroughly studied. Sodium fluoride has become the reference standard used in measuring fluoride concentration. Other compounds came into use, but sodium fluoride is still widely used, because of its unique physical characteristics.

Sodium fluoride (NaF) is a white, odorless material available either as a powder or in the form of crystals of various sizes. It is a salt that in the past was manufactured by adding sulfuric acid to fluorspar and then neutralizing the mixture with sodium carbonate. In 1983 and 1984, the chemical industry changed the way they manufactured sodium fluoride. It is now produced by neutralizing hydrofluosilicic acid with caustic soda (NaOH). Its formula weight is 42.00, specific gravity 2.79, and its solubility is practically constant at 4.0 grams per 100 milliliters in water at temperatures generally encountered in water treatment practice (see Table 2-1 below).

The relatively constant 4 percent solubility of sodium fluoride is the basis for the design of the saturator. The pH (hydrogen-ion concentration) of a sodium fluoride solution varies with the type and amount of impurities, but solutions prepared from the usual grades of sodium fluoride exhibit a nearly neutral pH (approximately 7.6). It is available in purities ranging from 97 to over 98 percent, with the impurities consisting of water, free acid or alkali, sodium silicofluoride, sulfites and iron, plus traces of other substances. Approximately 19 pounds of sodium fluoride will add 1 ppm of fluoride to 1 million gallons of water.

Powdered sodium fluoride is produced in different densities, with the light grade weighing less than 65 pounds per cubic foot and the heavy grade weighing about 90 pounds per cubic foot. The average density is 85 lbs./cu. ft. A typical sieve and analysis of powdered sodium fluoride shows 99 percent through 200 mesh and 97 percent through 325 mesh. Crystalline sodium fluoride is produced in six various ranges, usually designated roughly as coarse, fine and extra-fine, but some manufacturers can furnish many specific mesh sizes. The crystalline type is preferred when manual handling is involved, since the absence of fine powder results in a minimum of dust. Dust constitutes the most frequently encountered hazard in handling sodium fluoride. A more thorough discussion of handling precautions is presented in later sections.

TABLE 2-1

SOLUBILITY OF FLUORIDE CHEMICALS

Chemical	Temperature (°C)	Solubility (g per 100ml of H_2O)
1. Sodium Fluoride (NaF)	0.0	4.00
	15.0	4.03
	20.0	4.05
	25.0	4.10
	100.0	5.00
2. Sodium Silicofluoride (Na_2SiF_6)	0.0	0.44
	25.0	0.76
	37.8	0.98
	65.6	1.52
	100.0	2.45
3. Hydrofluosilicic Acid (H_2SiF_6)		Infinite at all temperatures

Sodium fluoride has a number of industrial uses: The manufacture of vitrified enamel and glasses; as a steel degassing agent; in electroplating; in welding fluxes; in heat treating salt compounds; in sterilizing equipment in breweries and distilleries; in paste and mucilage; as a wood preservative; and in the manufacture of coated paper. One use in the past was as a rodenticide. It is no longer used as such and is not included on the Environmental Protection Agency's (EPA) list of registered rodenticides.

2.5 Sodium Silicofluoride

Hydrofluosilicic acid can readily be converted into various salts, and one of these, sodium silicofluoride (Na_2SiF_6), is widely used as a chemical for water fluoridation. As with most silicofluorides, it is generally obtained as a by product from the manufacture of phosphorus fertilizers. Phosphate rock is ground up and treated with sulfuric acid, thus forming a gas by product. This gas reacts with water and forms hydrofluosilicic acid. When neutralized with sodium carbonate, sodium silicofluoride will precipitate out. The conversion of hydrofluosilicic acid (essentially a low-cost by product which contains too much water to permit economical shipping) to a dry material containing a high percentage of available fluoride results in a compound which has most of the advantages of the acid with few of its disadvantages. Once it was shown that silicofluorides form fluoride ions in a water solution as readily as do simple fluoride compounds, and that there is no difference in the physiological effect, silicofluorides (and hydrofluosilicic acid) were rapidly accepted for water fluoridation, and in many cases, have displaced the use of sodium fluoride, except in saturators.

Sodium silicofluoride is a white, odorless crystalline powder. Its molecular weight is 188.06 and its specific gravity is 2.679. Its solubility varies from 0.44 grams per 100 milliliters of water at 0 degrees centigrade (C) to 2.45 grams per 100 milliliters at 100 degrees C (see Table 2-1 on page 14). The pH's of solutions are definitely on the acid side, with saturated solutions usually exhibiting a pH between 3.0 and 4.0 (approximately 3.6). Sodium silicofluoride is available in purities of 98 percent or greater, the principal impurities being water, chlorides, and silica. Approximately 14 pounds of sodium silicofluoride will add 1 ppm of fluoride to 1 million gallons of water.

Sodium silicofluoride is sold in two commercial forms—regular and fluffy. The density of sodium silicofluoride ranges from 65 to about 95 pounds per cubic foot (lbs/cf.). The average density is approximately 75 lbs/cf. A typical sieve analysis of the regular grade shows more than 99 percent through a 200-mesh sieve and more than 10 percent through a 325-mesh sieve.

Sodium silicofluoride has some other industrial uses: Laundry scouring agent (neutralizing industrial caustic soaps); the manufacture of opal glass; and moth-proofing woolens. It has been used in the past as a rodenticide, but like sodium fluoride, it no longer is used in this way. The U.S. Environmental Protection Agency does not list it as a registered rodenticide.

As in the case of sodium fluoride, the principal hazard associated with handling sodium silicofluoride is dust. Precautions for dealing with this material are discussed in later sections.

2.6 Hydrofluosilicic Acid

Hydrofluosilicic acid (pronounced Hy-dro-FLEW-oh-suh-lys-ik), also known as hexafluosilicic, silicofluoric, or fluosilicic acid (H_2SiF_6), is a 20 to 35 percent aqueous solution with a formula weight of 144.08. It is a straw-colored, transparent, fuming, corrosive liquid having a pungent odor and an irritating action on the skin. Solutions of 20 to 35 percent hydrofluosilicic acid exhibit a low pH (1.2), and at a concentration of 1 ppm can slightly depress the pH of poorly buffered potable waters. It must be handled with great care because it will cause a "delayed burn" on skin tissue. The specific gravity and density of hydrofluosilicic acid are given in Table 2-2 on page 16. The average density of 23 percent acid is 10.1 lbs/gal. Hydrofluosilicic acid (23 percent) will freeze at approximately 4 degrees F or –15.5 degrees C. It takes approximately 46 pounds (4.4 gallons) of 23 percent acid to add 1 ppm of fluoride to 1 million gallons of water.

Hydrofluosilicic acid is manufactured by two different processes, resulting in products with differing characteristics. The largest production of the acid is a by product of phosphate fertilizer manufacture. Phosphate rock is ground up and treated with sulfuric acid, forming a gas by product. This gas is reacted with water, forming a weak hydrofluosilicic acid. The acid is then concentrated from 23 percent to 30

TABLE 2-2

PROPERTIES OF HYDROFLUOSILICIC ACID

Acid* (%)	Specific Gravity (s.g.)	Density (lbs/gallon)
0 (water)	1.000	8.345
10	1.0831	9.041
20	1.167	9.739
23	1.191	9.938
25	1.208	10.080
30	1.250	10.431
35	1.291	10.773

*Based on the other percentage being distilled water.
Note: Actual densities and specific gravities will be slightly higher when distilled water is not used. Add approximately 0.2 lb/gal to density depending on impurities.

percent strength. This type of acid is relatively impure and seldom exceeds 30 percent strength. A smaller amount of acid is prepared from hydrofluoric acid (HF) and silica, resulting in a purer product at a slightly higher strength. Acid prepared from phosphate rock contains colloidal silica in varying amounts, and while 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 hydrofluosilicic acid sell a "fortified" acid, which has had a small amount of hydrofluoric acid added to it to prevent the formation of the precipitate. Acid prepared from hydrofluoric acid and silica does not normally form a precipitate when diluted.

Hydrofluoric acid is an extremely corrosive material. Its presence in hydrofluosilicic acid, whether from intentional addition, i.e., "fortified" acid or from normal production processes, which yield hydrofluoric acid and silicon tetrafluoride as impurities in the hydrofluosilicic acid, demands careful handling. The fumes from hydrofluosilicic acid are lighter than air, unlike chlorine fumes which are heavier than air. Thus, the acid fumes will rise instead of settling to the floor.

Since hydrofluosilicic acid contains a high proportion of water, shipping large quantities can be quite expensive. Larger users can purchase the acid directly from the manufacturers in bulk (tank car or truck) lots, but smaller users must obtain the acid from distributors who usually pack it in drums or polyethylene carboys. The price varies because of the variable characteristics of the acid as it comes from fertilizer plants. Rather than attempt to adjust the acid strength to some uniform figure, producers sell the acid as it comes, and the price is adjusted to compensate for acid strength above or below the quoted figure. Note that the "23 percent basis" type of pricing applies only to bulk quantities. It is the usual practice for the supplier to furnish assay reports of the acid strength of each tank truck lot.

Attempts to dilute the acid are subject to errors in measuring both the acid and the diluting water. It is much better to use the acid undiluted as it comes from the containers in which it is shipped. If the acid is too concentrated for the solution feeder to handle, then weaker solutions of other compounds are generally indicated—for instance, saturated solutions of sodium fluoride. *CDC strongly recommends against the dilution of acid.* If the acid must be diluted, care should be taken to avoid the formation of a precipitate of silica, which will appear despite the quality (hardness) of the water used for dilution. Dilutions between 10:1 and 20:1 (water:acid) are where insoluble silica precipitates are most likely to occur.[4] Softening the water will not prevent this precipitation.

Like all other fluoride compounds, hydrofluosilicic acid has a number of industrial uses, including the sterilization of equipment; in the brewery and bottling industries; electroplating; tanning of animal hides; etching of glass; refining of lead; hardening of cement; and preservation of wood.

As with all other mineral acids, hydrofluosilicic acid should be handled with care to prevent injury to operators and damage to equipment from acid splatter or fumes. A more thorough discussion of handling precautions is presented in following sections.

2.7 Other Fluoride Chemicals

Ammonium silicofluoride, magnesium silicofluoride, potassium fluoride, hydrofluoric acid, and calcium fluoride (fluorspar) are being or have been used for water fluoridation. Each has particular properties which make the material desirable in a specific application, but each also has undesirable characteristics. None of these chemicals have widespread application in the United States, although calcium fluoride is widely used in South America.[5]

Ammonium silicofluoride has the peculiar advantage of supplying all or part of the ammonium ion necessary for the production of chloramine, when this form of disinfectant is preferred to chlorine in a particular situation. It has the disadvantage of hindering disinfection if there are short contact times. Also, it is more expensive than sodium silicofluoride.

Magnesium silicofluoride and potassium fluoride have the advantage of extremely high solubility, of particular importance in such applications as school fluoridation, when infrequent refills of solution containers are desired. In addition, potassium fluoride is quite compatible with potassium hypochlorite, so a mixture of the two solutions (in the same container) can be used for simultaneous fluoridation and chlorination. They can not be fed in dry form. Also, they are both more expensive, especially potassium fluoride, than sodium silicofluoride. Magnesium silicofluoride is widely used in Europe as a concrete curing compound and thus is mass produced. But, it is still more expensive than sodium silicofluoride. Potassium fluoride is one of the main ingredients in the manufacture of nerve gas.

Calcium fluoride (fluorspar) is the least expensive of all the compounds used in water fluoridation, but it is also the most insoluble. It has been successfully fed by first dissolving it in alum solution, and then utilizing the resultant solution to supply both the alum needed for coagulation and the fluoride ion. Some attempts have been made to feed fluorspar directly in the form of ultra-fine powder, on the premise that the powder would eventually dissolve or at least remain in suspension, until consumed. These attempts have not been very successful. Beds of fluorspar have been used in South America with some success. CDC is exploring the use of calcium fluoride in the United States.

Hydrofluoric acid (not hydrofluosilicic acid), although low in cost, presents too much of a safety and corrosion hazard to be acceptable for water fluoridation, although it has been used in a specially designed installation.

A number of other fluoride chemicals have been suggested for use in water fluoridation, among them ammonium and sodium bifluoride. These have the advantages of solubility and cost, but their potential corrosiveness has hindered their acceptance.

Table 2-3 on page 18 shows a comparison among the three most commonly used fluoride chemicals and the other fluoride chemicals.

2.8 Optimal Fluoride Levels

The recommended optimal fluoride concentrations for fluoridated water supply systems is given in Table 2-4 and in Figure 2-1 on page 19. These levels are based on the annual average of the maximum daily air temperature in the area of the involved school or community. In areas where the mean temperature is not shown on the chart, the optimal fluoride level can be determined by the following formula:[6,7]

$$\text{ppm fluoride} = \frac{0.34}{E}$$

TABLE 2-3

COMPARISON OF FLUORIDATION CHEMICALS

Type	Commonly Used Fluoride Chemicals			Other Fluoride Chemicals			
	Sodium silicofluoride (Na_2SiF_6)	Sodium fluoride (NaF)	Hydrofluosilicic acid (H_2SiF_6)	Calcium fluoride (CaF_2)	Magnesium silicofluoride ($MgSiF_66H_2O$)	Ammonium silicofluoride $(NH_4)_2SiF_6$	Potassium fluoride ($KF\ 2H_2O$)
Form	Powder	Powder or Crystal	Liquid	Powder	Crystal	Crystal	Crystal
Molecular weight	188.05	42.00	144.08	78.08	274.48	178.14	94.13
Commercial purity (%)	98 min	97 min	23-35	85-98	98	98	98
Weight lb/cu. ft.	65-95	65-90	9.9(23%) (lbs/gal)	10	72	80	58
lb. to fluoride at 1.0 ppm for 1 million gal. of water (98%)	14.0 (98%)	18.8 (98%)	45.7 (23%)	17.6 (96%)	20.5 (98%)	13.3 (98%)	42.1
Solubility g/100ml H_2O at 25 deg. C	0.76	4.1	Infinite	0.0016	64.8 (17 deg C)	18.5 (17 deg C)	100
pH of saturated solution	3.5	7.6	1.2	6.7	1.0	3.5	7.0

TABLE 2-4

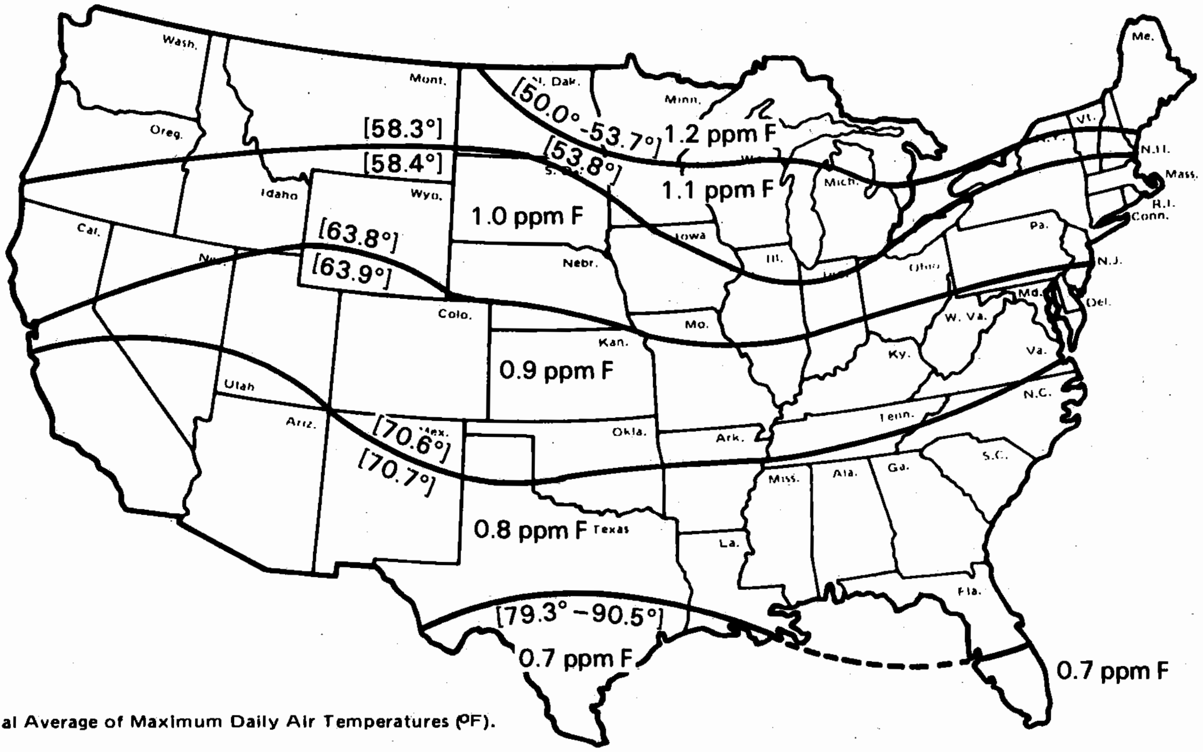
RECOMMENDED OPTIMAL FLUORIDE LEVEL

Annual Average of Maximum Daily Air Temperatures[1] (F)	Recommended Fluoride Concentrations		Recommended Control Range			
			Community Systems		School Systems	
	Community (ppm)	School[2] (ppm)	0.1 Below	0.5 Above	20% Low	20% High
50 ~~40.0~~ – 53.7	1.2	5.4	1.1	1.7	4.3	6.5
53.8 – 58.3	1.1	5.0	1.0	1.6	4.0	6.0
58.4 – 63.8	1.0	4.5	0.9	1.5	3.6	5.4
63.9 – 70.6	0.9	4.1	0.8	1.4	3.3	4.9
70.7 – 79.2	0.8	3.6	0.7	1.3	2.9	4.3
79.3 – 90.5	0.7	3.2	0.6	1.2	2.6	3.8

[1] Based on temperature data obtained for a minimum of five years

[2] Based on 4.5 times the optimum fluoride level for communities

FIGURE 2-1
OPTIMAL FLUORIDE LEVELS IN U.S.



Annual Average of Maximum Daily Air Temperatures (°F).

E is the estimated average daily water consumption for children through 10 years of age in ounces of water per pound of body weight. E is obtained from the formula:

$$E = 0.038 + 0.0062 \times \text{average maximum daily air temperature (degrees Fahrenheit)}$$

The recommended control range is shifted to the high side of the optimal fluoride level for two reasons. First, it has become obvious that many water plant operators try to maintain the fluoride level in their community at the lowest level possible. The result is that the actual fluoride level in the water will vary around the lowest value in the range instead of around the optimal level. Setting a higher level for the bottom of the recommended fluoride control limits will help overcome this problem. Second, some studies have shown that sub-optimal fluorides are relatively ineffective in actually preventing dental caries. Even a drop of 0.2 ppm below optimal levels can reduce dental benefits significantly.[8,9] Skewing the control limits of the optimal fluoride level will help assure that the benefits of fluoridation are being maintained even if the fluoride level in the water varies slightly. In water fluoridation, underfeeding is a much more serious problem than overfeeding.

2.9 Chemical Availability

From time to time, some concern has been raised about the availability of sodium fluoride, sodium silicofluoride, and hydrofluosilicic acid. Generally, most ''shortages'' are not shortages at the manufacturer's plant, but a temporary shortage at the local distributor's level. This type of problem is usually quickly eliminated. In the past, there have been some shortages at the manufacturing level, especially of hydrofluosilicic acid and sodium silicofluoride.

Since hydrofluosilicic acid and sodium silicofluoride (and most sodium fluoride now) are byproducts of phosphoric acid (the main ingredient of phosphate fertilizer) the sales of fertilizer will have a direct effect on the volume of fluoride chemicals produced. In the past, there have been lags in sales of fertilizer resulting in a temporary shortage of these two fluoride chemicals. These shortages have been relatively mild because the number of fluoridated communities was much smaller and a lower volumes of sodium silicofluoride and hydrofluosilicic acid were needed than at the present time. There was a shortage in 1955-1956, in the summer of 1969, in the spring and summer of 1974, in the summer of 1982, and finally, in the early months of 1986.[10] Because of these shortages, CDC recommends that storage of fluoride chemicals be increased as much as practical. At a minimum, it is recommended that 3 months' storage be kept on hand at all times.

Sodium fluoride and sodium silicofluoride can be imported, primarily from Belgium and Japan. The Belgium sodium fluoride is produced only as a powder, thus generally it is not suitable for use in water fluoridation. Japan makes both the powder and crystal forms.

Phosphate fertilizer companies produce only about one-half the amount of fluoride chemicals they have the potential to produce. If all the potential hydrofluosilicic acid was made and converted to municipal grade acid, the fertilizer companies could produce more than 200,000 tons of acid per year. They don't because of the short-term contracts with municipalities and the cost of the equipment necessary to produce municipal-grade acid. A fertilizer company is understandably reluctant to make an expensive commitment unless it can be assured of consumer demand.

There are three broad areas where fluoride chemicals are used: In the aluminum industry; in the water fluoridation industry; and for miscellaneous uses. In 1984, the aluminum industry made major changes in their aluminum smelting processes which may result in significant reductions in the amount of hydrofluosilicic acid used in the future. The miscellaneous uses include fluoride salts used in toothpastes, mouthrinses, tablets, etc., and fluoride compounds used for other industrial uses, such as electroplating, tanning of animal hides, etching glass, and hardening of cement. See Table 2-5 on page 21 for the amount of fluoride chemicals produced in the United States.[11] These figures are approximations and will vary from year to year.

TABLE 2-5

CONSUMPTION OF FLUORIDE CHEMICALS IN UNITED STATES

Industry Name	Amount Used* (tons/year)
1. Aluminum	150,000 to 200,000
2. Water Fluoridation	
A. Hydrofluosilicic Acid (23%)	150,000
B. Sodium Silicofluoride	20,000
C. Sodium Fluoride	5,600
3. Miscellaneous uses	75,000 to 1,000,000

*Approximate Figures based on 1986 data from L.C.I., SRI International and Kaiser Chemicals Company

2.10 Dissociation of Fluoride Chemicals

All fluoride chemicals commonly used in water fluoridation greatly dissociate to a great degree, i.e., in solution, the ions separate and become independent. (They do not tend to ionize in solution. To "ionize" means to form ions, and the fluoride compounds are already formed in ions.) Water is a strong dissociating solvent.

Sodium Fluoride (NaF) has virtually 100 percent dissociation into the simple ions:

(1) $NaF \rightleftharpoons Na^+ + F^-$

Sodium Silicofluoride, Na_2SiF_6, has virtually 100 percent dissociation:

(2) $Na_2Si\,F_6 \rightleftharpoons 2Na^+ + SiF_6$

The SiF_6 radical also will be dissociated in several ways:

(3) $SiF_6^{=} + 2\,H_2O \rightleftharpoons 4H^+ + 6F^- + SiO_2\downarrow$

and/or

(4) $SiF_6^{=} \rightleftharpoons + 2F^- + SiF_4\uparrow$

and

(5) $SiF_4\uparrow + 3\,H_2O \rightleftharpoons 4HF + H_2SiO_3$

and/or

(6) $SiF_4\uparrow + 2\,H_2O \rightleftharpoons 4HF + SiO_2\downarrow$

and, of course

(7) $HF \rightleftharpoons H^+ + F^-$

When sodium silicofluoride is dissolved in water the dissociation into the sodium and silicofluoride ions takes place very rapidly (2). But, the silicofluoride ions dissociate very slowly into the silicon tetrafluoride and fluoride ions (4). The silicon tetrafluoride reacts quickly to form silicic acid (5).

Hydrofluosilicic acid ($H_2 SiF_6$) also has virtually 100 percent dissociation very similar to Na_2SiF_6:

(8) $H_2 Si F_6 \rightleftharpoons 2HF + SiF_4\uparrow$

and

(9) $SiF_4\uparrow + 2 H_2O \rightleftharpoons 4HF + SiO_2\downarrow$

and

(10) $SiF_4\uparrow + 3 H_2O \rightleftharpoons 4HF + H_2SiO_3$

and, of course

(11) $HF \rightleftharpoons H^+ + F^-$

Silicon tetrafluoride (SiF_4) is a gas that will easily evaporate out of water when in high concentrations. Silica (SiO_2) is very insoluble in water. Silica is the main ingredient in glass. Hydrofluoric acid (HF) is very volatile and will attack glass and electrical contacts. It will tend to evaporate in high concentrations.

Note, the symbol ↓ means to precipitate out as a solid, and the symbol ↑ means to evaporate out as a gas.

2.11 Chemical Storage and Handling

A number of criteria govern the selection of a storage site for fluoridating chemicals: Dry chemicals must be kept dry and convenient to the hopper; they should preferably be isolated from other water treatment chemicals to preclude accidental intermixing; the storage area must be clean and well ventilated, and should be equipped with running water and a floor drain for ease in cleaning up spills.

Dry fluoride compounds, i.e., sodium fluoride and sodium silicofluoride, have a tendency to compact or cake when exposed to moisture or when bags are stacked too high. Similar conditions can result from long periods of storage, so an oversupply of chemicals should be avoided. Store dry fluorides on pallets, in stacks preferably not more than six bags high. If fiber drums are used, keep the tops closed to prevent moisture absorption. Do not allow unauthorized personnel, especially small children, in areas where fluoride chemicals are fed or stored.

When fluoride sacks are handled carelessly, or if the bags are emptied too quickly, airborne fluoride dust levels may become dangerously high. Do not toss the bags. When opening the bags, cut an even slit across the top to avoid tearing the sides. Pour the contents of the bags gently into the feed hopper. Do not bellows the empty bag. Good ventilation is absolutely necessary in work areas, even if there is no visible dust production.

The disposal of empty fluoride containers has always been a problem. The temptation to re-use fiber drums is difficult to overcome, since the drums are convenient and sturdy. Paper bags are dusty and could cause a hazard if they are burned, and empty acid drums could contain enough acid to cause contamination. The best approach is to rinse all empty containers with plenty of water—even the paper bags are strong enough to withstand repeated rinses. After all traces of fluoride are removed, the bags should be disposed of in a proper manner. Please check with the solid waste division of your State's Environmental Protection Program for correct advice. Even supposedly well-rinsed drums should never be used where traces of fluoride could present a hazard. If possible, the storage area should be kept locked and not be used for any other purpose. Workers should particularly be warned against eating in a fluoride storage area.

Hydrofluosilicic acid presents particular storage problems, for the vapors are corrosive and will even etch glass. Containers must be kept tightly closed and vented to the outdoors. Large quantities of acid can be stored in underground or enclosed tanks equipped with outside vents. The 30 percent acid has a freezing point at 4 degrees F. The 100 percent acid will freeze at –4 degrees F. Do not store hydrofluosilicic acid containers in the hot sun where they can build hydrostatic pressure, or in open areas subject to winter freezing.

Hydrofluosilicic acid should be stored in well ventilated areas, well away from switches, contacts, and control panels. Although the acid is available in all-polyethylene drums, some suppliers continue to ship it in lined steel drums which may suffer leakage problems. Wash down all spills immediately.

When hydrofluosilicic acid is purchased in bulk, tanks are necessary for storage. Bulk storage tanks can be made of fiberglass (coated with epoxy resin) polyethylene, or rubber-lined steel. The polyethylene should be manufactured from high density crosslinked material (cross-linked provides strength). The plastic should contain a minimum of 0.25 percent ultraviolet stabilizer to protect against sun light. They are still relatively new—so the age of the tank is still to be determined. Fiberglass and rubber-lined steel tanks are used about equally for bulk storage of hydrofluosilicic acid. Fiberglass tanks usually will last about 7-10 years. Several years ago, fiberglass was the most popular. Then, the steel tanks were the most popular. Now, the polyethylene bulk storage tanks are the most frequently purchased. The steel tanks are always lined with rubber. Most linings are made of natural rubber but can be made of neoprene or butyl rubber. Butyl rubber is best, but the most expensive. The steel-rubber-lined tanks will last about 20 years.

Always wear protective safety gear when handling fluoride chemicals. The following is a list of protective clothing and equipment which is the minimum recommended for each fluoride chemical:

1. **Sodium fluoride/Sodium silicofluoride**
   a. NIOSH/MSHA approved high efficiency dust respirator (chemical mask) with soft rubberface-to-mask seal and replaceable cartridges*
   b. Gauntlet neoprene gloves (12'' glove minimum length)
   c. Heavy duty neoprene aprons

2. **Hydrofluosilicic acid**
   a. Gauntlet neoprene gloves (12'' glove minimum length)
   b. Full 8'' face shield or acid type safety goggles
   c. Heavy duty acid type neoprene aprons
   d. Safety shower/eye washer in easily accessible location (or pint bottle of eyewash solution)

Chemical respirators with cartridges for acid gases should be worn if the concentration is sufficient to cause irritation to the nose.

Spill control pillows can be used to clean up small hydrofluosilicic acid spills. The liquid is absorbed and contained within the pillow by a highly efficient ''foamed-sand'' type of absorbent, which is chemically inert and can absorb up to 10 times its weight. The pillows are commercially available in various sizes ranging from 1 to 4 liters.

Water plant personnel should regularly receive safety training on all chemicals, including fluoride. Hazards and first aid measures should be reviewed and explained. Emergency spill procedures should be established and personnel trained in the execution of those procedures.

Based on safety records, the water treatment plant personnel have one of the highest accident/injuries rate in the U.S. Until water plant managers/supervisors insist on proper safety training and utilization of safety equipment, this poor record shall continue.

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*The NIOSH/MSHA approval is given to various masks. Each brand is evaluated by NIOSH/MSHA for the proposed use and conditions.

2.12 Fluoride Exposure

2.12.1 Toxic Exposure

While potable water with fluoride levels at the recommended concentration of 1.0 ppm has been exhaustively studied and firmly established as safe beyond question, the fluoride levels to which the water plant operator can be exposed are potentially much higher. To prevent overexposure, the best safety measure is proper handling of fluoride chemicals. Proper handling implies adequate knowledge of the material, the practice of correct procedure, and the use of indicated safety equipment.

There are times, however, that the operator may be overexposed to the fluoride chemicals, especially the dusts. These overexposures, whether they occur in water or air, are called toxic exposures. There are two kinds of toxic exposures, chronic toxic exposures and acute toxic exposures. A clear distinction must be made between chronic toxic exposure from large doses of fluoride spread over a number of years and acute toxic exposure, which results from a single massive dose.

2.12.2 Chronic Toxic Exposure

The only toxic effect of low levels of fluoride over a prolonged period (2 to 8 times that of the optimal level) is mottled enamel of the teeth. At higher levels of fluoride intake, osteosclerosis, calcification of ligaments and tendons, and/or vertebrae consolidation can occur. With chronic toxic exposure from fluoride chemical dusts, there may be a general lack of appetite, slight nausea, some shortness of breath, constipation, pain in the liver region, and anemia.

Perhaps the greatest chance for overexposure to fluoride chemicals comes from the inhalation of dust generated when the feeder hoppers are being filled. To prevent over exposure during the filling operation, the operator should wear an effective NIOSH approved respirator, 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 application. The maximum allowable concentration of fluoride dust in the area (TLV) should be 2.5 mg/m^3 of air.[12,13,14]

2.12.3 Acute Toxic Exposure

Acute fluoride poisoning may result from ingestion, inhalation or bodily contact with concentrated fluoride compounds. Not a lot is known about acute fluoride poisoning caused by ingestion or inhalation because it is a very rare occurrence. Accidental ingestion is quite unlikely, but might occur by mistaking the compound for sugar or salt or through carelessness, allowing areas where food is consumed to become grossly 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 perhaps coughing or respiratory distress. These symptoms generally start at approximately 10 mg per cubic meter of air. Acid spill or splash may cause a tingling or burning sensation of the skin, or if the eyes are involved, severe eye irritation.

Ingested toxic overdoses generally cause vomiting, stomach cramps, and diarrhea. If the poisoning involves ingestion of large aounts of fluorides, the vomitus may be white (or colored if the fluoride contains dye), and the victim may experience muscular weakness, articulation difficulty, disturbed color vision, and thirst. The final stages of fluoride intoxication would include weak pulse, unconsciousness, and convulsions. Ingestion of 5 to 10 grams of fluoride (as sodium fluoride) per 154 pounds bodyweight may be fatal.[15,16]

There are many bodily functions that help prevent an acute fatal dose of fluoride. First, there are initial symptoms of severe nausea and vomiting at high levels of fluoride. Second, at lower levels, individuals in a stable fluoride balance (equilibrium) will excrete fluoride at a level approximately equal to the water concentrations.

2.12.4 First Aid for Acute Toxic Exposure

Once fluoride poisoning is established, first aid treatment should be started while waiting for medical help. The recommended first aid for ingested toxic fluoride overdose is given in Table 2-6, page 25.[17]

TABLE 2-6

EMERGENCY TREATMENT FOR INGESTED FLUORIDE OVERDOSE[17]

Milligrams fluoride ion	Treatment
Less than 5.0 mg/kg* (226 mg/100 lb)	1. Give calcium orally (milk) to relieve gastro-intestinal symptoms. Observe for a few hours. (Note: A can of evaporated milk can be kept on hand for a long period of time. 2. Induced vomiting not necessary.
Over 5.0 mg/kg	1. Move the victim away from any contact with fluoride and keep him warm. 2. If a victim is conscious, induce vomiting by rubbing back of the throat with a spoon or your finger; or use syrup of Ipecac. While vomiting, the patient should be placed face-down with the head lower than the body to prevent inhalation of vomitus. (For patients with depressed gag reflex caused by age (6 months old), Down's syndrome, or severe mental retardation, induced vomiting is contraindicated and endotracheal intubation should be performed before gastric lavage.) 3. Give the victim a glass of milk or any source of soluble calcium. (5% calcium gluconate, or calcium lactate solution). 4. Take the victim to the hospital as quickly as possible.

*Average weight/age 1-2 years = 15 kg; 4-5 years = 20 kg; 6-8 years = 23 kg.

The recommended first aid for air-borne fluorides (nose bleed) is as follows:

1. Move the victim from the exposed area.
2. Keep the victim quiet.
3. Place the victim in a sitting position, leaning forward, if possible; if that is not possible, place the victim in a reclining position with the head and shoulders raised.
4. Apply pressure directly by pressing the bleeding nostril toward the midline.
5. Apply cold compresses to the victim's nose and face.
6. If bleeding cannot be controlled by the preceding measures, insert a small, clean pad f gauze (not absorbent cotton) into one or both nostrils and apply pressure externally with the thumb and index finger. A free end of the pad must extend outside the nostril so that the pad can be removed later.
7. If bleeding continues, obtain medical assistance.

The recommended first aid for an acid splash is as follows:

1. Wash away the chemical with large amounts of water as quickly as possible. Remove the victim's clothing from the affected areas and continue washing for at least 5 minutes.
2. Where skin damage has occurred, cover the burn with a dressing bandage and seek medical attention.
3. If the eye is involved, immediately begin to wash the eye, eyelid, and face. Hold the eyelid open and wash the eye for at least 5 minutes.
4. After a thorough washing, cover the eye with a clean, dry, protective dressing and hold bandage in place, then transport the victim to a doctor.
5. All instances of eye injury require medical attention. Even seemingly minor eye injuries can leave the eye vulnerable to infections which can lead to blindness.

Keep in mind that hydrofluosilicic acid can be neutralized with sodium bicarbonate. Thus, spills which can't be washed away can be neutralized.

CHAPTER THREE

FLUORIDATION EQUIPMENT

3.1 General

3.1.1 Methods of Feeding Fluorides

Fluoride must be fed into the water supply system in liquid form or as a solution. This is true for both dry chemical feeders or solution feeders.

Fluorides can be fed into a water supply in the following ways:

1. The amount of dry chemical compound (usually sodium silicofluoride) can be measured with a machine, then added to a mixing tank (solution tank) where it is thoroughly mixed and then delivered to the main flow of water.

2. A small pump can be used to add solutions of hydrofluosilicic acid directly to the water supply system. This method can utilize the acid as delivered, or if necessary, the acid can be diluted with water to a specific strength. The dilution method is not recommended.

3. Saturated solutions of sodium fluoride in constant strengths of four percent can be produced in a saturator tank at almost any temperature of water encountered in the usual water plant. This saturated solution can be pumped with a small solution feeder directly into the main flow of water of a water supply system. The use of these devices eliminates the need for weighing sodium fluoride, measuring solution water volume, and stirring to ensure dissolving.

4. Unsaturated solutions of sodium silicofluoride or sodium fluoride may be prepared by weighing amounts of the compounds, measuring quantities of water, and thoroughly mixing them together. This method of feeding fluorides is not very desirable and should be avoided.

3.1.2 Types of Equipment

Devices for feeding fluorides accurately have generally been adapted from those machines originally designed for feeding a variety of liquid or solid chemicals in water treatment and industrial plants. In many cases, the equipment is the same.

Fluoride chemicals are always added to a water supply as liquids, but they may be measured in either liquid or solid form. The solid form of fluorides must be dissolved into a solution before entering the water supply system. Chemical feeders can therefore be broadly divided into two types: (1) Metering pumps, which are essentially small pumps used to feed a measured quantity of liquid fluoride solution during a specific time; and (2) dry feeders, which deliver a predetermined quantity of the solid material during a given time interval. The term ''metering pump'' is used in this manual for the terms ''solution pump'', ''feed pump'', and ''solution feeder''.

The choice of a feeder depends on the fluoride chemical used and the amount to be fed. The rate of feed will depend on the desired fluoride content of the treated water, the amount of water to be treated passing a given point, and the fluoride content of the untreated water. In general, metering pumps are used for smaller water supply systems and dry feeders for larger systems. There is a wide area within which either type would be equally successful.

Table 3-1 on page 27 lists the types of feeders and their capacities.

TABLE 3-1

USUAL RANGE OF FLUORIDE FEEDERS

Type of Feeder	Chemical Used	General Rate Range
Gravimetric (dry feeder)	Na_2SiF_6	2 to 5,000 lbs. per hr
Volumetric (dry feeder)	Na_2SiF_6	0.02 to 5,000 lbs per hr
Piston or centrifugal pump (metering pump)	Solutions of H_2SiF_6 Solution of NaF	18 to 5,000 lbs per hr
Diaphragm Pump – mechanical (metering pump)	Solutions of H_2SiF_6 Solution of NaF	9 to 2,500 gallons per day
Diaphragm Pump – Electronic (metering pump)	Solutions of H_2SiF_6 Solution of NaF	0.2 to 96 gallons per day
Peristaltic Pump (metering pump)	Solutions of Solution of NaF	0.5 to 85 gallons per day

3.2 Metering Pumps

3.2.1 Introduction

All pumps may be classified as steam, electrical, water power, wind power, etc., in accordance with the kind of power used to actuate them. They may also be classified as well pumps, low-service pumps, high-service pumps, or metering pumps, in accordance with the kind of service to which they are to be put; or they may be classified as positive displacement, centrifugal, impulse, or bucket pumps, in accordance with the mechanical principles of their operation.[1] For feeding fluoride solutions, as with most other water treatment chemicals, electrically powered pumps (pumps with an electrical motor) are generally used. They are classified as metering pumps, and, regarding the mechanical classification, the fluoride feed pumps almost always are of the positive displacement type. Only transfer pumps are not of this type. They are usually centrifugal pumps.

In general, a metering pump is nothing more than a small pump, of which there are almost unlimited varieties. For feeding fluoride solutions, almost any type of metering pump which is used for feeding other water treatment chemicals can be used with, at most, only minor modification in construction details. If there is, indeed, any requirement for a fluoride metering pump which distinguishes it from metering pumps for other purposes, it is the accuracy and constancy of delivery required. The optimal fluoride level has been prescribed between very narrow limits and thus requires that the fluoride be added in precise proportion to the quantity of water being treated. This requirement favors the positive displacement type of metering pump.

A positive displacement pump, as used in waterworks, is a device that draws in and expels liquid as a result of the alternate filling and emptying of a closed chamber. It delivers a specific volume of liquid for each stroke of a piston, diaphragm, etc. Of course, very few metering pumps deliver replicate volume under all conditions, for such factors as pressure and viscosity can affect the volume displaced by the driving member of the pump. However, by using fluoride solutions of fixed strength, by feeding against a fixed pressure, and by pumping usually into a constant flow of water, the positive displacement metering pump has shown sufficient reliability. The positive displacement pump has a problem that if the line becomes plugged for any reason, the pump continues to operate until something breaks. (The one major exception to this is the electronic metering pump.)

Ordinarily, such solution feeding devices as centrifugal pumps, bucket pumps, gravity feed pumps, pot feeders, or head tanks and orifice are not used for fluoridation because of their relative inaccuracy. There are several types of rotary pumps which qualify as positive displacement feeders. These include gear, swinging-vane, sliding-vane, oscillating screw, eccentric and cam pumps, and various modifications of these pumps. They generally are not used in fluoridation either.

The criteria used in selecting a metering pump are capacity, corrosion resistance, pressure capability, accuracy, and durability. A point to consider is that most pumps perform most accurately near mid-range of both stroke length and stroking frequency and should be selected accordingly.

Most metering pumps come equipped with plastic heads and resilient check valves, which are generally satisfactory for discharge pressures up to 100 psi. For higher pressures, corrosion-resistant alloys such as 316 stainless steel or Carpenter 20 alloy are required for metering pump head construction. The type of plastic the metering pump heads should be made of depends upon the fluoride chemical used. Acrylic, polypropylene, and PVC heads can be used for hydrofluosilicic acid as well as sodium fluoride and sodium silicofluoride. In addition, Kynar, Ryton, and Tril heads can also be used with sodium fluoride and sodium silicofluoride. Metering pump heads of stainless steel (S.S.) 316 and 304, as well as the 20 series S.S. alloys, can be used with all three fluoride chemicals.

The check valves can be made of ceramic, Teflon, or 316 stainless steel. If hydrofluosilicic acid is used, then the check balls and spring must be coated with Teflon or its equivalent. The acrylic head is one of the most popular heads on metering pumps used in water fluoridation.

The volume of solution pumped by most metering pumps is adjusted by both 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 in selecting the size of the pump for a particular application.

In all types of metering pumps, a pulsating flow of chemical solution into the water line will occur because of the reciprocating nature of the operating mechanism. Ordinarily, this is not objectionable if variations in fluoride levels cannot be detected in the distribution system. However, if the closest consumer to the water plant has drinking water with a fluoride level varying more than 0.1 ppm, then a method to suppress this variation should be provided. This can be done in three ways: (1) A mixing basin or detention tank can be inserted in the line after the point of application of the fluoride solution, or an in-line static mixer can be added; (2) the frequency of metering pump stroking can be increased—this will also require a proportional reduction in the amount of solution delivered per stroke; (3) or dual metering pumps can be used so that the feeding stroke of one will occur during the intake stroke of the other—this plan may require a dilution of the fluoride solution. The last method is usually not considered very desirable.

Many manufacturing companies recommend that their metering pumps operate with a "flooded suction." This means the pump should be located below the level of the storage vessel. In fluoridation, it is important that the pumps never operate below the level of the storage vessel because of the danger of back-siphonage and overfeeding the fluoride chemical.

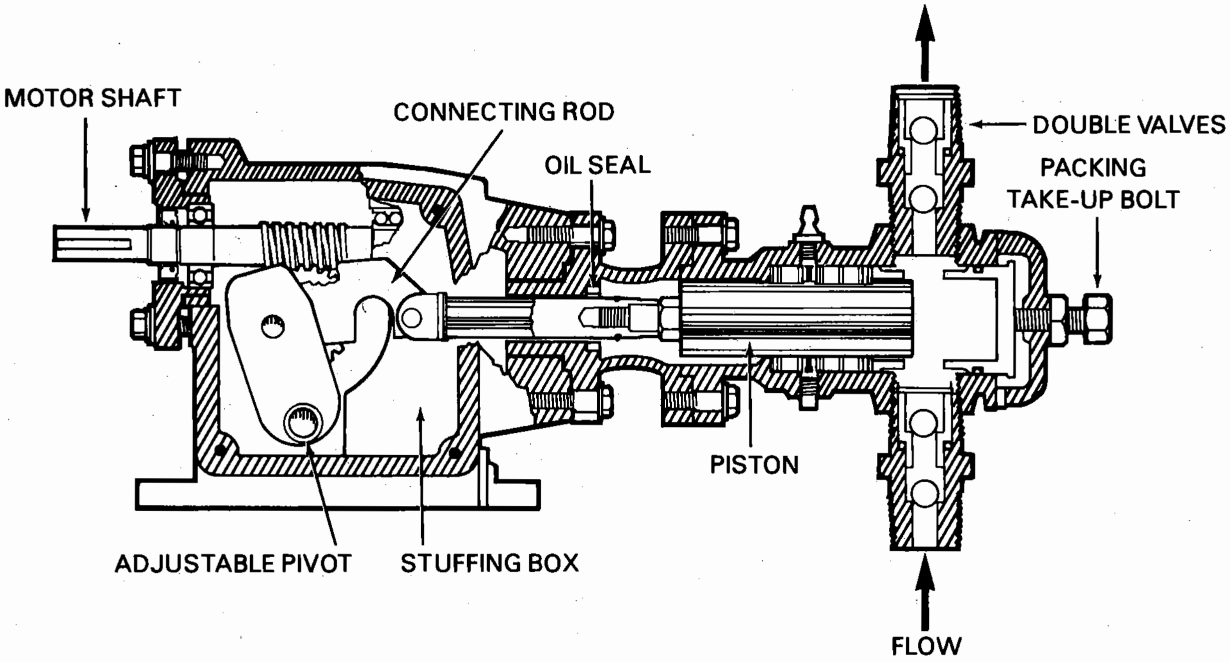
There are three types of positive displacement metering pumps which are commonly used in water fluoridation: the piston pump, the peristaltic pump, and the diaphragm metering pump.

3.2.2 Piston Metering Pumps

In a piston pump a reciprocating piston or plunger alternately forces solution from a reservoir into and out of a chamber. See Figure 3-1 on page 29. An eccentric cam driven by a motor pushes the connecting rod crosshead and plunger out from the center of rotation in a straight line. When the mechanical drive for the pump is an electric motor, then a gear box or system of belts and pulleys determines the number of strokes in a given time interval. Pneumatic or hydraulic drives are also available.

The piston metering pump, frequently called a plunger metering pump, is generally used for discharging fluoride solution in water lines with pressures greater than 100 psi. Some pumps can discharge into water lines with pressure as great as 4,000 psi or more. It is also much more expensive, and thus is not as popular as the diaphragm pump. One disadvantage of the piston type is the presence of a stuffing box, which must

FIGURE 3-1
TYPICAL PISTON METERING PUMP



be designed to resist the pressure of the solution being fed so that no objectionable leaks occur around the piston.

3.2.3 Peristaltic Metering Pumps

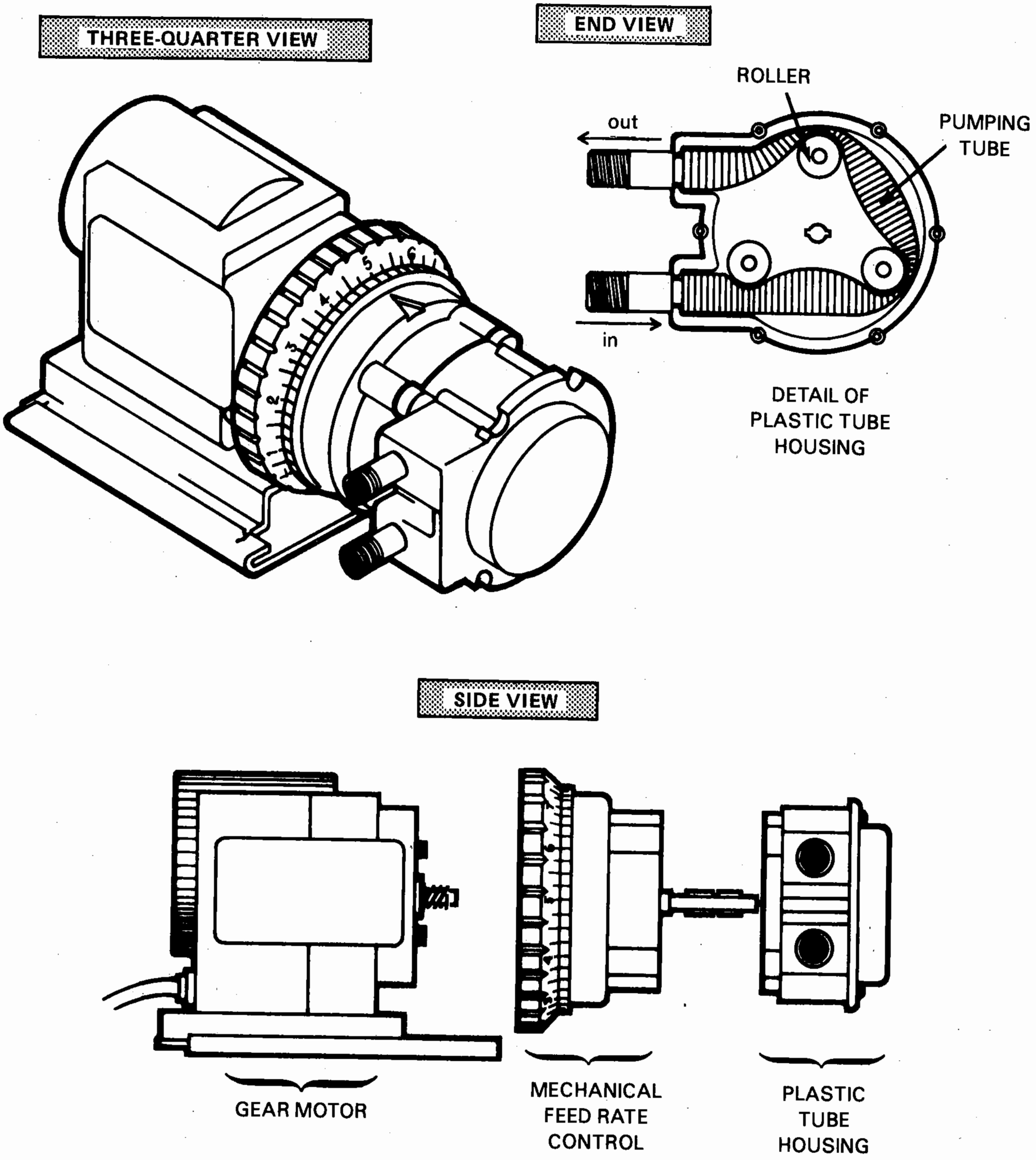
A peristaltic metering pump is a positive displacement pump that uses the alternating waves of contraction and dilation of a plastic tubing to move liquid (fluoride solution) through the tubing into the water line. (This is the peristaltic principle similar to the action of the large intestines in the human body). A rotary gear rolls over the plastic tubing creating a suction on the solution side of the feeder. Thus, fluoride solution is drawn in one end of the tube and is forced out the other end.

The peristaltic pump is adjusted by means of a dial ring and the size of the tubing. At full setting of the dial, the rotor turns continuously. At lower settings of the dial, the rotor starts and stops, moving at slower intervals. At the lowest setting, the rotor moves in very small jerks. The tubing size ranges from 1/8 inch to 1/4 inch with the standard size tubing being 3/16 inches. The tubing also comes in low pressure (up to 20 psi) and high pressure (up to 100 psi) types. The high pressure type tubing is used for most pumps designed for fluoridation.

The peristaltic metering pump is self-priming and will not be damaged by the freezing of the solution being pumped. The range of feed is from .5 gallons per day up to 85 gallons per day. The tubing is designed to last from one to 2 years, depending upon usage. Proper installation of the correct type of tubing is very important.

Peristaltic pumps are generally used in small fluoridation systems. They are not widely used at the present time, but in some parts of the country (and overseas) they are quite common. They have several advantages over the diaphragm pump because the check valves, diaphragm, and back siphonage devices are all eliminated. The most frequent problem with the peristaltic pump is the short durability or life of the tubing. See Figure 3-2 on page 30.

FIGURE 3-2
TYPICAL PERISTALTIC METERING PUMP



3.2.4 Diaphragm Metering Pumps

3.2.4.1 Introduction

The diaphragm pump is by far the most common type of metering pump used in fluoridation. A flexible diaphragm is driven to alternately force solution out of a chamber, and on the return stroke, the diaphragm refills the chamber by pulling solution from a reservoir. In a typical diaphragm pump there is no chemical packing which would result in leaking through a packing gland. Typically, a diaphragm is made of Hypalon, Teflon, polyurethane, or Viton.

Diaphragm pumps are ideally suited for medium-pressure service—up to about 125 psi (pounds per square inch). They should not be used against pressures less than about 15 psi and never against a vacuum, such as that obtained in the suction side of a well pump. A constant positive pressure on the discharge is a guarantee of their continued accuracy. Some metering pumps are equipped with spring-or rubber-loaded discharge valves that assure the maintenance of such positive pressures. Negative suction heads should not exceed 4 feet. In other words, the metering pumps should be no more than 4 feet above the solution container.

Diaphragm pumps are driven by almost any source of power such as: electric motors of various speeds, hydraulic pressure, solenoid, etc. The principal characteristic of such prime movers is that they are operated at a constant speed proportional to the quantity of water to be treated.

Three common types of diaphragm metering pumps are used in fluoridation: Mechanically-driven, hydraulic, and electronic. Other types are available, such as water-powered, pneumatic-driven, etc., but they are rarely used in water fluoridation.

3.2.4.2 Mechanical Diaphragm Metering Pumps

In the mechanical-driven diaphragm metering pump, the eccentric-push rod assembly is the heart of the system. See Figure 3-3 on page 32. An eccentric mechanism converts rotary motor input to a reciprocating push-rod motion. The motor drives an input shaft via pulleys. A worm on this shaft engages a worm gear on an eccentric shaft to rotate the eccentric. A ring, driven by the eccentric, drives the diaphragm push rod. Forward motion produces the discharge stroke. A heavy spring returns the push rod for the suction stroke. An adjustable return-stroke stop varies the stroke length.

As with all diaphragm pumps, the alternating motion forces solution out of a chamber, and, on the return stroke, refills the chamber by pulling solution from a reservoir. Again, as is typical of all other diaphragm pumps, the back pressure (main water line pressure) which these pumps operate will range from 15 psi to 125 psi. Some brands of mechanical diaphragm pumps can operate with a back pressure up to 150 psi. SCR variable feed drives, or automatic stroke control, are available to add on to most pumps.

Some companies produce a mechanical-driven metering pump with two diaphragms and a fluid, generally silicone oil, between them. This is done to provide a measure of safety for the drive mechanism. A break in the main diaphragm will allow only the silicone oil to be contaminated. But, this type pump is still a mechanical-driven pump, not a hydraulic metering pump. It is commonly confused with the hydraulic pump.

3.2.4.3 Hydraulic Diaphragm Metering Pumps

In a hydraulically-actuated diaphragm metering pump, a plunger, reciprocating at a fixed stroke, displaces hydraulic fluid which creates the pumping action. The capacity of the pump is regulated by controlling the volume of hydraulic fluid which passes through a valve. A diaphragm separates the oil from the fluoride solution. The diaphragm is free to move in exact response to the volume displaced by the piston, but the diaphragm does not do any actual work. It acts only as a separator. Consequently, the displacement of the oil is translated into an equal amount of fluoride solution displacement.

The reciprocating action of the piston causes the product to enter through the suction check valve as the piston travels to the rear of its chamber. A like quantity of product is discharged through the discharge check valve on the forward stroke of the piston. See Figure 3-4 on page 32.

FIGURE 3-3
TYPICAL MECHANICAL DIAPHRAGM METERING PUMP

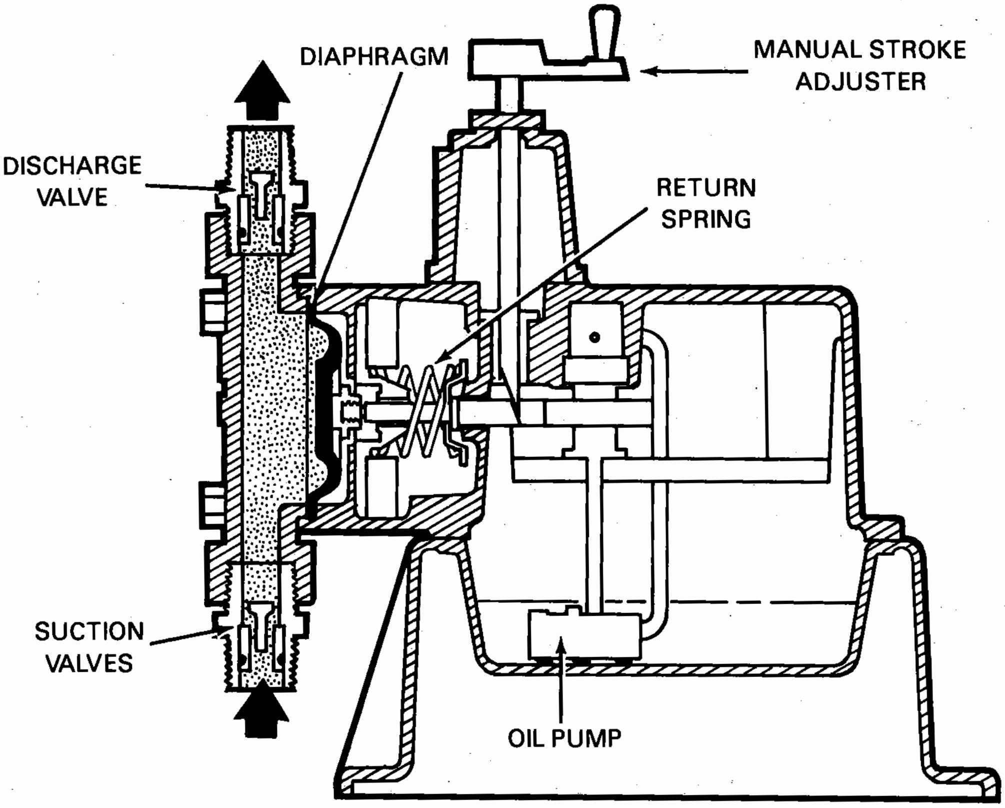
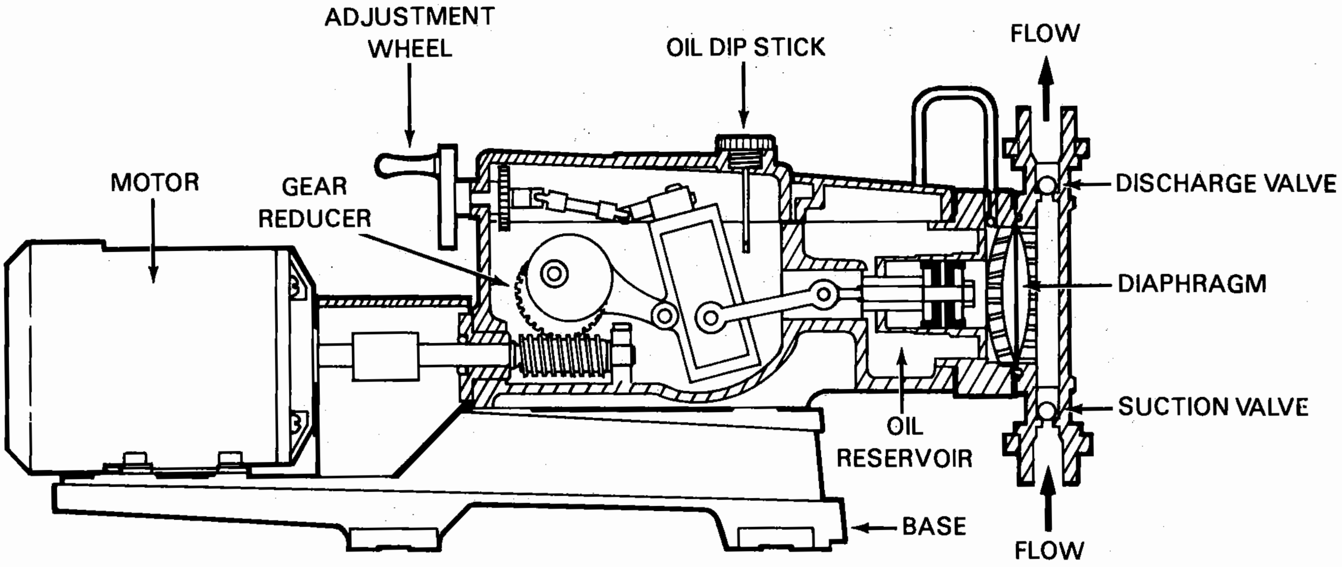


FIGURE 3-4
TYPICAL HYDRAULIC DIAPHRAGM METERING PUMP



Generally adjustments in pumping rates are made manually but can be done automatically by instrument signal. While most diaphragm pumps require only a minimum discharge pressure (back pressure) of 15 psi, some hydraulic metering pumps will require at least 50 psi pressure. As with most diaphragm pumps, they will discharge into water with pressures up to approximately 125 psi, although the more expensive hydraulic metering pumps can discharge into pressures up to 2,000 psi.

3.2.4.4 Electronic Diaphragm Metering Pumps

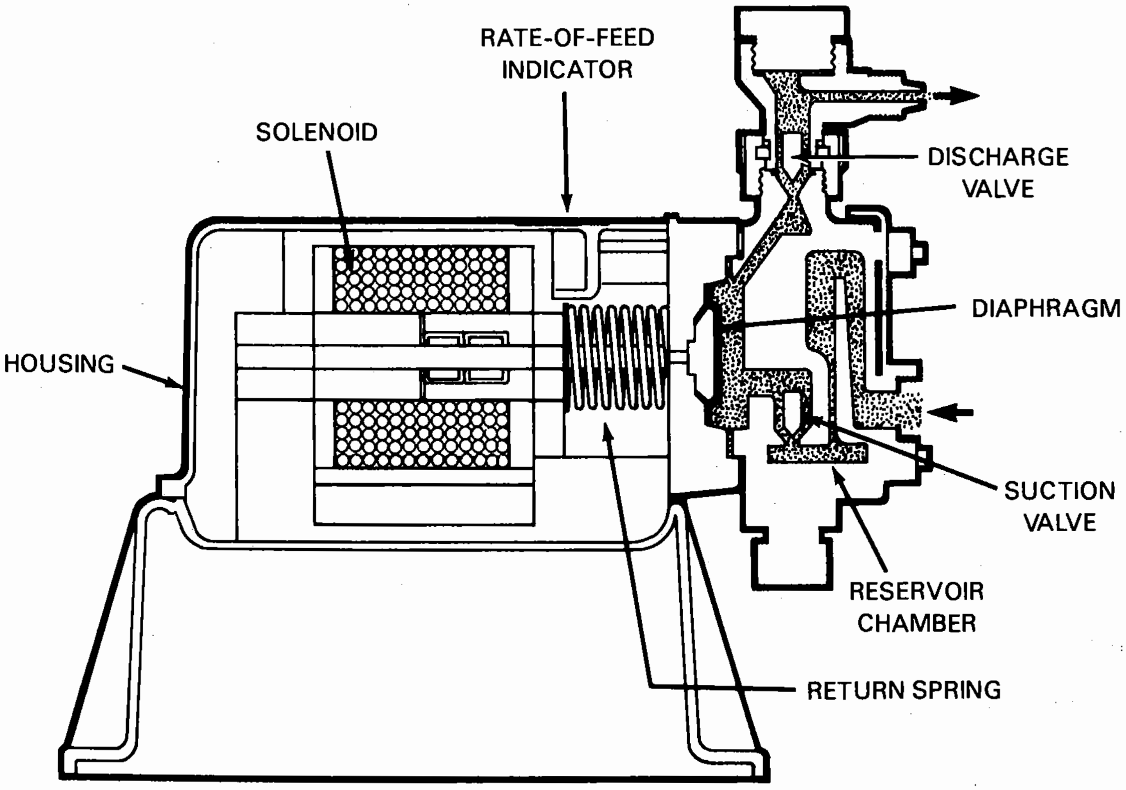
The electronic diaphragm metering pump is the newest and most popular fluoride metering pump in the field today. The pump has gained rapidly in acceptance because it is ideal for smaller flow rates—thus, it predominates in small fluoridated water systems and in school fluoridation systems.

The electronic metering pump is a special version of a diaphragm pump. See Figure 3-5 below. Most diaphragm pumps used for fluoridation, as explained in the previous sections, have a flexible diaphragm driven by a mechanical linkage. In the electronic metering pump, a solenoid armature that is periodically energized moves the flexible diaphragm. It has solid state electronics, circuit breakers, and built-in potentionmeters. The stroke is extremely short with a maximum stroke length of 1.25 mm. Thus, the diaphragm is practically free of wear even during continuous prolonged operation.

Another characteristic of the electronic pumps is the fact that a blocked or plugged line during operation will not break or burn up the pump because there is no mechanical linkage. When the back pressure in the line exceeds the strength of the magnetic force developed by the power coil, the pump simply stops stroking, and no damage will occur to the pump. Yet, the electronic diaphragm pump is still considered a positive displacement pump.

There are several other advantages to the electronic metering pump over other diaphragm pumps: There is only one moving part—the armature-diaphragm assembly; they can be easily adapted to automatic controls;

FIGURE 3-5
TYPICAL ELECTRONIC METERING PUMP



and the actual speed of each discharge stroke remains the same, no matter how low the stroke frequency is set. Also, both the stroke length and stroke frequency are adjustable and have a multiplying effect. A practical adjustability range of 200 to 1 is common. The electronic pumps generally do not require lubrication. And finally, electronic pumps use power only during the discharge portion of the stroke, thus causing minimum electrical consumption and low heat generation.

3.2.5 Calibration of Metering Pumps

Metering pumps usually have name plates or a chart showing their pump capacity. If this unfortunately is not available, then, the pump must be calibrated by adjusting the pump to various settings and measuring the amount of solution pumped during the measured time intervals. This should also be done periodically to verify the delivery rate of a metering pump or to make adjustments when the feed rate is too high or too low.

Simply measuring the output from the discharge outlet of the metering pump is unsatisfactory, since even the output of so-called positive displacement pumps varies with pressure. One acceptable way is to measure the volume of the liquid being pumped, preferably in a graduated cylinder (without losing prime or spilling any solution). Feed for a timed interval, withdraw the suction tube and note the volume of solution remaining. The difference will represent the volume fed during the measured interval. By adjusting the feeder to various scale settings, a calibration chart or curve can be developed which will be representative of the pumping conditions and the chemical pumped at the time.

Another way to calibrate a metering pump that is superior to the above method, especially with acid solutions, is to equip the solution tank with a calibrated sight glass. By closing the valve between the sight glass and tank (the sight glass is outside the tank, parallel to the side) while the metering pump is operating normally, solution will be withdrawn from the sight glass only, and the volume over a timed interval can be calculated. This system has the advantage of freedom from interruption of the fluoride addition as well as avoiding direct contact with the chemical being fed. After the measurement, opening the valve will be all that is necessary to resume normal feed.

The rate of feed in milliliters per minute can be calculated from the feed rate in pounds per day. Once the feed rate has been calculated in pounds per day, it is a simple matter to determine the metering pump feed rate in ml/min. Please see the fluoridation calculation section (Section 4.2) for the step-by-step calculations.

3.3 Saturators

3.3.1 Introduction

The saturator is a type of chemical feed equipment that is unique to fluoridation. The principle of a saturator is that a saturated fluoride solution will result if water is allowed to trickle through a bed containing a large amount of sodium fluoride. A small pump then delivers the solution of sodium fluoride into the water supply system. Although saturated solutions of sodium fluoride can be manually prepared, an automatic feed solution is recommended.

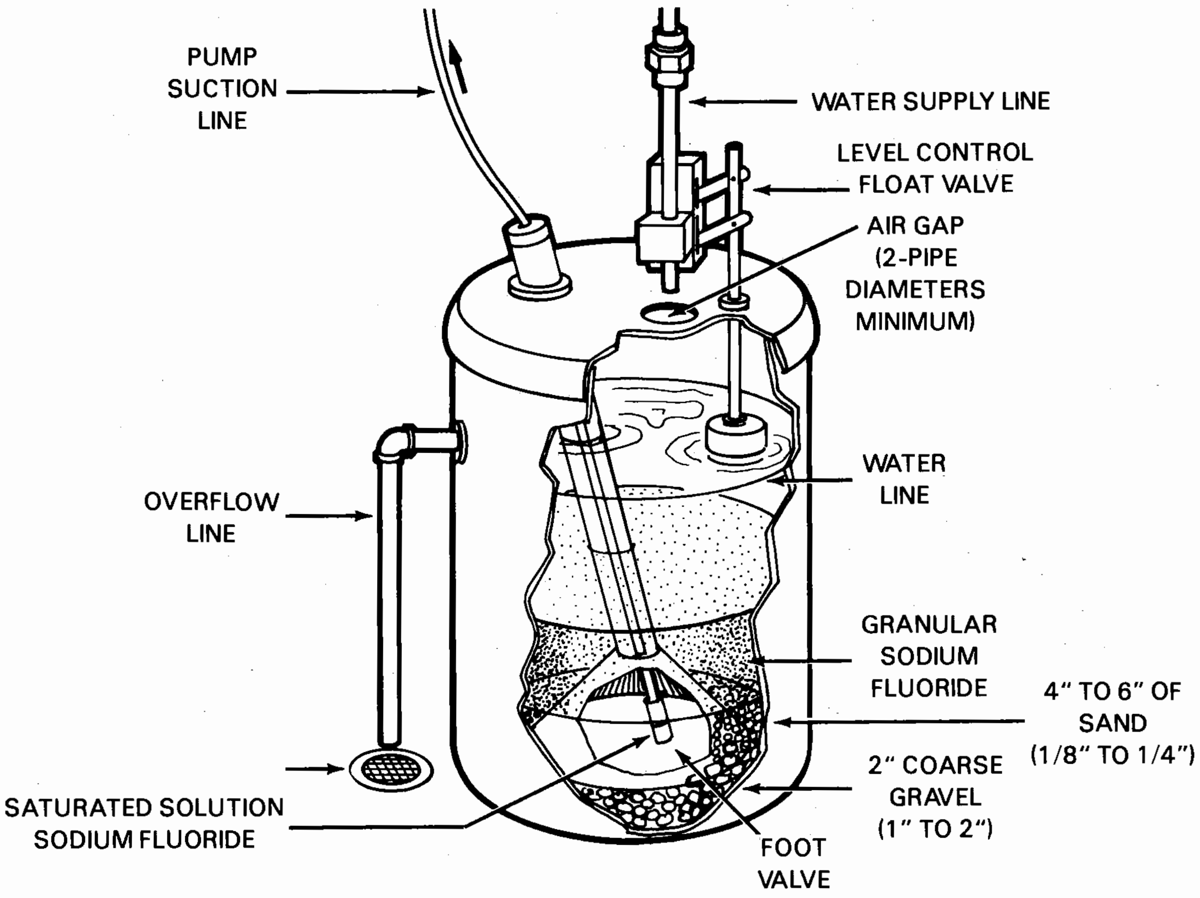
There are two kinds of saturators: upflow and downflow. The downflow saturator was developed in the late 1940's by Proportioneers Incorporated and engineers in the U.S. Public Health Service. It did not receive wide application until the late 1950's and early 1960's. In the mid-1970's, the upflow saturator was developed, and by the late 1970's, was becoming more popular than the downflow. After 1980, the downflow saturator was no longer manufactured by any company and has been replaced in most States by the upflow saturator.

3.3.2 Downflow Saturators

In a downflow saturator, a bed of granular sodium fluoride is placed on layers of sand and gravel to prevent particles of undissolved sodium fluoride from infiltrating the solution area under the cone or within the pipe manifold. The metering pump draws the solution from within the cone or manifold at the bottom of the plastic drum. See Figure 3-6 on page 35.

When a downflow saturator is in operation, water is admitted at the top of the saturator tank (an air gap avoids the possibility of a cross-connection) and the level is regulated with a float-operated controller. The

FIGURE 3-6
TYPICAL DOWNFLOW SATURATOR



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 where it is withdrawn by the metering pump. The only operator attention required is to see that an adequate quantity of sodium fluoride is kept in the saturator and that the saturator is kept in a reasonably clean condition.

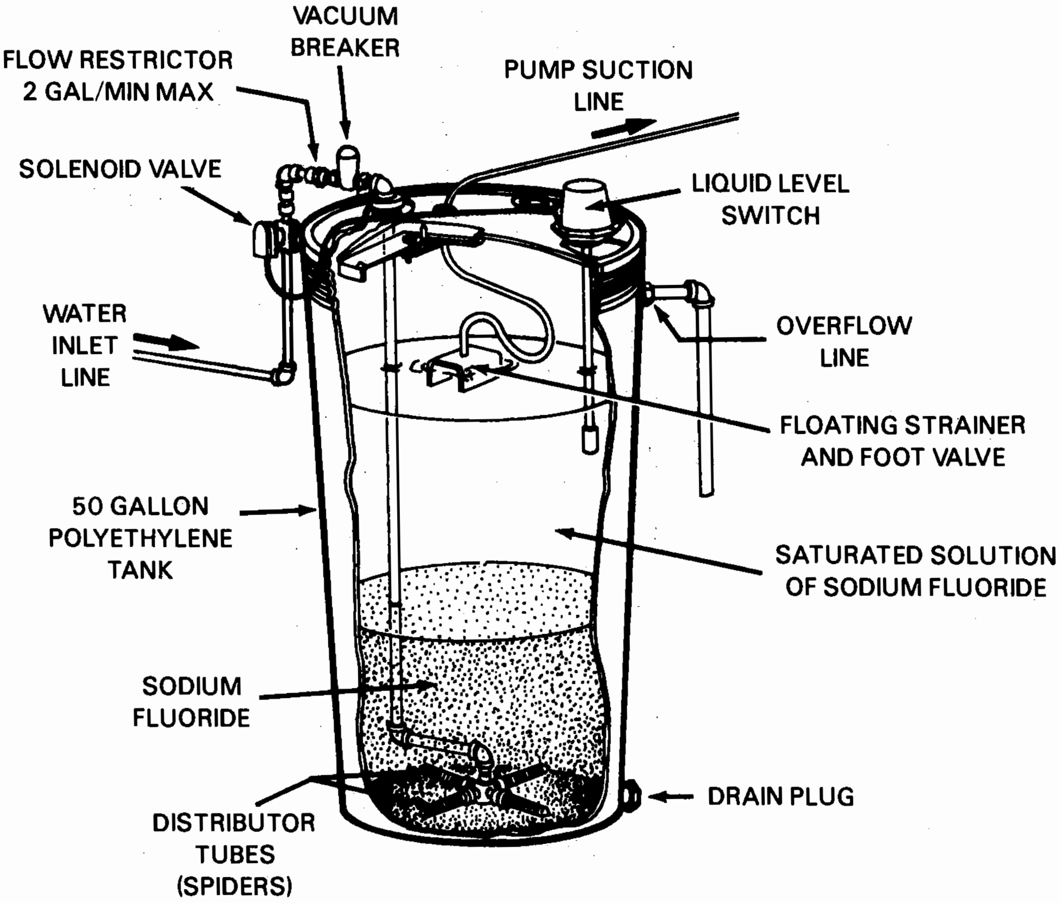
3.3.3 Upflow Saturators

In an upflow saturator, the layer of sand and gravel is eliminated, and the bed of undissolved sodium fluoride is placed on the bottom of the tank. See Figure 3-7 on page 36. 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 the sodium fluoride bed at a controlled rate to assure the desired 4 percent solution. The metering pump intake line floats on top of the solution in order to avoid withdrawal of undissolved sodium fluoride. The water pressure requirements are 20 psi minimum to 125 psi maximum, and the upward flow must not exceed 2 gpm. Since introduction of water to the bottom of the saturator constitutes a definite cross-connection, a mechanical syphon-breaker must be incorporated into the water line.

3.3.4 Venturi Saturators

The majority of the community water systems that use saturators, uses either upflow or downflow types. But in the 1970's, John Leo, an Indian Health Service (USPHS) engineer, designed a venturi-type of fluoride feed system.[2] Because of unique problems with the conventional saturators (primarily varying fluoride levels) on many Indian reservations, the venturi saturator was developed. Although a majority of Indian Health Service fluoridated systems use either an upflow or downflow saturator, some systems are now using the venturi saturator.

FIGURE 3-7
TYPICAL UPFLOW SATURATOR



The saturator operates using a venturi to move the feed water through a zeolite water softener, then through a bed of sodium fluoride, and back into the water main. See Figure 3-8 on page 37. Because of the configuration of the venturi, the water pressures at the point where the feed water enters the venturi is greater than at the point where the saturated solution enters the venturi. This differential pressure causes feed water to flow through the softener and saturator. A screw micro-meter type needle valve is located in-line between the softener and the saturator. This valve allows accurate adjustments of the feed water flow rate. An encrustation removal plunger located on the venturi will remove any salt build-up in the orifice throat. The plunger can be used without taking the venturi system out of service. Using the plunger once every 2 to 3 weeks should be adequate for the removal of any salt build-up.

There are several advantages of the venturi over conventional fluoride feed systems. First, there is no possibility of accidental overdoses or slugs of fluoride being induced into the distribution system when the main water pump is inoperative. Also, since the unit is non-electrical, it can be installed anywhere, including water supplies that have a spring as a source. The fact that the tank containing fluoride is made of a clear plexiglass enables the operator to visually inspect the level of chemical at any time and replenish it.

Joseph Olguin, another IHS engineer, has also been developing a modification of the venturi.[3] See Figure 3-9 on page 38. The principle is the same, but the operation is somewhat different. Two bottle shaped fiberglass tanks are used. The water flows from the main line through a salt vat through the first tank with zeolite, and through the second tank with sodium fluoride. The salt vat is normally empty but can be filled with salt to regenerate the zeolite softener. Again, a needle valve is used to control the final fluoride levels. Water flows through each tank through two pipes, a 1/2 inch perforated PVC pipe inside a solid 3/4 inch PVC pipe.

FIGURE 3-8
VENTURI SATURATOR (LEO)

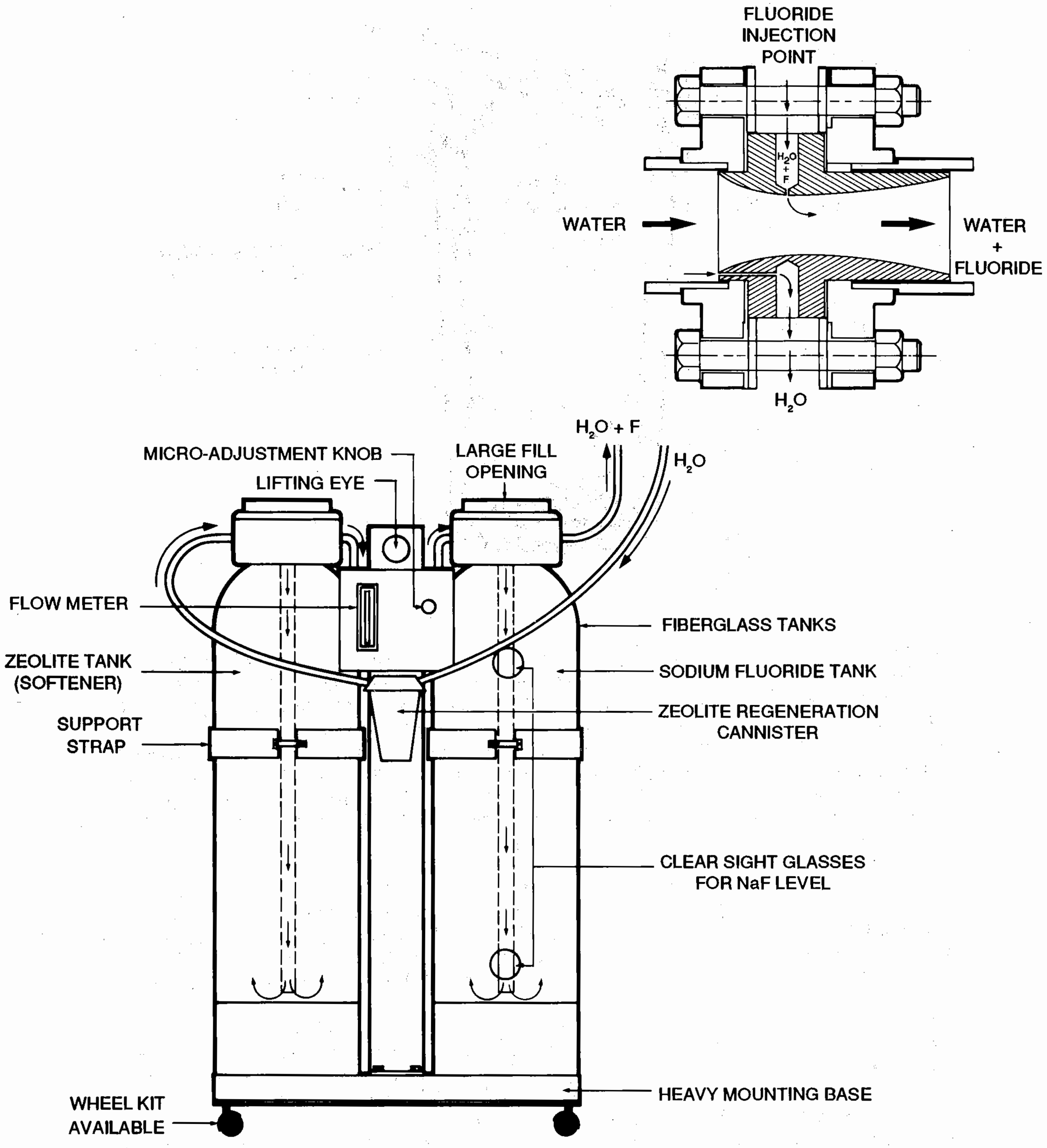
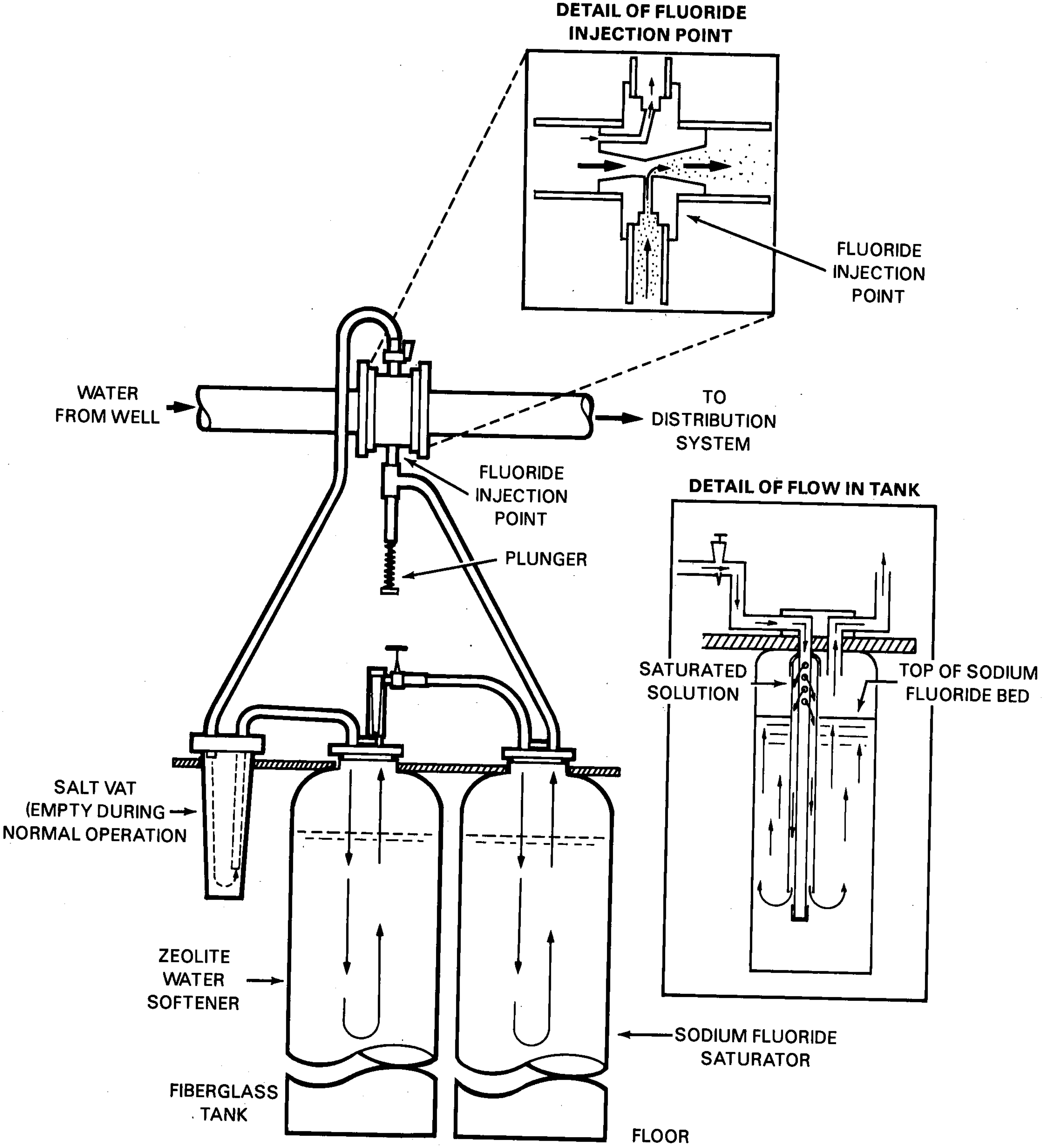


FIGURE 3-9
VENTURI SATURATOR (OLGUIN)



Both venturi saturators probably will change in design over the next few years. In the future, the designs of both venturi saturators may be combined into one unit.

3.3.5 Liquid Level Switches

Liquid level switches, or controllers, are used to automatically maintain preset (fluoride) liquid levels in sodium fluoride saturators. In rare instances, they are used with hydrofluosilicic day tanks when these are filled from a bulk storage tank or with dry feeder solution tanks. The switches keep the tanks from going dry or overflowing, and may also be used to prevent a metering pump from running dry. The switch may be of the manual (lower cost) or electrical (higher cost) type. See Figure 3-10 on page 40.

Several different types of switches are on the market today and work on different principles: mercury, air pressure, electrode, conductivity, and encapsulated reed. Most newer models today are electrical (12 or 115 volt) and are wired to control a solenoid valve (electrically operated open-close valve), on a water line to a saturator. The manual type requires no electricity and uses water pressure or a float valve to activate a type of ball cock, similar to the common float valve in a water closet.

Liquid level switches are adjustable and the high and low levels may be changed as necessary, however, the high liquid level must be set below the overflow pipe. The overflow should terminate in an air gap arrangement so the operator will notice any malfunction and take steps to prevent any overflowing.

3.3.6 Softeners

When a fluoridation system uses a sodium fluoride solution (primarily a saturator) remember that while sodium fluoride is quite soluble, the fluorides of calcium and magnesium are not. Thus, the fluoride ions in solution will combine with calcium and magnesium ions in the make-up water and form a precipitate which can clog the metering pump, the injection point, the metering pump suction line, the saturator bed, etc. For this reason, water used for sodium fluoride saturators should be softened whenever the hardness exceeds 50 ppm or even less if the amount of labor involved in clearing stoppages or removing scale is objectionable. Remember—the entire water supply need not be softened—only the water used for solution preparation (the make-up water).

Two types of softening treatment are available: ion exchange and the use of polyphosphates (calgon, micromet, etc.). The ion exchange method removes excess hardness. Polyphosphates are used for sequestering (keeping in solution) calcium and magnesium and other hardness elements. The amount required usually ranges from 5 to 12 mg/l, although new more efficient types of polyphosphates are now available. They are fed at a rate of 1-1/2 mg/l to 2 mg/l. The polyphosphate may be added directly into the solution tank, or, in some cases, a metering pump will be required.

The ion exchange method removes excess hardness by using a zeolite medium or synthetic resins. Since the volume of water to be softened is usually quite small, a household type of zeolite softener is usually adequate. This type of softener can be installed directly in the pipeline used for solution make-up water. When the softening capacity is exhausted, the zeolite (or synthetic resin) can be regenerated with brine made from common salt. See Figure 3-11 on page 41.

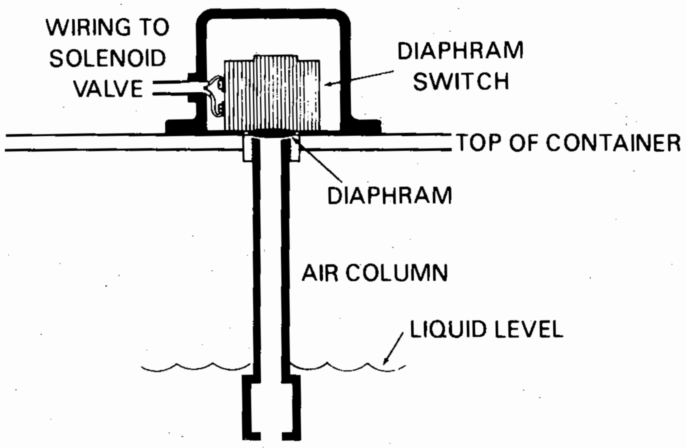
When the softener is in service, it is strongly recommended that a complete recharge program be performed before the softener runs out of capacity. This is important in order to protect the conditioning media from injury and to maintain its capacity. For example, waters containing corrosive hydrogen sulfide can strip and permanently damage the media if the capacity of the filters is allowed to exhaust. Iron bearing waters, too, can cause an exhausted media bed to become impacted and fouled with chunks of rust. If these conditions are allowed to develop, the result will be a noticeable reduction in capacity and poor performance.

The pH of the water supply is an important consideration and should be checked closely before the equipment is installed. Water having a pH value below 6.5, for example, can be corrosive to the conditioning media.

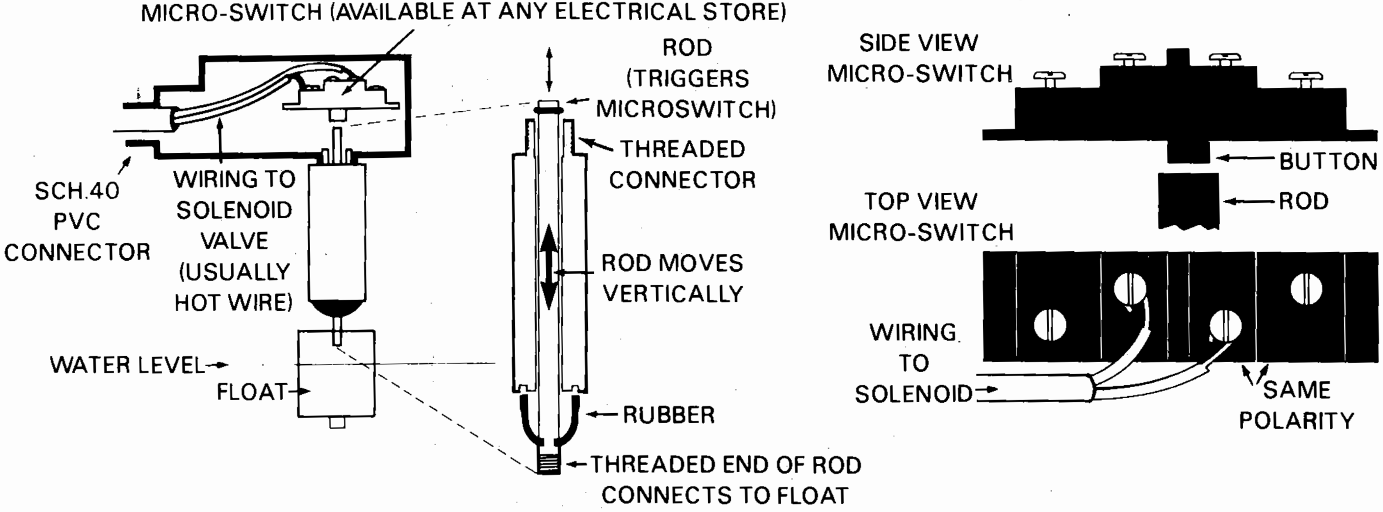
A bypass system is a necessary part of the installation and is used to divert the flow of water around the conditioner during recharge and/or servicing. A drain line is also essential. It is used during recharge to direct the flow or regeneration of water to a suitable waste outlet.

FIGURE 3-10
LIQUID LEVEL CONTROLLERS

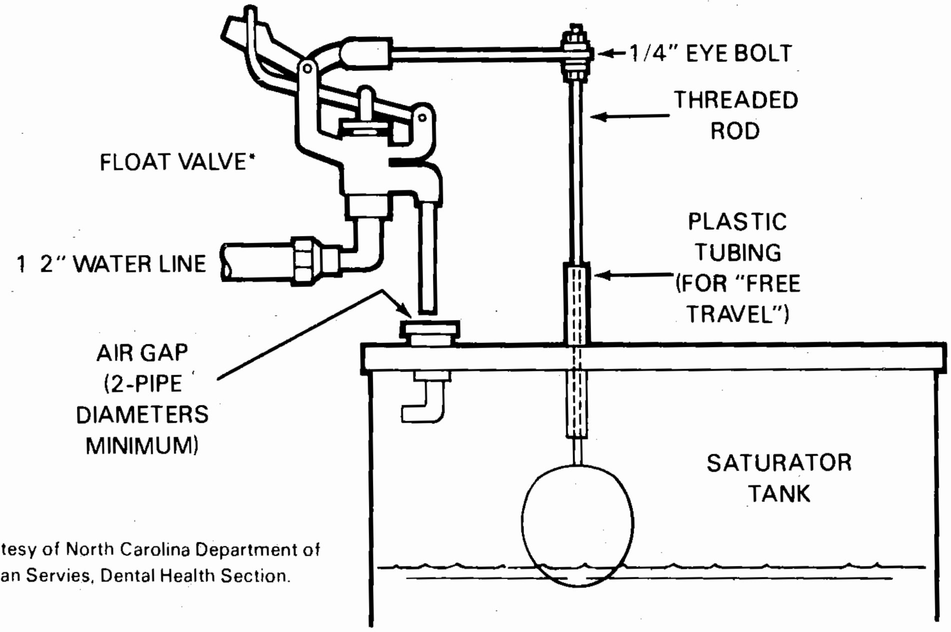
PROBE



MICRO-SWITCH

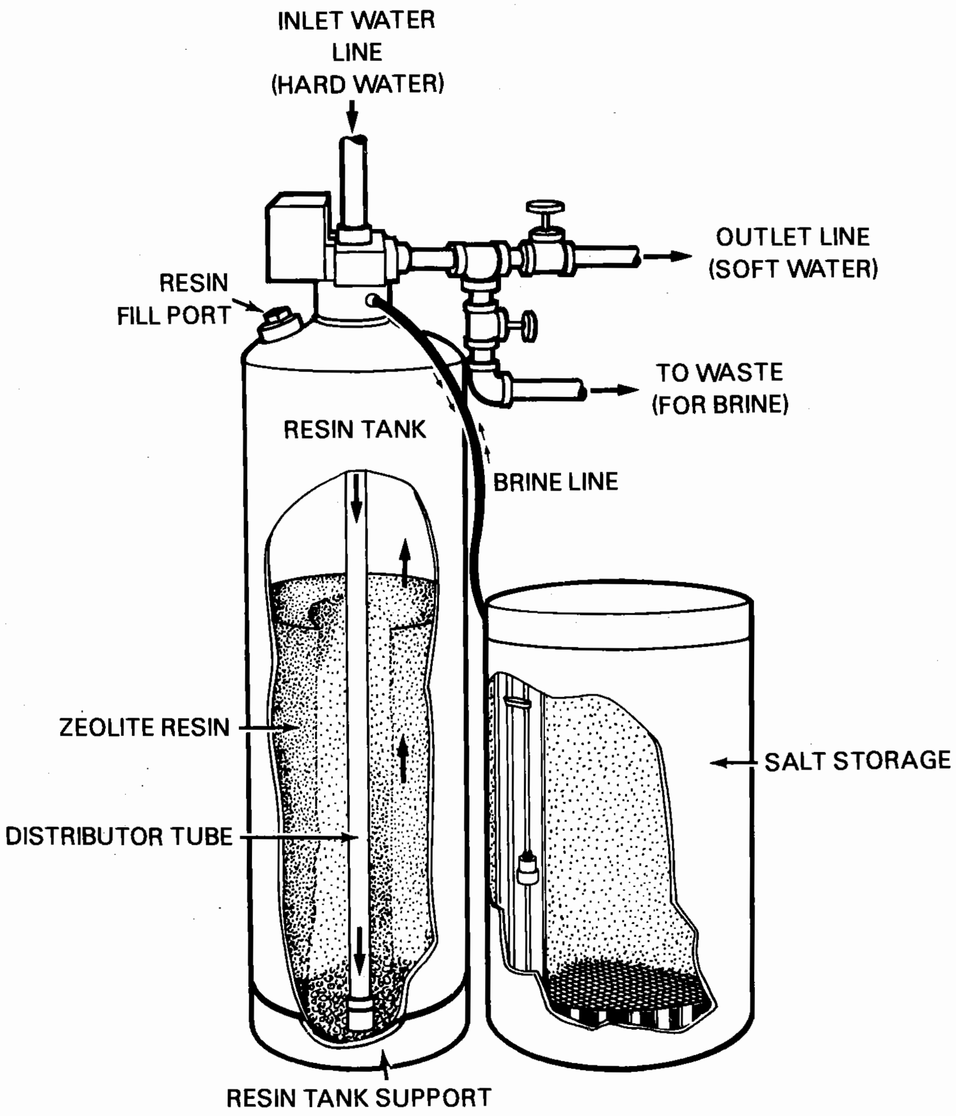


FLOAT VALVE



*Courtesy of North Carolina Department of Human Servies, Dental Health Section.

FIGURE 3-11
ZEOLITE WATER SOFTENER



The water pressure to the softener should be checked. Most manufacturers recommend operation between 20 psi and 100 psi.

3.4 Dry Feeders

3.4.1 Introduction

Dry chemical feeders deliver a predetermined quantity of fluoride chemical in a given time interval. Th are two types of dry feeders, volumetric and gravimetric. The volumetric dry feeder delivers a meas *volume* of dry fluoride chemical per unit of time and the gravimetric dry feeders deliver a measured *we* of chemical per unit of time.

Many water treatment plants that treat surface water (rivers, lakes, reservoirs, etc.) will utilize dry feede add other chemicals to the water. Thus, many surface water plants will consider using dry feeders fluorides to be consistent with their other equipment. In fluoridation, dry feeders are used to feed sodiu silicofluoride almost exclusively. Very few water supply systems use sodium fluoride because the high cost of this chemical usually dictates the use of sodium silicofluoride.

3.4.2 Volumetric Feeders

Volumetric feeders essentially consist of a combination of a driving mechanism for delivering a constant volume of dry compound, a hopper for holding the compound, and a chamber for dissolving the compound before discharge into the water supply.

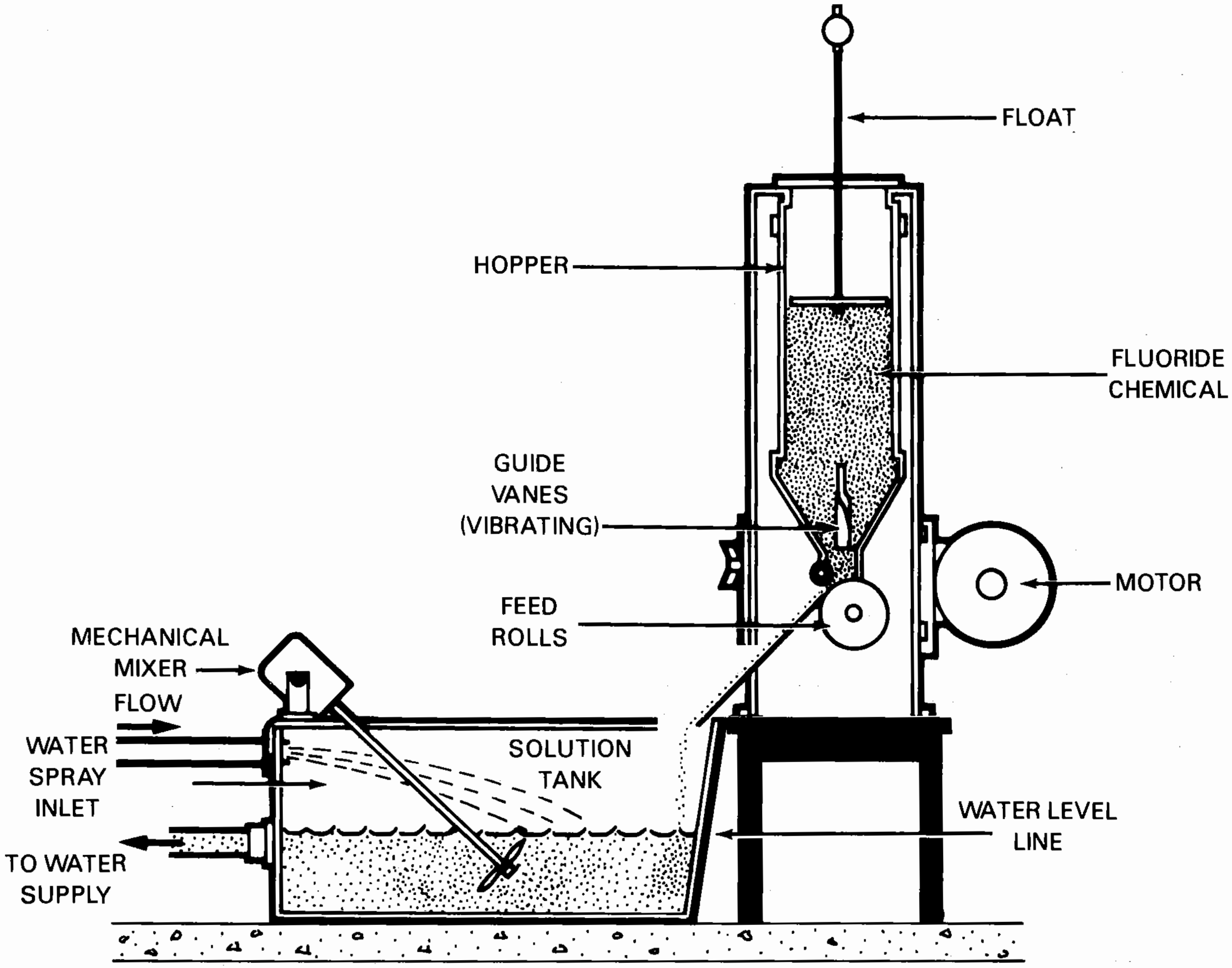
The chemical delivery mechanism distinguishes one type of volumetric feeder from another. Almost every manufacturer has a different design for feeding chemicals volumetrically and can be classified according to several types: rotating disk, oscillating pan, vibratory pan, rotating screw, rotating roller, star wheel, and combinations of these types.

Brief descriptions of the various types are given here merely to indicate the broad principles of operation. More complete details are readily obtainable from the manufacturers.

The roll-type feeder with a feed slide adjustment was one of the most widely used feeders, particularly in smaller plants. See Figure 3-12 below. They are not as popular today as the screw-type feeders. In the roll-type feeder, the fluoride chemical is placed in the hopper through a top opening. From the hopper, it flows by gravity to the feed rolls.

Stainless steel feed rollers which are driven in opposite directions form the material into a smooth ribbon of uniform thickness. The feed rate is adjusted externally on a graduated feed slide by varying the width of this ribbon. If the feeder is equipped with a variable speed drive, it has no feed slide. The feed rate is then adjusted by changing input rpm to the three-speed gearbox. Material leaves the rolls at a uniform rate, falls into a solution tank, and is discharged to the main water system.

FIGURE 3-12
VOLUMETRIC FEEDER, ROLL-TYPE



The roll-type volumetric feeder feeds powdery or granular dry, free-flowing materials at rates from 6 lbs/hr to 2,100 lbs/hr, although the very fine powder will tend to run freely through the rollers.

The oscillating-pan type of feeder consists essentially of a flat, narrow pan or trough into which the fluoride compound falls from a hopper above. Either the pan or the lower part of the hopper slowly oscillates along the axis of the pan, forcing the removal along the two open edges of the pan of a portion of the chemical in the pan. Delivery rates are controlled by both the speed of oscillation and the length of the stroke or the thickness of the chemical on the pan.

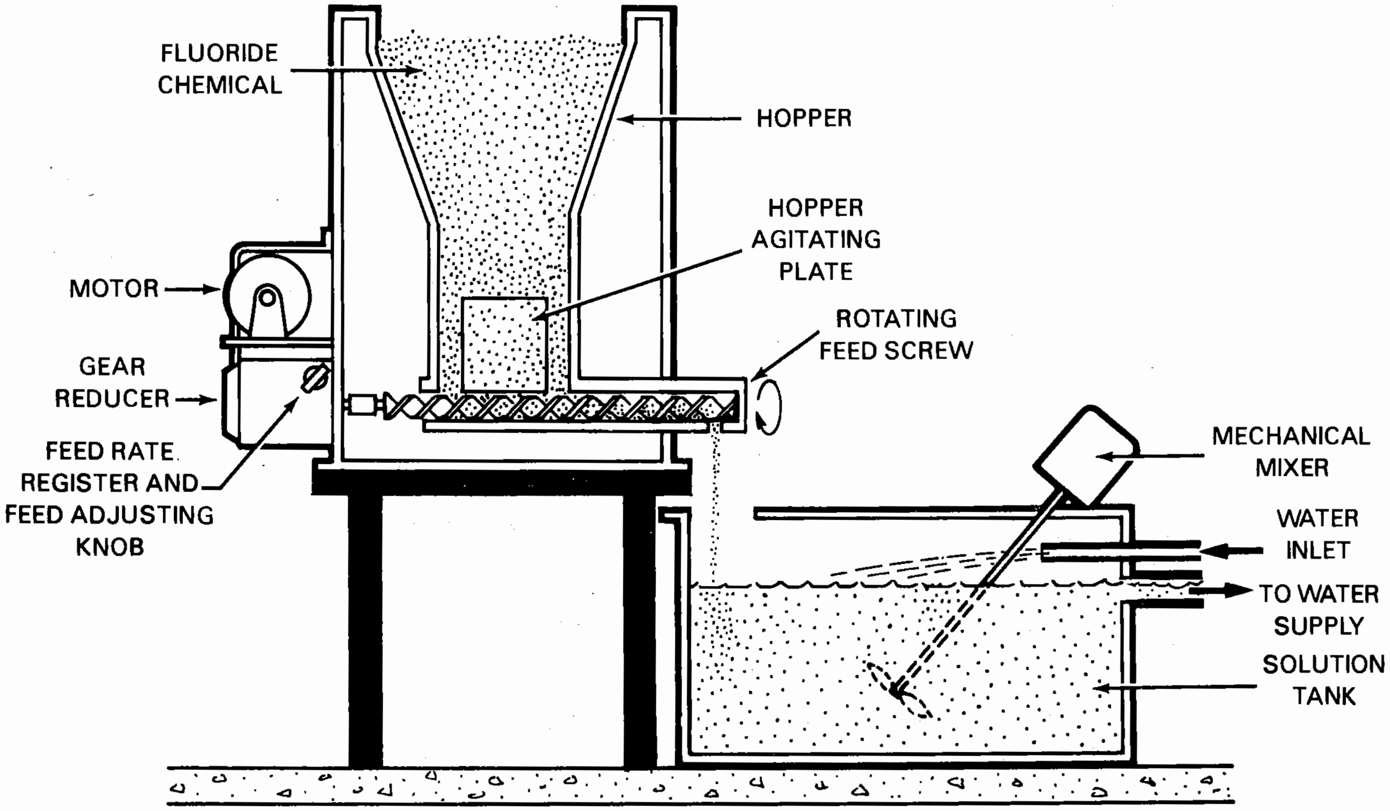
The vibratory-pan dry feeder is a device for discharging a volume of chemical from a pan, chute, or trough made to vibrate electrically. A magnet is energized by means of a pulsating current (either ordinary alternating current or rectified, pulsating direct current). The trough is mounted on springs and connected directly to the magnet. The action of the tray is downward and backward on the power stroke, and upward and forward on the next stroke through the action of the springs. The material on the tray moves forward slightly on each stroke and appears to flow like water because of the high stroking frequence (3,600 strokes per minute on 60-cycle current). The rate of delivery is controlled by a rheostat, which determines the voltage and consequently, the degree of movement of the trough.

The most popular type of volumetric feeder is the rotating screw feeder. See Figure 3-13 below. The fluoride chemical is placed in the hopper through the top. It settles to the bottom by gravity. An arrangement with vibrating plates in the hopper walls provides constant agitation. The agitation extends to the feed screw (hopper bottom) and is designed to prevent arching and packing. It also helps maintain uniform delivery to the feed screw. An eccentric on the feed screw shaft drives a rocker arm connected to vibrating plates in the hopper walls. The feed screw gives single-ended delivery of fluoride to the solution tank at a uniform rate via the discharge line. There is a range of feed rates between 0.02 and 5,000 lbs. per hour.

3.4.3 Gravimetric Feeders

Gravimetric feeders discharge chemicals at a constant weight rather than at a constant volume during a given period of time. There are two general types of gravimetric dry feeders—those based on loss-in-weight of the

FIGURE 3-13
VOLUMETRIC FEEDER, SCREW-TYPE

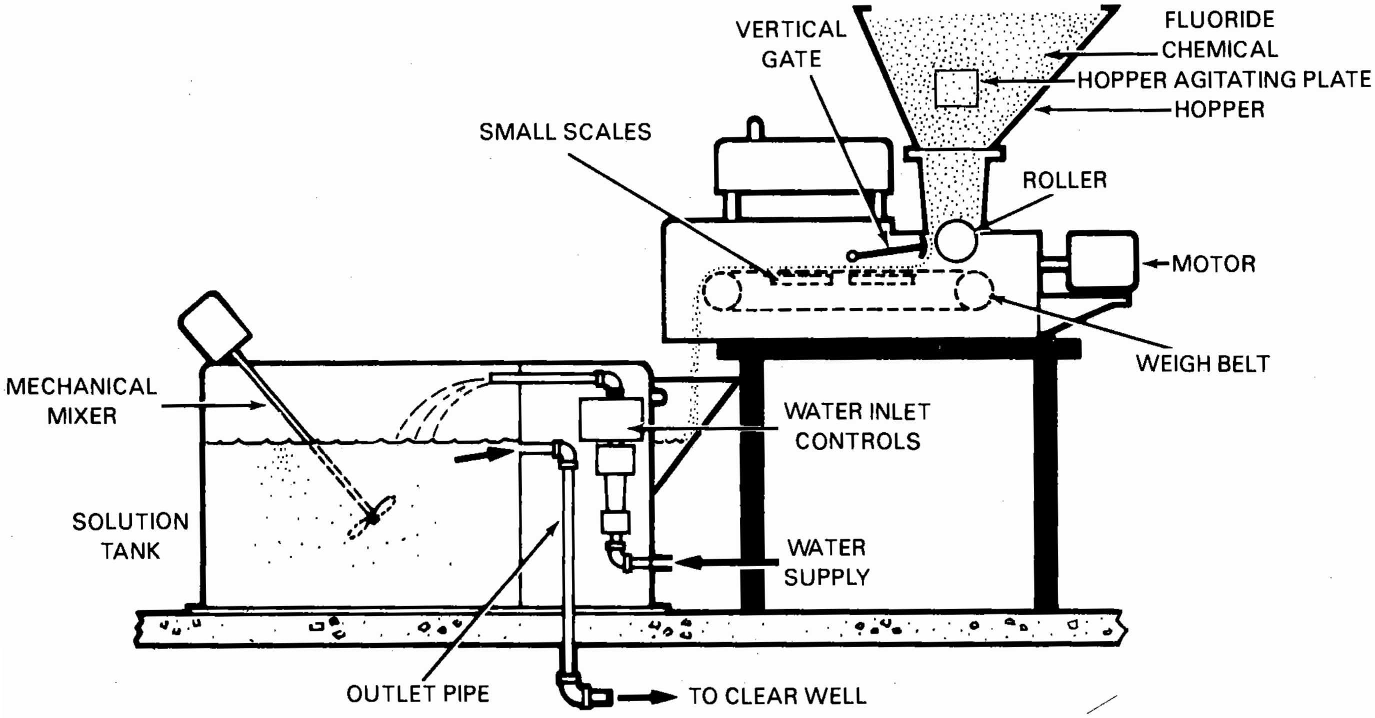


feeder and those which are based on the weight of material on a section of a moving belt. Many gravimetric dry feeders also incorporate some of the features of volumetric feeders, in that they have a rotary feed mechanism between the hopper and the weighing section, or use a mechanical vibrator to move chemicals out of the hopper. Since, ultimately, 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 which these feeders are capable.

The first type (loss in weight) consists of a hopper suspended from a scale system, an electrical-mechanical system for moving the poise on the scale beam, a mechanical means for moving the compound from the hopper in an amount depending on the position of the scale beam, and a solution tank. The lead screw drive (a synchronous motor) moves the poise along the beam at a pre-set rate of speed. If more material is fed momentarily than indicated by the position of the poise, then the beam will lower. This action moves the control wedge (near the oscillator) downward, permitting a decrease in the amplitude of the stroke driving the star wheel or vibrating feeder mechanism. Less material will then be delivered until the weight of the compound remaining in the hopper is again balanced by the weight of the scale beam. The margin of error in feeding for this type of feeder is generally less than 1 percent. The minimum delivery is 1.6 pounds per hour with a range of feed in the order of 100 to 1, while some models can deliver more than 2 tons per hour.

The other type of gravimetric feeder is one in which a section of a loaded, moving belt is continuously weighed. See Figure 3-14 below. The weight of the belt is balanced by a scale beam. The position of the beam controls delivery of the compound onto the belt. Any deviation from this weight on the belt causes the vertical gate to go up or down, thus causing more or less material to fall onto the belt. Vibrations imparted to a diaphragm on the hopper are generated by an eccentric and transmitted through a wedge which varies the amplitude of the vibrations, depending on the position of the scale beam. Accuracy in these feeders is in the order of 99 percent or more. Range of feed is as much as 100 to 1, and adjustments are readily made merely by moving the poise on the scale beam.

FIGURE 3-14
GRAVIMETRIC FEEDER, BELT-TYPE



3.4.4 Solution Tanks

The materials discharged from a dry feeder are continuously dissolved in a chamber beneath the feeder. From this chamber the clear solution falls or is pumped into the water to be treated. This chamber has been referred to as the solution tank, dissolver tank, solution pot, or dissolving chamber. While some chemicals can be fed directly into flumes or basins without using a solution tank, the fluorides are not among them. The necessity for accurate feed rates will not permit the possibility of slurry feed which may form build-ups of undissolved dry material.

Solution tanks come in sizes from 5 gallons on up, with the size often being determined by the size of the feeder under which they are mounted. If there is a choice, the largest size available should be used for fluoride compounds. Mixing of the chemical with water may be accomplished by a system of baffles, and agitation can be provided by a paddle driven by jets of water, but it is strongly recommended by CDC that a mechanical mixer be used. Please refer to Section 3.5.7. Experience has shown that the jet mixer is not nearly as dependable as a good mechanical mixer, even under ideal conditions. Solution tanks should be covered if possible, the lid should be lined with fiberglass. The solution tank should be made of stainless steel or a fiberglass. Because of the corrosive nature of sodium silicofluoride, painted metal solution tanks are not recommended.

The failure to produce a clear, homogeneous solution discharge from the solution tank of a dry feeder indicates that: (1) The solution tank is too small; (2) the detention time is too short; (3) too little solution water is being provided; (4) agitation is insufficient, and/or (5) dry chemical is short-circuiting and is not being adequately mixed with the water.

It has been determined experimentally that detention time (the length of time the fluoride compound remains in the solution tank) needs to be a minimum of 5 minutes to provide a concentration which is one-fourth the maximum solubility, provided the water temperature is above 60 degrees F and the chemical is in the form of a fine powder. If the chemical is in the form of crystals or the water temperature is below 60 degrees F, the dissolving time should be doubled; if both, the time should be tripled (i.e., 15 minutes). Table 3-2 below gives the relationship between detention times and sodium silicofluoride dry feed rates.

Short-circuiting (which is the flow of water directly from the inlet to the outlet without any mixing) is essentially a problem in the solution tank design, and is more likely to occur in the smaller tanks. If the short-circuiting does occur, the remedy is to add baffles to the tank so that the path of the chemical to the outlet of the chamber is sufficiently deflected to provide the necessary mixing for solution.

TABLE 3-2

DETENTION TIME OF SODIUM SILICOFLUORIDE IN SOLUTION TANKS

Feed Rate lbs/hr	Min. Water Feed Rate Required for Solution	Solution Tank Size					
		5 gal.	10 gal.	25 gal.	35 gal.	50 gal.	100 gal.
1	1 gpm	5 min	10 min	25 min	35 min	50 min	100 min
2	2		5	12.5	17.5	25	50
3	3			8.3	11.7	16.7	33.3
4	4			6.2	8.7	12.5	25
5	5			5	7	10	20
6	6				5	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

Since the usual arrangement for a solution tank is to have the water inlet below the outlet, there is a cross-connection which requires adequate safety measures. If a break occurs in the water line, fluoride solution from the solution tank could be drawn back into the water line. If the solution 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 entry and be elevated above the lip of the tank. If there is a solenoid or manually operated valve on the water inlet line, *the vacuum breaker must be installed between the valve and the tank* for adequate cross-connection protection. See Section 3.5.4 on page 54.

3.4.5 Dry Feeder Accessories

For holding the fluoride chemical, many dry feeders will be purchased with a small hopper. In large installations, an additional extension is provided above the main hopper for additional chemical storage. Access to the extension hopper is usually located one floor above the dry feeder. The sodium silicofluoride, if stored on the second floor, can then be conveniently loaded into the hopper.

In small plants, the chemical hopper should be large enough to hold slightly more than the entire bag or drum of chemical. The hopper does not have to be completely emptied before a new bag or drum can be added. By loading an entire container this way, handling of chemicals, dust and spillage is minimized.

When the hopper is installed directly above the feeder, the operator must lift the bag of chemical a considerable height to fill the hopper. A bag loader is more then a necessity in this situation. A bag loader is a hopper extension large enough to hold a single 100 lb. bag of chemical. The front of the loader is hinged so that it will swing down to a more accessible height. The bag is fastened by running an attached rod through the bottom of the bag. The bag is then opened and the loader is swung back into position. This device makes emptying the bag easier and minimizes dust.

Handling powdered dry chemicals always generates dust. For this reasons, an operator should wear a respirator. When small quantities of fluoride are being handled, ordinary care will minimize dust, and 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 that completely encloses the hopper-filling area and is equipped with an exhaust fan, prevents dust from spreading throughout the loading area. To prevent dust from escaping into the atmosphere and into the area surrounding the water plant, dust filters should be incorporated into the exhaust system. Dust collectors and exhaust fans are sometimes incorporated into the hoppers of larger dry feeders.

A float in the hopper lid indicates the level of material in the hopper. The sides of the hopper and the built-in guide vanes flex with an oscillating motion to provide constant agitation. This prevents arching, caking, or packing and assures uniform feeding to the feed rollers.

If a beam scale is used to weigh the dry chemicals or solutions that are added, a recorder can be attached to keep a record of the weight of the chemical fed. Many volumetric dry feeders have recorders available as an accessory.

3.4.6 Calibration of Dry Feeders

The rate of feed of a dry chemical feeder can be varied by adjusting the controls according to a scale. The numbers on this scale have no particular units and cannot be converted to ppm or mg/l until a calibration chart or curve has been prepared. A separate calibration chart is required for each machine and for each chemical fed by the machine. If it is possible to operate your water plant at more than one rate, then you must also have different calibration charts for each plant rate.

To calibrate a dry feeder, fill the hopper to the normal depth with the chemical to be fed. Be sure the chemical is dry, free-flowing, and contains no lumps.

Set the machine adjustment on a low number—certainly lower than the normal operation. Allow the machine to run for few minutes so that it is feeding uniformly. Use a pan or cardboard box (which has been weighed empty), to catch the total discharge of chemical from the feeder for several minutes (say 5 minutes). Weigh the chemical on the laboratory balance (in grams) and make a record on a chart.

Repeat the same operation for other scale settings on the machine—usually four or five different settings. Be sure to cover the full range at which the feeder will be operated. Post the calibration curves near the machine (be sure to label each curve for the right machine) so that they can be used without mistakes or loss of time.

The feed rate of a given machine, when operating at a given setting, will vary, depending on machine wear, humidity, variation in texture of chemical being fed, etc.; therefore, *a calibration curve should not be used over an extended period without verifying the accuracy of the curve.*

3.5 Auxiliary Equipment

3.5.1 Introduction

Most systems that fluoridate require additional equipment beyond the bare minimum. The following sections will explain each type of auxiliary equipment commonly used and where each item belongs in a fluoridation system. As the size and complexity of the fluoridation system grow, the amount and complexity of auxiliary equipment required also increases.

3.5.2 Water Meters

Meters are used for two primary purposes in water plants in connection with fluoridation. One is to register total flow (water flow) to determine the amount of fluoride chemicals based on water usage. The other important use is as a pacing meter for variable flow conditions. The pacing meter will vary the frequency of a metering pump to maintain a desired fluoridation dosage at any flow rate.

The water meter, often absent in the smallest water plants, is one of the primary requisites for accurate fluoride feedings. A water meter measures the flow of water in a water line (volume). Usually, the unit of measurement is gallons or cubic feet. See Figures 3-15 and 3-16 on pages 48 and 49. This type of meter in the water line at home is read once a month and the difference between two months' figures is the amount of water used that month. But note, that with a water meter there is no way to know the *rate of flow* or when the water was used.

One other use of small totalizing water meters is to record the make-up water for a sodium fluoride saturator. The amount of make-up water is directly related to the amount of sodium fluoride injected since a saturator provides a constant 4 percent solution. By relating make-up to total water being treated over an equal time span, fluoride dosage can be monitored and adjusted. This requires the smallest type of positive displacement totalizing water meter available (usually 5/8")—that will record low flows—since saturator make-up flows are very low. Many times the term "water meter" is used to describe water meters, flow meters, pacing meters, compound meters, etc. While this is incorrect, it is a common practice in the waterworks field.

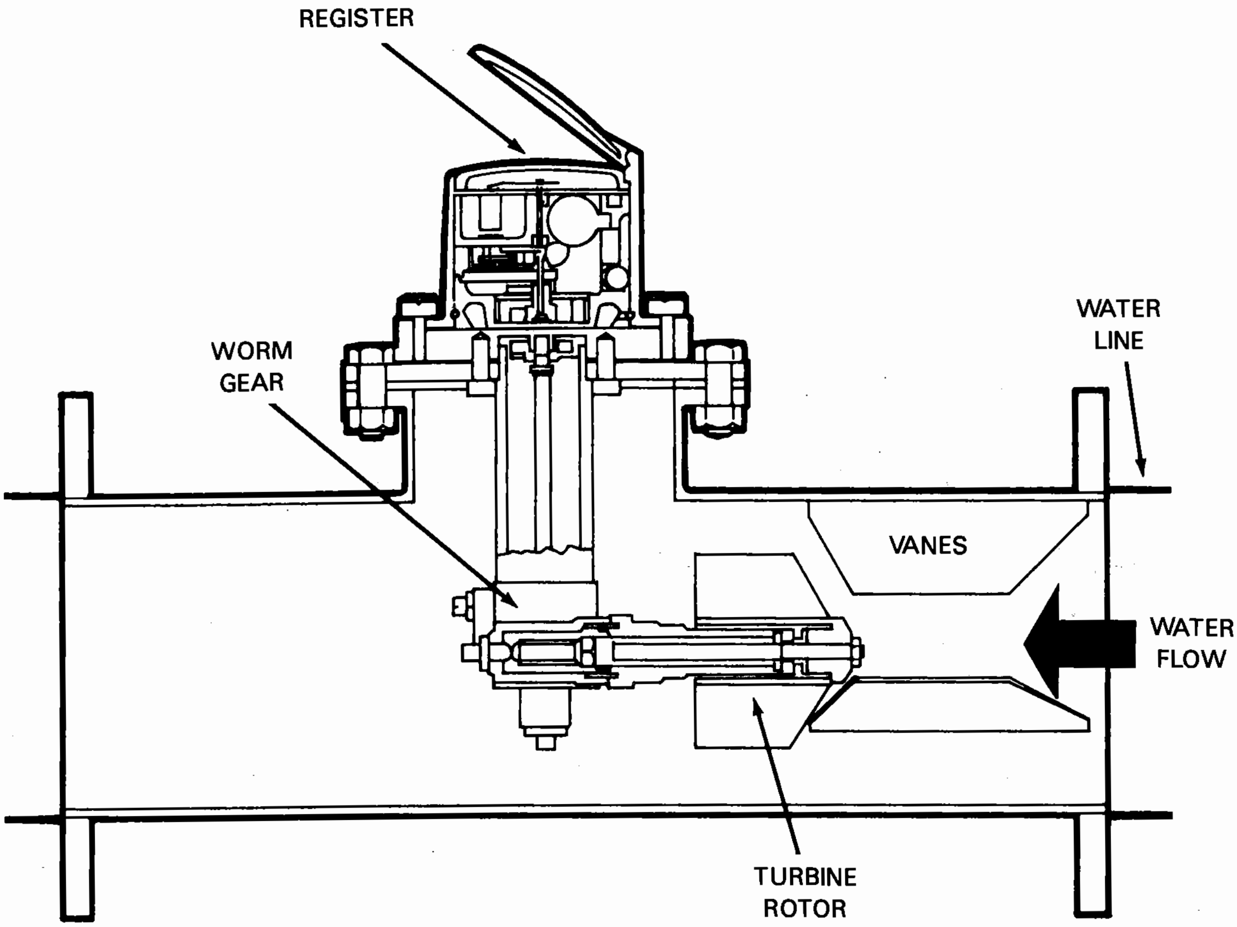
3.5.3 Pacing meters

A flow meter, in contrast to an ordinary water meter, measures *rate of flow* rather than *volume of flow*. It has units of gallons per minute, gallons per hour, cubic feet per minute, etc. and is installed in-line where the flow is to be measured. Some types of flow meters, in addition to measuring the rate of flow, can also produce signals relative to the rate of flow. These flow meters are called pacing meters.

Many water systems, because of their design, will have varying flows. Varying flows can be the result of: (1) gravity flow (2) systems that have two or more water pumps that feed into a common line and are not always all operating simultaneously; and (3) a variable output from pumps because of a changing head. It can be more economical to use one fluoridation system paced by a meter on a common main than to have a system for each pump. The paced system is generally more accurate than a chemical metering pump timed to turn on with a water pump.

Pacing meters provide a signal which is proportional to rate of flow. Some also provide totalizing as a secondary function which is useful but not necessary. This signal that is proportional to rate of flow controls

FIGURE 3-15
TYPICAL PROPELLER WATER METER (MASTER)



the fluoride injection pump output which is also directly proportional to the water flow in the line being treated so as to maintain the desired dosage ratio at all flow rates possible.

There are generally two types of signals used for pacing chemical metering pumps. They are the standard analog 4 to 20 mA DC instrument signal and a digital signal whose frequency is proportional to flow rate and digitally proportional to volume.

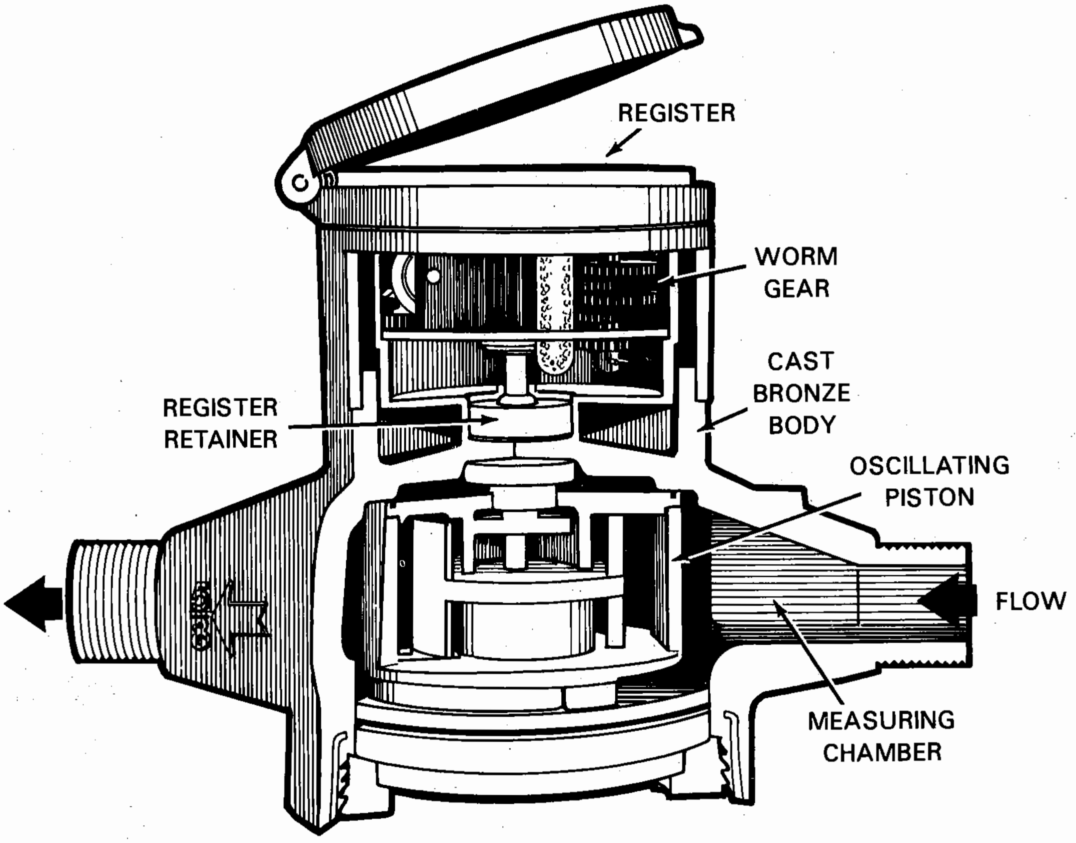
Meters that were specifically designed for pacing electronic pumps and some motor pumps provide a digital signal, since that is the most accurate and easiest to use.

The meters discussed here either provide a digital signal or, with an accessory, provide a 4 to 20 mA DC analog signal proportional to flow. When the 4 to 20 mA DC analog signal is provided, a current to frequency converter is needed to convert the analog signal to digital for pacing electronic pumps. These converters are generally provided by the pump manufacturer or built into some models of pumps.

Electronic metering pumps, controlled by either of the above, generally have a control range of at least 100 to 1. See Figure 3-17 on page 50.

Motor driven metering pumps can be paced by three different methods. The most versatile method uses a clutch between the motor and the gear reduction system of the pump. This clutch is actuated to provide timed intervals of operation, either by a 4 to 20 mA DC signal or a digital signal. This gives a control range as high as 50 to 1.

FIGURE 3-16
TYPICAL WATER METER (RESIDENTIAL)



A second method is a variable speed motor which can be controlled by a 4 to 20 mA DC signal producing a motor speed proportional to the 4 to 20 mA DC signal. This provides an efficient operational range of approximately 5 to 1. See Figure 3-18 on page 51.

The programmable turbine flowmeter, with an electronic metering pump, is a very common installation on many smaller paced systems. See Figure 3-19 on page 52.

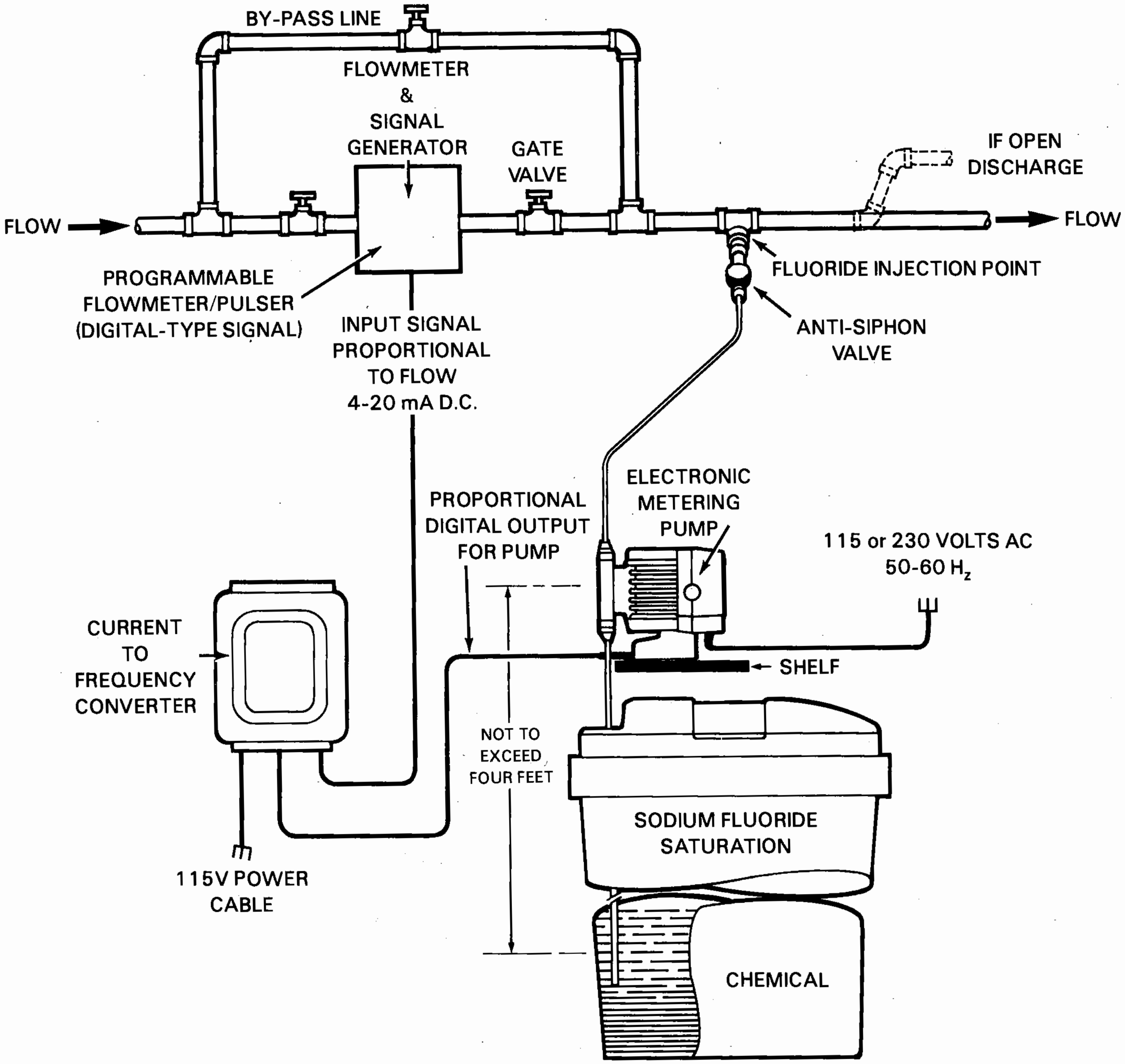
Still another system for controlling output of motor driven pumps is varying the stroke length proportionally to a 4 to 20 mA DC signal by means of a servo motor. This produces an effective range of 10 to 1. For greater range, the variable speed motor and stroke length are combined to increase range but are more expensive.

Meters should be sized to the maximum flow rate, not to pipe size. This is important, since meters have given ranges of accuracy, and the flow rate of the line being monitored must be within the parameters of the type of meter selected. Four general types of meters are commonly used to provide a signal proportional to flow rate described here: Differential pressure, velocity, ultrasonic, and electromagnetic.

Differential pressure meters are most commonly used for high flow rates because they are available in large sizes, and their cost is relatively low compared to others of the same size. They operate on the principle that the pressure drop across the meter is proportional to the square of the flow rate. The pressure differential is measured and the flow rate is obtained by extracting the square root.

To pace a chemical metering pump, a device must be added to this type of meter that will provide an electronic analog signal that is proportional to flow rate. This signal is usually the 4 to 20 mA DC standard instrument signal.

FIGURE 3-17
PACING METER – ELECTRONIC METERING PUMP



Differential pressure meters can be divided into various types as follows:

> *Orifice meters* have a relatively low cost, are usable on high flow rates, are simple to install, and are maintenance free. Their disadvantages include the need for up to 30 diameters of straight pipe upstream and accuracy over a range of only 4 to 1.
>
> *Venturi meters* have a medium cost, are usable at high flow rates, are maintenance free, but need 20 pipe diameters upstream, and only have an accuracy range of 4 to 1.

FIGURE 3-18
PACING METER – VARIABLE SPEED MOTOR CONTROL

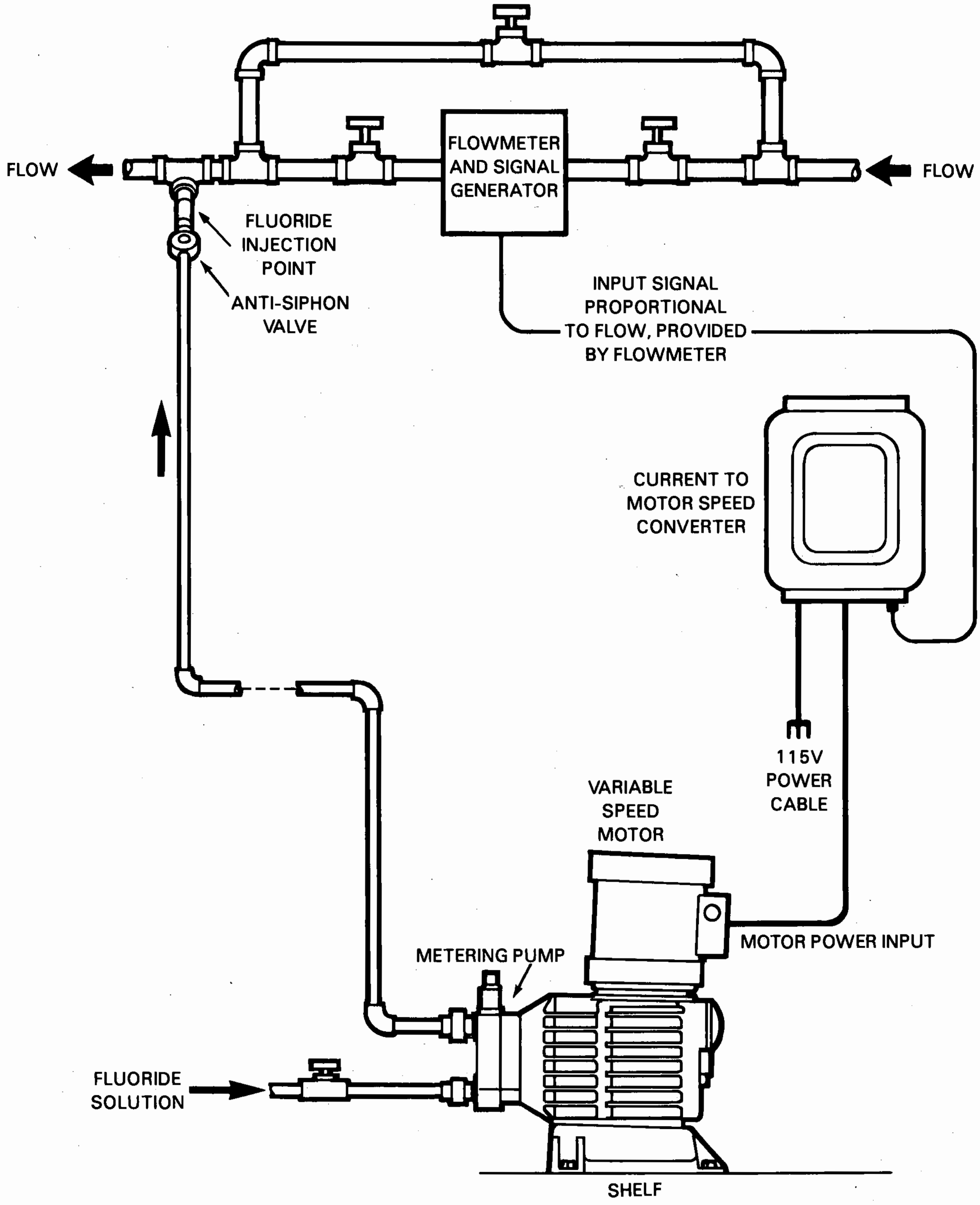
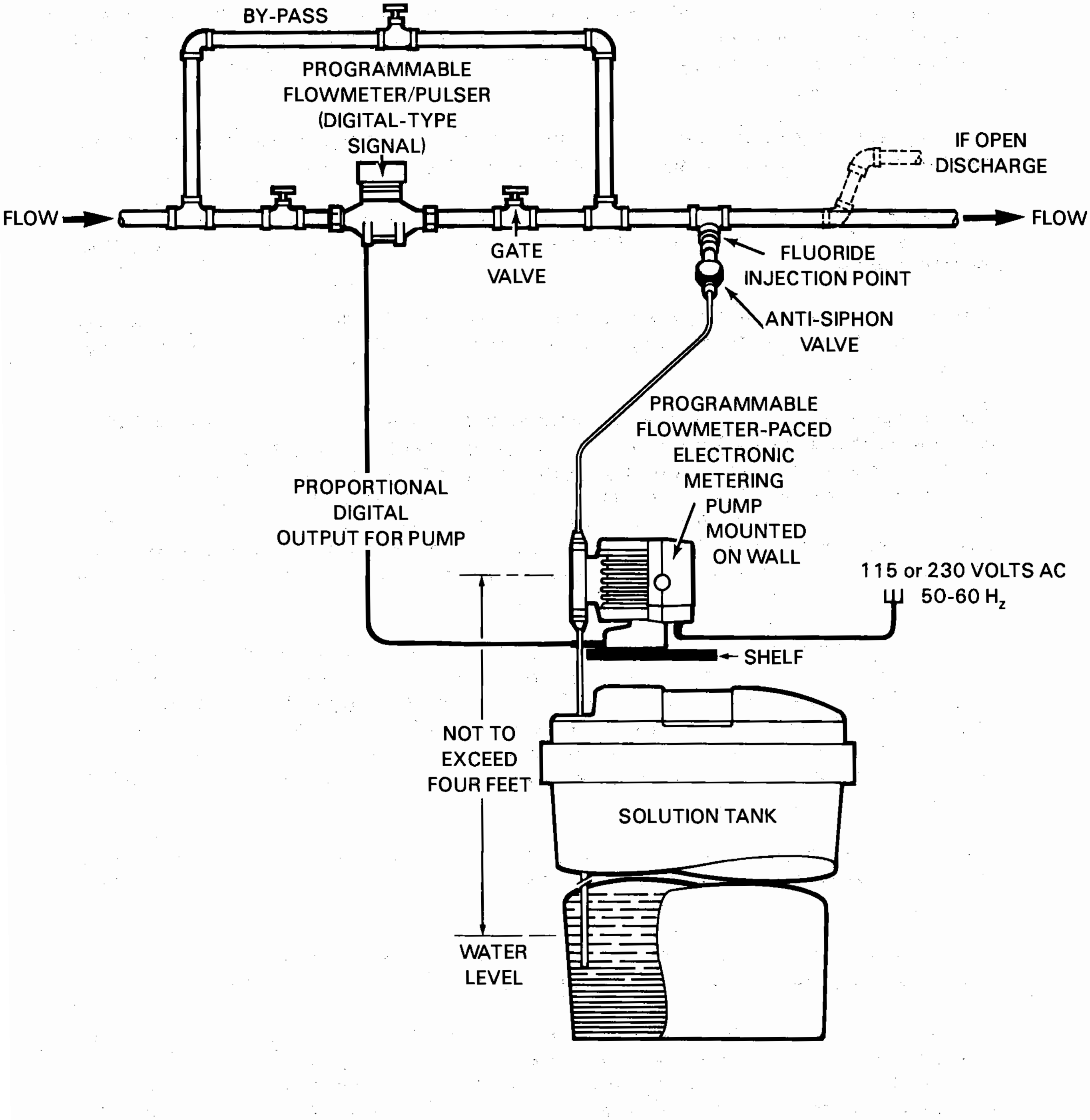


FIGURE 3-19
PACING METER – PROGRAMMABLE WITH DIGITAL SIGNAL



Flow nozzle meters handle high flows, with very low pressure drop at medium cost. They have the disadvantage of only a 4 to 1 range and need up to 30 diameters of straight pipe upstream.

Pitot tube meters are simple and usable on high flow rates with very low pressure drop, but can plug and have a range of only 3 to 1. They need 30 diameters of straight pipe upstream.

Elbow meters are low in cost, and are available in high flow rates with very low pressure drop, but are accurate only over a 3 to 1 range, and need 30 diameters of straight pipe upstream.

Velocity meters can be divided into three general types: vertical turbine, horizontal turbine, and paddle wheel.

The vertical turbine is the most accurate, with ranges up to 125 to 1 and long life, because the impeller has zero weight in water, so there is little bearing wear. They have flow rates and sizes from very low to medium high and provide a digital signal proportional to the flow rate for direct pacing of electronic and clutch operated chemical metering pumps. They require no power source other than that provided by low voltage from the pump.

There are two types of vertical turbine meters. One provides a digital signal proportional to flow from a reed-switch closure, with a possibility of 10 different ratios preset at the factory.

The other type provides a digital signal proportional to flow, is programmable by means of digital divider wheels, and can provide up to 9999 ratios. This type is the most versatile and the easiest to set up to provide the desired dosage ratio.

Vertical turbine programmable flowmeters are the meters of choice within their flow range because of their cost, accuracy, and simplicity. Turbine meters generally provide totalizing as well as signals for pump pacing.

The horizontal turbine is accurate over a narrower range than the vertical turbine, and has a higher rate of bearing wear. They do provide higher flow rates than vertical turbine types. The main problem is that they do not provide a signal for direct pacing of an electronic or clutch operated pump. It is possible for most manufacturers of this type of meter to provide a device that will produce a 4 to 20 mA DC signal that is proportional to flow. With this signal and the 4 to 20 mA DC converter, electronic pumps and clutch operated pumps can be controlled by automatic stroke length, or variable speed motors with the proper intermediate converters. The horizontal turbine should have up to 10 diameters of straight pipe upstream of installation.

The paddle wheel type meter is usable at high flows, can provide direct electronic metering pump pacing by digital signal, and with accessories, provide the 4 to 20 mA DC signal flowrate read out, as well as totalizing. The accurate range is usually about 10 to 1. They must be calibrated for the installation and require up to 30 diameters of straight pipe upstream of the installation. They are probably the meter of choice for higher flows where the necessary installation criteria can be provided. One advantage is that their cost does not increase proportionately with pipe size or flow rate. They are, however, susceptible to turbulence caused by pipe roughness.

Ultrasonic meters can handle very high flow rates over a range of 20 to 1. They require up to 30 diameters of straight pipe upstream. They can provide the 4 to 20 mA DC signal, but their cost is high, and they must be calibrated.

Electromagnetic meters can handle very high flow rates and have a range of 40 to 1. They require only 5 diameters of straight pipe upstream, but they must be calibrated, and their cost is high.

Many times it is possible to find existing meters in water plants that, with the proper accessories, will provide the standard 4 to 20 mA DC signal that is the primary signal in many pacing systems. The addition of a current to frequency converter, available from electronic pump manufacturers, will provide direct pacing of most electronic pumps. Rarely will it be possible to convert existing meters to a usable switch closure for digital pump pacing.

Meter selection, other than the turbine type, generally requires the technical assistance of someone trained in specifying the particular type to be selected, since no effort has been made here to provide the necessary data. Turbine meters can be selected from data supplied by the manufacturer, taking into account flow rate and pressure loss. Programmable flowmeters and contacting head reed switch meters supplied by chemical metering pump manufacturers usually come with enough data to select the meter, as well as the proper pump, to provide ratio ranges for appropriate fluoride amounts.

A pacing meter is a complicated piece of equipment and should only be used in fluoridation systems when it is necessary. In a typical water plant, when there is only one well pump operating at a fixed rate, the fluoride feeder can be tied electrically to the pump operation and a pacing system is not required. When the well is in operation, the water flow is constant, and the fluoride metering pump can feed at a constant rate. Generally, a meter paced system is necessary when the rate of flow past the point of injection varies by more than 15-20 percent.

3.5.4 Vacuum Breakers

The simplest method for preventing a potential back-siphonage situation is to provide an air-gap in the line. Since this is frequently impossible or impractical, a device known as a vacuum breaker is installed.

Many States require a vacuum breaker (non-pressure type) on the potable make-up water lines to upflow type saturators, dry feeder solution tanks, and hose bibs located in the fluoride area. The most common use in fluoridation is on the make-up water lines to the saturators. See Figure 3-20 on page 55. The vacuum breaker is different from a metering pump anti-siphon (backpressure) valve, and the two must not be confused.

When in operation, the disc in the vacuum breaker is kept closed by water pressure. Whenever water is normally flowing through, when the water stops flowing through, the valve disc drops, thus opening the atmospheric vent and allowing air to be drawn in rather than pulling the fluoride solution back into the line.

Most vacuum breakers are of the atmospheric or non-pressure type. The vacuum breaker must, therefore, be installed after (downstream) the last shut-off valve or solenoid valve and be elevated 6 inches above the top of the saturator liquid level.

Always install the vacuum breaker where it will be accessible for observation and cleaning. Do not install it where it will be under water, subject to freezing, out of sight, or where emergency water spillage will create any problems.

If the vacuum breaker is functioning correctly, air bubbles will be momentarily visible from the bottom of the upflow type saturator during each fill cycle. Failure to see air bubbles means the vacuum breaker needs immediate service or replacement.

The vacuum breaker is important for adequate cross connection protection and must not be removed. Keep a spare on hand, inspect the disc for wear annually, and replace as directed by the manufacturer.

3.5.5 Anti-siphon Valves

Most States require that an anti-siphon valve or spring be located on the discharge side of the fluoride metering pump wherever a fluoride solution is added to any pipeline, channel, or clearwell. Of all the auxiliary equipment used, the anti-siphon valve is probably the most important from a safety viewpoint. See Figures 3-21 and 3-22 on page 55. The lack of an anti-siphon valve has resulted in several overfeeds which could have been prevented. The anti-siphon valve is different from an atmospheric or non-pressure type vacuum breaker, which was discussed previously.

The purpose of the anti-siphon valve is to prevent a potential overfeed of fluoride which could occur when the metering pump is not pumping or is unplugged. It prevents dynamic siphoning (''free wheeling'') and flow-through when suction pressure exceeds discharge pressure. Always install an anti-siphon valve on the discharge (pressure) side of the metering pump head when it is accessible for observation and cleaning. Do not install it where it will be under water or out of sight.

The anti-siphon valve operates by a spring being compressed whenever the pump diaphragm strokes. Usually the spring is protected by a hypalon or teflon diaphragm, but not always. If hydrofluosilicic acid is used, the spring must be protected by a diaphragm or be coated. The diaphragm type anti-siphon valve is better than the coated valve because the spring itself is protected from the fluoride solution. Some anti-siphon valves can be adjusted by turning a screw and some are pre-set at the factory. Most are set in the range of 15-20 psi. Some anti-siphon valves are built into the pump head, but most are considered additional

FIGURE 3-20
VACUUM BREAKER

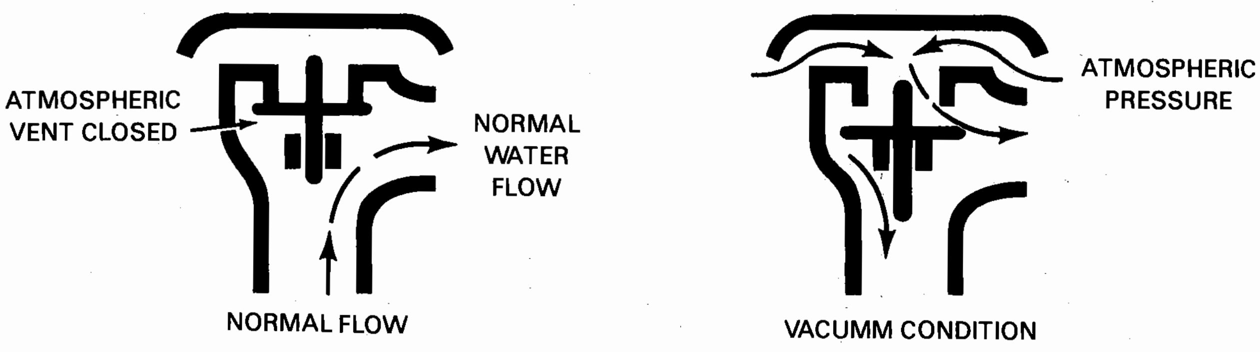


FIGURE 3-21
ANTI-SIPHON VALVE (PUMP MOUNTED)

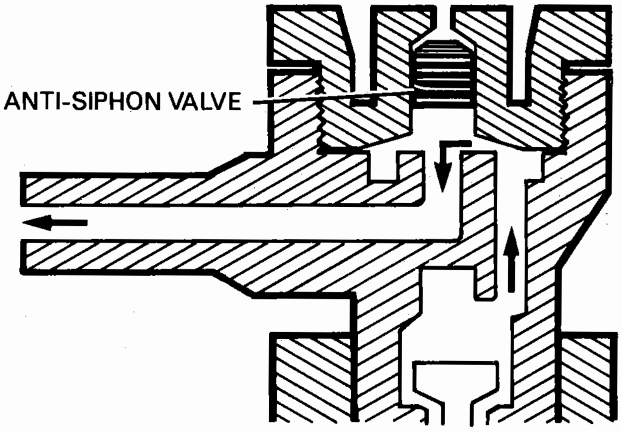
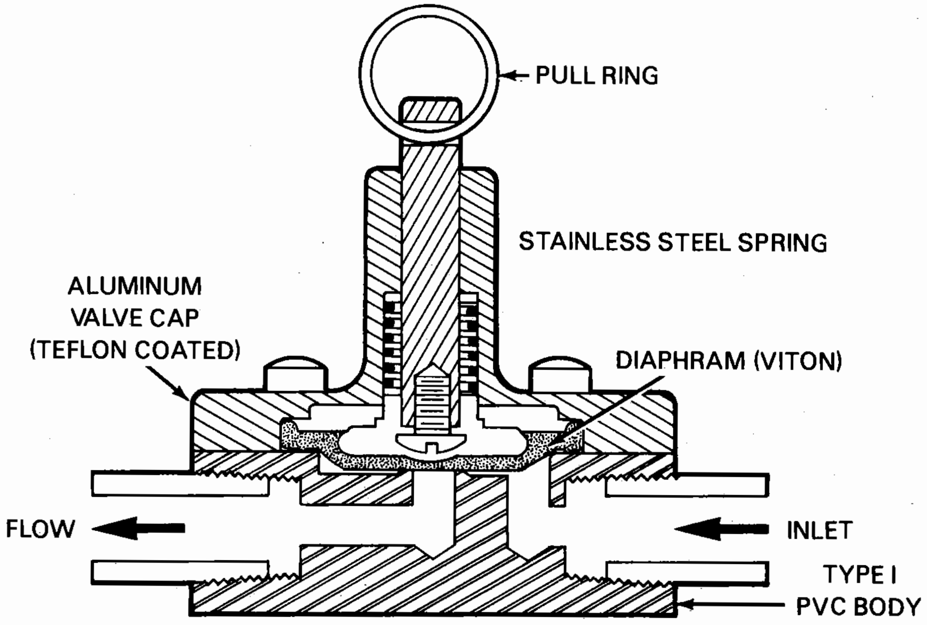


FIGURE 3-22
ANTI-SIPHON VALVE (IN-LINE)



and must be purchased separately. Always check with the pump manufacturer or distributor to determine if it is included with the pump assembly.

The anti-siphon valve spring should be inspected for wear annually and replaced as directed by the manufacturer. A spare should be kept on hand.

3.5.6 Day Tanks

A day tank is just what the name implies—a tank which holds a day's supply of a particular water treatment chemical. It is a convenient and often necessary means for isolating the supply of fluoride solution which will be fed during 1 day or shift at the water plant. Sometimes these tanks are called 30-hour tanks. Also, there are times the day tank will hold enough solution to last for a week, but this is not recommended.

The day tank is a necessity when feeding large amounts of hydrofluosilicic acid, particularly if the acid is received and stored in a large tank (bulk storage). In order to provide a record of the weight of acid fed, a small quantity of the acid is pumped or siphoned into a small tank mounted on a platform scale, and it is from this day tank that the hydrofluosilicic acid is fed into the water system. A similar arrangement can be used for sodium fluoride solutions or hydrofluosilicic dilutions. A large batch of the solution or dilution can be prepared, and a smaller amount transferred to the day tank mounted on the platform scale. This system reduces the amount of labor required for preparing solutions or dilutions, and is an additional safeguard against over-feeding.

The types of construction materials used in for day tanks are determined by the chemical being used but generally are of three types: rubber-lined steel tanks, fiberglass, or polyethylene. Polyethylene day tanks are the most common in the U.S., but care must be taken to protect them from intense sunlight. Strong sunlight will cause the plastics to ''age'' and eventually crack. Black coloring reduces the effects of sunlight, but most plastic day tanks are made of the white translucent polyethylene.

Day tanks are made in all kinds of shapes, but the best for fluoridation is the cylindrical tank with a flat bottom and seamless construction. The lid should have a lip and be airtight, and the day tank should be mounted on a scale. The tank can be provided with graduations or a gauge so that approximate volume measurements can be used.

For systems using hydrofluosilicic acid and bulk storage, the day tank should be sealed and vented to the outside. All others should be vented to the outside. The day tank lid should be sealed around the edges or lip, the two openings where the vent line and the pump suction line exits must also be sealed. These line openings are frequently left unsealed. There is no need for an overflow line if the day tank is properly vented.

A special kind of an application of the day tank is the break box. See Section 5.5.2 on page 100.

3.5.7 Mixers

Whenever solutions are prepared, whether manual preparation of sodium fluoride solutions, dilution of hydrofluosilicic acid, or the output of a dry feeder, it is particularly important that the solution be homogeneous. Slurries must not be tolerated in the feeding of fluorides, since undissolved fluoride compounds can go into solution, subsequently causing a higher-than-optimal concentration. If the fluoride compound remains undissolved, a lower-than-optimal concentration will result. Undissolved material can also cause clogging of equipment and other devices having small openings, and if allowed to accumulate, results in considerable waste.

Two kinds of mixers are commonly used in fluoridation—the in-line and small mechanical high speed. The in-line mixer is used in the main water line to insure proper mixing of the fluoride solution prior to the potable water being consumed. The mechanical mixer is used in the solution tanks of dry feeders and in the manual preparations of fluoride solutions.

In the manual preparation of solutions, thorough mixing is a must. Even when a solution is being diluted, as in the preparation of hydrofluosilicic acid, specific gravities tend to stratify, and such stratification could result in feeding a solution too concentrated, or, at the other extreme, plain water. Sodium fluoride is quite soluble, but even the preparation of the most dilute solutions requires sufficient agitation. Undissolved materials will remain in the bottom of the solution tank while a too-dilute solution is being fed, and even if it gradually dissolves, the strong solution formed at the bottom of the tank will tend to remain in its own stratum.

While a paddle accompanied by sufficient ''elbow grease'' (manual mixing), will suffice for the preparation of the dilution solution, a mechanical mixer is preferred. Mixers come in various sizes, with shafts and propellers made of various materials. A fractional horsepower mixer (1/2 to 1/3 hp.) with a 316 stainless-steel shaft and propeller will be satisfactory for sodium fluoride or sodium silicofluoride solutions. A similar mixer with a corrosion-resistant alloy or PVC coated shaft and propeller will handle hydrofluosilicic acid. See Figure 3-23 below.

The dissolving of sodium silicofluoride in the solution tank of a dry feeder can be accomplished by a jet mixer, but, again, a mechanical mixer is strongly recommended. Because of the low solubility of sodium silicofluoride, particularly in cold water, and the limited detention time available for dissolving, violent agitation is a must to prevent the discharge of a slurry. Preferred construction materials are 316 stainless-steel or PVC-coated steel. One note of caution, if the mixing is too vigorous, water may splash up into the feed mechanism and cause plugging problems.

An in-line mixer (see Figure 3-24 on page 58) should be a simple motionless mixer made of a fixed arrangement of geometrically designed elements enclosed in a tube or pipe. The flowing water provides the energy needed for mixing. There are no moving parts in an in-line mixer. Surprisingly, most in-line mixers are very efficient, with very little head loss. Mixers are available in sizes from 3/4 inch to 6 feet in diameter. Construction materials include stainless steel, carbon steel, fiberglass, and PVC. For fluoridation, 316 stainless steel is generally recommended.

An in-line mixer requires very little, if any, maintenance. Thus, it can be installed underground or in other inaccessible locations. Any location that requires proper mixing of the fluoride chemical but is close to the

FIGURE 3-23
TYPICAL MECHANICAL HIGH SPEED MIXER

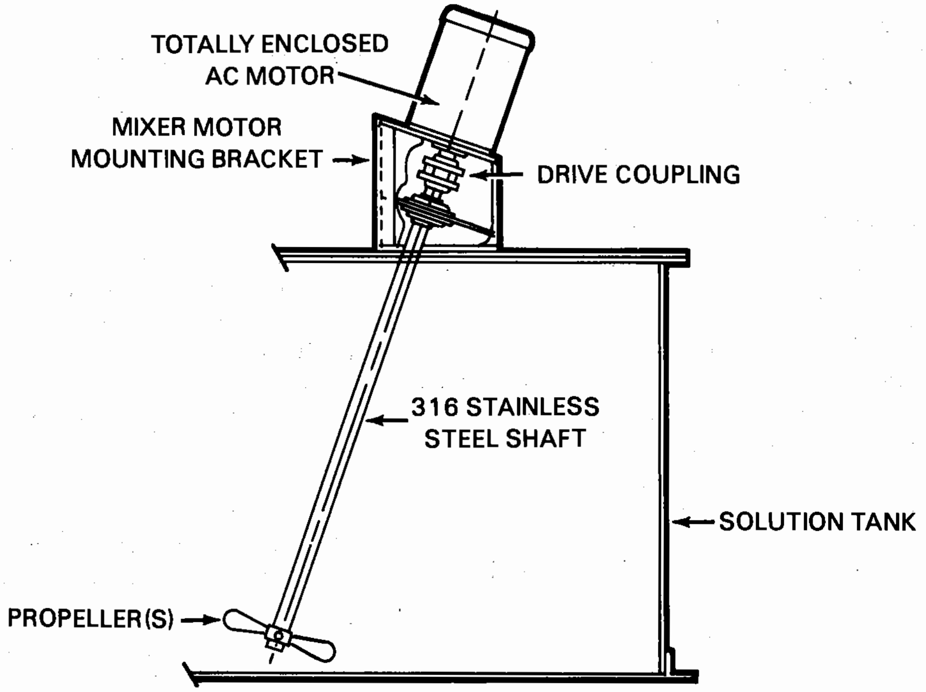
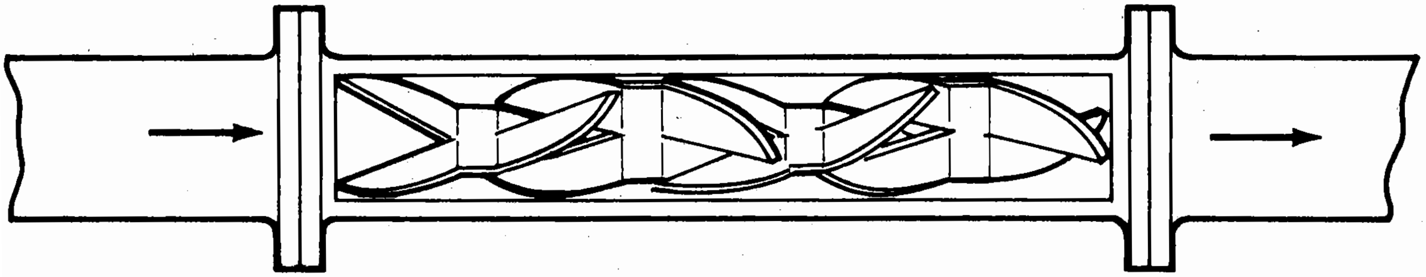


FIGURE 3-24
TYPICAL IN-LINE MIXER



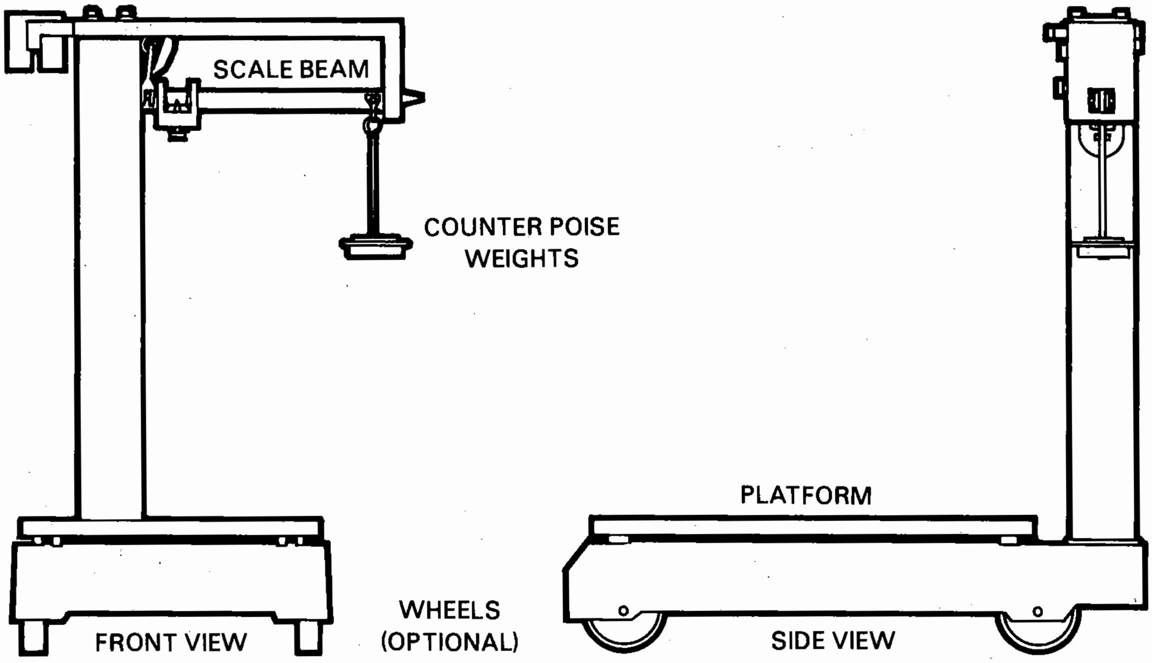
point of injection is a place that may require an in-line mixer. CDC recommends an in-line mixer be used if the first customer is 100 yards or less from the fluoride injection point and there is no storage tank located before the customer. This is a minimum distance, assuming normal valves and bends in the line.

3.5.8 Scales

In any fluoridation installation, except for one based on a sodium fluoride saturator, scales are a necessity for weighing the quantity of solution fed, or weighing the quantity of dry fluoride compound or hydrofluosilicic acid delivered by the appropriate feeder.

The type of scale can vary—from a small household-type used for weighing a pound or two of sodium fluoride for solution preparation—to a complex type with a built-in mechanism. The general types are beam scales, dial scales, and digital read-out (very expensive) scales. The most generally applicable is the beam-type scale with a platform. It is frequently erroneously called a platform scale. See Figure 3-25 below.

FIGURE 3-25
TYPICAL BEAM SCALES



A solution tank, a carboy of acid, or an entire volumetric dry feeder can be placed on the platform of the beam scales. Although the scales may be designed for a specific application, as are those supplied by manufacturers of volumetric dry feeders, in many cases an ordinary hardware-store type of scale will be perfectly acceptable. 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 why they cannot be used. Capacity and sensitivity are the only serious considerations. The scales must be capable of weighing the tank and its contents when full, or the volumetric feeder and its hopper when full. Measurement to the nearest pound or better is adequate for dry feeders. The hydrofluosilicic acid should be weighed to the nearest 1/2 pound. For small scales used for measuring sodium fluoride in manual solution preparation, sensitivity to the nearest ounce should be sufficient. Generally, a 1000-pound minimum scale should be specified, as it is better constructed. The life of a good beam scales is approximately 15 years.

No particular problems should be encountered when mounting equipment on beam scales, except when there is a connection to a water line or discharge line. All such connections must be flexible enough to permit the scale to operate properly. This flexible connection should be horizontal for best results.

3.5.9 Other Appurtenances

Unions

Unions, are a type of plumbing fitting, and are used for joining pipes or tubing that may be disconnected at a later date for maintenance or repair purposes. Unions save time and money when removing or disconnecting any fixtures for repair or replacement.

Unions may be constructed of many materials, such as bronze or PVC, and should be compatible with the fluoride chemical in the pipe. Unions are especially recommended on a saturator system, because equipment must be removed, drained, and cleaned more often than other fluoridation systems. The cleaning process requires disassembly of the overflow pipe, submerged make-up water line to the upflow saturator, and a make-up water line inlet to the saturator. All of the above connections should have unions.

Other places to consider using unions are at connections to a softener, small water meter, and reduced pressure backflow preventer, and if so equipped, on a saturator make-up line, and adjacent to any metering pump if plastic pipe is used.

Strainers

Pump check valves and other parts of the equipment are highly susceptible to dirt and other contaminants in the water. To prevent accumulation of dirt which can cause a malfunction, Y-strainers are recommended in most plumbing lines. The Y-strainer must be installed in the direction of flow. It is easy to install them backwards by mistake. One hundred mesh size screen is commonly used in the strainers used in fluoridation systems.

Timers

An interval timer as used in fluoridation is basically a clock mechanism, usually electric, which will operate an electric pump upon receipt of a signal. Timers are frequently used in conjunction with water meter contactors to operate electric-motor operated feeders. Thus, the timer serves to extend the impulse received from the contactor.

Another application of a timer is in those installations where the minimum reliable feeder setting is still too high for the water flow. In these cases, the timer can be set to provide a proportion of the full-time feed rate. For example, by setting the timer to operate the feeder at 75 percent of each 10-minute period, the feed rate will only be 75 percent of that obtained without the use of the timer.

A word of caution: Using a proportional timer at low percentages, particularly for long interval settings, can result in cyclic fluoride levels. If there is insufficient detention time in clear wells or pipelines before the water reaches the consumers, the on-off action of the feeder will result in alternately too high and too low fluoride readings. The remedy, other than using a smaller metering pump, is to make the proportioned time interval as short as possible. If possible, it is best not to use timers in water fluoridation.

Alarms

To prevent underfeeding or even loss of feed, alarm systems can be included in either solution or dry feed systems. The alarm alerts the operator when the solution level in the day tank is low or when a new bag of dry chemical should be put into the hopper. An alarm can also signal that the water supply to a saturator or dissolving tank has either stopped or diminished. The alarms are rigged by level switches, flow switches, or pressure switches.

Flow Switches

In fluoridation installations it is important that the fluoride metering pump operates only when the water is flowing. This is especially true in school fluoridation systems. CDC recommends an additional safety device, the flow switch, be electrically interconnected with the well pump and the fluoride metering pump. See Chapter Six.

A flow switch is a device installed in a water main that will trip an electrical switch whenever there is flow in the water line. When there is no flow, the electrical switch will remain open. There are two general types of flow switches used in water fluoridation, the mechanical and the thermally actuated. Both are used in the United States in fluoridated school systems.

The mechanical flow switch has a paddle or wheel inserted into the water line. See Figure 3-26 on page 61. When there is flow, then the paddle (wheel) will close an electrical contact. This type of flow switch can fit into a water line as small as 3/4 inch or as large as 16 inches. This is a high maintenance item and needs to be provided with regular care. The most common problem is with corrosion or breakage of the paddle.

The thermally actuated flow switch is a temperature differential flow sensor. See Figure 3-27 on page 61. It detects variations in flow velocity by sensing changes in the heat transfer properties of the flowing water. The sensing head consists of three stainless steel thermowells, (two matched pairs of resistive temperature sensors [one active and one reference] and a low-powered heating element in the third thermowell). The heating element is located so as to heat the active temperature sensor. This creates a temperature differential between the active and the reference temperature sensors. Changes in the flow rate cause changes in the temperature differential. This temperature differential is electronically converted to a signal that is inversely related to actual flow.

The thermally actuated flow switch is much more expensive than the mechanical flow switch but requires less maintenance. The response time is very fast (2 - 50 seconds, depending on the switch point adjustment). It can operate at almost any water pressure (up to 2,000 psi) and can detect flow velocities as low as 0.01 ft/sec.

Pressure Switches

The pressure switch is a simple device that when installed will detect changes in pressure. In a water line, the change in water pressure will cause a diaphragm to flex and thus open or close on electrical contact. This, in turn, will activate or deactivate an electrical circuit.

Pressure switches are commonly used in individual well systems such as rural school systems. The pressure switch will regulate the operation of the well pump. If the school is fluoridated, the pressure switch should be electrically interlocked with the fluoride metering pump. Also, as an additional safety measure, some States have recommended that the pressure switch be installed in-line and electrically in series with a flow switch (or switches). This would be an additional safe guard against a fluoride overfeed. CDC believes that this additional protection is unnecessary.

FIGURE 3-26
TYPICAL MECHANICAL FLOW SWITCH

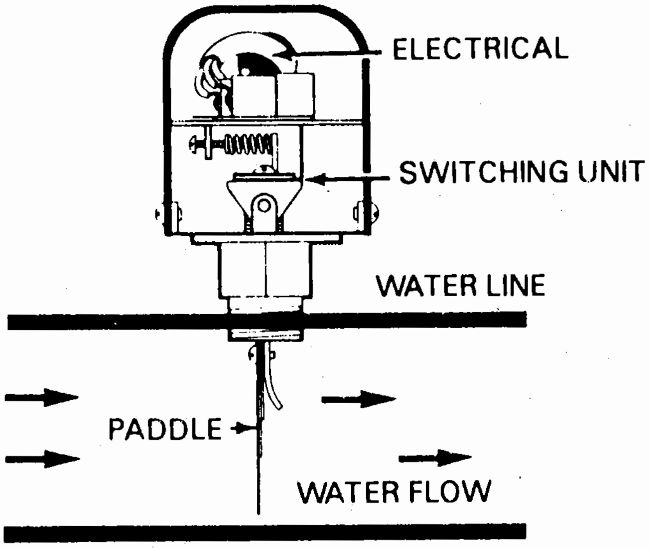
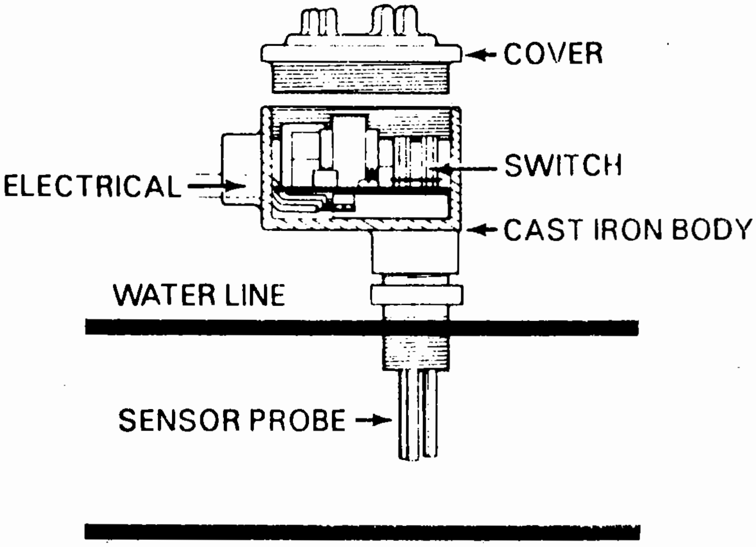


FIGURE 3-27
TYPICAL THERMALLY ACTUATED FLOW SWITCH



CHAPTER FOUR
DESIGN OF FLUORIDATION SYSTEMS

4.1 Introduction

The individual engineering aspects of fluoridation have been discussed—including fluoride chemicals, fluoride equipment, and auxiliary equipment—but designing a specific fluoridation system requires additional knowledge. One must know how to calculate fluoride feed rates, the approximate costs of fluoridation systems, and how to select the proper chemicals and equipment. All of these factors are involved in the proper design of fluoridation systems and will be discussed later. Also, there are other factors which should be considered during the design stage. These include the type of operating personnel available and the preferences of the State water supply personnel and water plant operator(s).

4.2 Fluoridation Systems - Calculations

4.2.1 General

Prior to the design of any fluoridation system, some basic calculations must be made. While these calculations can be done several ways, the results should be the same. One way of figuring the calculations is described in this manual. Ervin Bellack, in his "Fluoridation Engineering Manual," uses another method.[1] Many States have their own individual ways of doing the basic calculations, and all are usually correct. Some States use short cuts, such as nomographs, or constants, to get the same answers. Most State fluoridation engineers or technicians will develop their own style. This material is offered as one way to do the basic fluoridation calculations.

4.2.2 Optimal Fluoride Level

To find the optimal level of fluoride, the annual average of the maximum daily air temperature must be known. Call the local U.S. Weather Bureau office to obtain the temperature data for the last 5 years. The average of these five temperatures will give the annual average maximum daily air temperature for 5 years.[2,3] With this information, the optimal fluoride concentration in the drinking water can be obtained from the chart given below:

Annual average of maximum daily air temperature – F*	Recommended fluoride concentration in milligrams per liter
50.0 - 53.7	1.2
53.8 - 58.3	1.1
58.4 - 63.8	1.0
63.9 - 70.6	0.9
70.7 - 79.2	0.8
79.3 - 90.5	0.7

*Based on temperature data obtained for a minimum of 5 years.

In most States, the State officials in the drinking water programs will know what the optimal fluoride level should be for each drinking water supply system. For annual temperatures below 50 degrees, use 1.2 mg/l, and for temperatures above 90.5 degrees, use 0.7 mg/l.

4.2.3 Dosage

The unit of expression, milligrams per liter, is used in laboratory work to indicate very small concentrations. It is a weight/volume relationship. Milligrams per liter (mg/l) and parts per million (ppm) are equivalent so long as the liquid used has a density of 1.0 grams per cubic centimeter (the specific gravity of water is 1.0). In this manual the terms ppm and mg/l are used interchangeably. While mg/l is the preferred term, ppm is used in many instances in the interest of clarity or tradition. (Note: The term "ppm" is a unitless expression).

The dosage is defined as the amount of fluoride chemical needed to be added 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 of the water to be fluoridated, the dosage is:

Dosage (mg/l) = Optimal level (mg/l) – Natural level (mg/l)
Dosage (mg/l) = 1.2 mg/l – 0.2 mg/l
Dosage = 1.0 mg/l

4.2.4 Maximum Pumping Rate (Capacity)

There is usually some confusion over the terms used to describe the flow rate used in the design of fluoride feeders. There are three terms which will be used in this manual: the maximum pumping rate or plant capacity; average daily production rate; and the actual daily production.

The maximum pumping rate, or plant capacity, refers to the maximum amount of water that can be produced. The capacity of a water plant may be measured in gallons per minute (gpm) or millions of gallons per day (MGD). The plant capacity is a set amount which is limited by factors such as the size of the pumps, area of the filters, etc. (There are some instances where there may be a difference between the maximum pumping rate and the plant capacity.)

It is important to note that the sizing of a fluoride feeder is *based on the maximum flow rate at the point of injection*—referred to in this manual as the maximum pumping rate or plant capacity.

It is this maximum pumping rate, or plant capacity, which must be used to determine the fluoride feed rate. The fluoride must be added at the correct proportion to raise the fluoride to optimal level, regardless of how many hours per day the plant is in operation, since the fluoride feeder will be functioning only when there is flow occurring at the fluoride injection point.

The average daily production rate is the *average* amount of water produced on a daily basis. The average production rate of a plant in MGD can be used to estimate chemical costs. Average daily production rate for a water plant is usually significantly less than the capacity of the plant.

The actual daily production is the amount of water actually treated or produced during a 24-hour period. It is used to determine the calculated dosage. There usually is a difference between the maximum pumping rate or plant capacity and the actual amount of water a water plant treats each day. A plant may operate at a capacity of approximately 700 gpm or 1.0 MGD; however, if the plant only operates 12 hours per day, it will only treat 0.5 MGD. In this case, the plant capacity would be 1 MGD and the actual daily production would be 0.5 MGD.

For simplicity, the rate of production in gpm may be converted to MGD by multiplying by the number of minutes in a day. (Note: gpd = gallons per day.)

$$700 \text{ gpm} \times 1440 \text{ minutes/day} = 1{,}008{,}000 \text{ gpd}$$
$$1{,}008{,}000 \text{ gpd} \div 1{,}000{,}000 = 1.008 \text{ MGD}$$

4.2.5 Chemical Purity and Available Fluoride Ion (AFI) Concentrations

It is well known that it is the fluoride ion from which dental benefits are obtained. Several chemical compounds used today form fluoride ions in a water solution and also meet water quality standards. For each chemical, the fluoride ion is bound with other chemicals, such as sodium, silica, etc.—hence, only a portion of the chemical is available as a fluoride ion when it is dissolved in water. As supplied by the chemical manufacturers, the chemicals used in fluoridation are not 100 percent pure. The following chart gives the available fluoride ion concentration (AFI) and is the most common purity for the three commonly-used chemicals for fluoridating water systems:

Chemical	Formula	Purity	Available Fluoride Ion Concentration (AFI)
Sodium Fluoride	NaF	98%	0.452
Sodium Silicofluoride	Na_2SiF_6	98.5%	0.607
Hydrofluosilicic Acid	H_2SiF_6	23%	0.792

If the available ion concentration is multiplied by the chemical purity, the product represents the actual portion of the chemical available as the fluoride ion after it is dissolved in water. For example, sodium fluoride contains 45 percent F^- and has a commercial purity of 98 percent to yield:

$$\begin{aligned}\% \text{ available fluoride} &= \% F^- \times \% \text{ commercial purity}\\ \% \text{ available fluoride} &= 0.45 \times 0.98\\ \% \text{ available fluoride} &= 0.44\end{aligned}$$

Available fluoride ion concentration is abbreviated as AFI in the calculations which follow.

4.2.6 Fluoride Feed Rate

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 consistent rate. To calculate the fluoride feed rate for any fluoridation feeder in terms of pounds of fluoride to be fed per day, it is necessary to determine the dosage, maximum pumping rate (capacity), chemical purity, and the available fluoride ion concentration, as previously shown.

The fluoride feed rate formula is a general equation used to calculate the concentration of a chemical added to water. It will be used for all fluoride chemicals except sodium fluoride when used in a saturator. (Note: As stated in Section 4.2.3, mg/l is equal to ppm.) The formula for the fluoride feed rate (the amount of chemical required to raise the fluoride content to optimal level) is as follows:

$$\boxed{\text{Fluoride Feed Rate (lb/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34 \text{ lbs/gal}}{\text{AFI} \times \text{chemical purity}}}$$

If the capacity is in MGD, the fluoride feed rate will be in pounds per day. If the capacity is in gpm, the feed rate will be pounds per minute if a factor of 1 million is included in the denominator. (Note the previous page where gpm is converted to MGD):

$$\boxed{\text{Fluoride Feed Rate (lb/min)} = \frac{\text{dosage (mg/l)} \times \text{capacity (gpm)} \times 8.34 \text{ lbs/gal}}{1{,}000{,}000 \times \text{AFI} \times \text{chemical purity}}}$$

4.2.7 Problems (Fluoride Feed Rate)

Some examples for determining the fluoride feed rate are given below:

A. Sodium Silicofluoride

EXAMPLE 1. A water plant produces 2,000 gpm and the city wants to add 1.1 mg/l of fluoride. What would the fluoride feed rate be?

$$\text{Fluoride Feed Rate (lb/day)} = \frac{1.1 \text{ mg/l} \times 2.88 \text{ MGD} \times 8.34 \text{ lbs/gal}}{0.607 \times 0.985}$$

Fluoride Feed Rate = 44.19 lb/day

The fluoride feed rate is 44.19 pounds per day. Some feed rates from equipment design data sheets are given in grams/minute. To convert to grams/minute, divide by 1440 minutes/day and multiply by 454 grams/pound.

Fluoride Feed Rate (gm/min) = 44.19lb /day ÷ 1440 min /day x 454 gm /lb

Fluoride Feed Rate = 13.9 gm./min.

EXAMPLE 2: A water plant has a daily average production of 695 gpm and the city wants to have 1.0 mg/l fluoride level in the finished water. The natural fluoride level is less than 0.1 mg/l. Find the fluoride feed rate using sodium silicofluoride:

(a) Convert the plant rate to MGD

$$\frac{695\text{ gpm} \times 1440\text{ min/day}}{1{,}000{,}000} = 1.0\text{ MGD}$$

(b) Find the fluoride feed rate

$$\text{Fluoride Feed Rate (lb/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\text{ lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{1.0\text{ mg/l} \times 1.0\text{ MGD} \times 8.34\text{ lbs/gal}}{0.607 \times 0.985}$$

Fluoride Feed Rate = 13.95 lbs/day

Therefore, it takes about 14 lbs. of sodium silicofluoride to treat 1.0 MG of water to a concentration of 1.0 mg/l of fluoride.

At times, the fluoride feed rate must be given in cubic feet per hour. Since a cubic foot of sodium silicofluoride weighs in the range of 75 lbs., to convert to cubic feet per hour:

Fluoride Feed Rate (ft^3/hr) = 13.95 lb/day ÷ 75 lb/ft^3 ÷ 24 hrs/day

Fluoride Feed Rate = 0.0078 ft^3/hr

B. Hydrofluosilicic Acid

EXAMPLE 1. If it is known that the plant rate is 4,000 gpm and the dosage needed is 0.8 mg/l, what is the fluoride feed rate in ml/minute?

$$\text{Fluoride Feed Rate (lb/min)} = \frac{\text{dosage (mg/l)} \times \text{capacity (gpm)} \times 8.34\text{ lbs/gal}}{10^6 \times \text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lb/min)} = \frac{0.8\text{ mg/l} \times 4000\text{ gpm} \times 8.34\text{ lb/gal}}{10^6 \times 0.79 \times 0.23}$$

Fluoride Feed Rate = 0.147 lb/min

A gallon of 23 percent hydrofluosilicic acid weighs 10 pounds (see Table 2-2 on page 16) and there are 3785 ml per gallon; thus the following formula can be used to convert the feed rate to ml/min:

Fluoride Feed Rate (ml/min) = 0.147 lb/min ÷ 10 lb/gal × 3785 ml/gal

Fluoride Feed Rate = 55.6 ml/min

EXAMPLE 2. What is the fluoride feed rate if the plant rate is 1.0 MGD, the natural fluoride level is 0.2 mg/l, and the desired fluoride level is 1.2 mg/l?

$$\text{Fluoride Feed Rate (lb/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lb/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lb/day)} = \frac{(1.2-0.2)\ \text{mg/l} \times 1.0\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.79 \times 0.23}$$

Fluoride Feed Rate = 45.8 lb/day

Thus, it takes 45.8 pounds of 23 percent hydrofluosilicic acid to treat 1.0 MG of water to a concentration of 1.0 mg/l of fluoride.

C. Sodium Fluoride

EXAMPLE If a small water plant wishes to use sodium fluoride in a dry feeder, and the water plant has a capacity (flow) of 180 gpm, what would be the fluoride feed rate? Assume 0.1 mg/l natural fluoride and 1.0 mg/l is desired in the drinking water.

$$\text{Fluoride Feed Rate (lbs/min)} = \frac{\text{dosage (mg/l)} \times \text{capacity (gpm)} \times 8.34\ \text{lbs/gal}}{10^6 \times \text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/min)} = \frac{(1.0-0.1)\ \text{mg/l} \times 180\ \text{gpm} \times 8.34\ \text{lbs/gal}}{10^6 \times 0.45 \times 0.98}$$

Fluoride Feed Rate = 0.003 lb/min or 0.18 lb/hr

Thus, sodium fluoride can be fed at a rate of 0.18 lbs/hr to obtain 1.0 mg/l of fluoride in the water.

4.2.8 Fluoride Feed Rates for Saturator

A sodium fluoride saturator is unique in that the strength of the saturated solution formed is always 18,000 ppm. This is due to the fact that sodium fluoride has a solubility which is practically constant at 4.0 grams per 100 milliliters of water at temperatures generally encountered in water treatment. This means that each liter of solution contains 18,000 milligrams of fluoride ion (40,000 mg/l times the percent available fluoride [45 percent] equals 18,000 mg/l).

This simplifies calculations because it eliminates the need for weighing the chemicals. All that is needed is the volume of solution added to the water; for calculated dosage, this volume is provided by a meter on the water inlet of the saturator.

$$\boxed{\text{Fluoride Feed Rate (gpm)} = \frac{\text{capacity (gpm)} \times \text{dosage (mg/l)}}{18{,}000\ \text{mg/l}}}$$

The fluoride feed rate will have the same units as the capacity. If the capacity is in gallons per minute (gpm), the feed rate will be in gpm also. If the capacity is in gallons per day (gpd), the feed rate will be in gpd.

For the purist, the following derivation is given. From page 64:

$$\text{Fluoride Feed Rate (lb/min)} = \frac{\text{dosage (mg/l)} \times \text{capacity (gpm)} \times 8.34\ \text{lb/gal}}{10^6 \times \text{AFI} \times \text{chemical purity}}$$

To change the Fluoride Feed Rate from pounds of dry feed to gallons of solution, divide by the concentration of sodium fluoride and the density of the solution (water). (Note: The chemical purity of the sodium fluoride in solution will be 100%.)

$$\text{Fluoride Feed Rate (gal/min)} = \frac{\text{capacity (gpm)} \times \text{dosage (mg/l)} \times 8.34\ \text{lb/gal}}{10^6 \times \text{AFI} \times \text{chemical purity} \times \%\text{concentration} \times \text{density}}$$

$$\text{Fluoride Feed Rate (gal/min)} = \frac{\text{capacity (gpm)} \times \text{dosage (mg/l)} \times 8.34\ \text{lb/gal}}{10^6 \times 0.45 \times 100\% \times 4\% \times 8.34\ \text{lb. gal}}$$

$$\text{Fluoride Feed Rate (gal/min)} = \frac{\text{capacity (gpm)} \times \text{dosage (mg/l)}}{10^6 \times 0.45 \times 1.00 \times 0.04}$$

$$\boxed{\text{Fluoride Feed Rate (gpm)} = \frac{\text{capacity (gpm)} \times \text{dosage (mg/l)}}{18{,}000\ \text{mg/l}}}$$

4.2.9 Problems (Fluoride Feed Rate for Saturator)

EXAMPLE 1. A water plant produces 1.0 MGD and has less than 0.1 mg/l of natural fluoride. What would the fluoride feed rate be to obtain 1.0 mg/l in the water?

$$\text{Fluoride Feed Rate (gpd)} = \frac{\text{capacity (gpd)} \times \text{dosage (mg/l)}}{18{,}000\ \text{mg/l}}$$

$$\text{Fluoride Feed Rate (gpd)} = \frac{1{,}000{,}000\ \text{gpd} \times 1.0\ \text{mg/l}}{18{,}000\ \text{mg/l}}$$

Fluoride Feed Rate = 55.6 gpd

Thus, it takes approximately 56 gallons of saturated solution to treat 1 MG of water at a dose of 1.0 mg/l.

EXAMPLE 2. Assume a small water plant will have a daily flow of drinking water at 180 gpm and the natural fluoride level is 0.1 mg/l. If 1.0 mg/l is desired in the water, at what rate, in ml/min, must the sodium fluoride be fed?

$$\text{Fluoride Feed Rate (gpm)} = \frac{\text{Capacity (gpm)} \times \text{dosage (mg/l)}}{18{,}000\ \text{mg/l}}$$

$$\text{Fluoride Feed Rate (gpm)} = \frac{180\ \text{gpm} \times (1.0\text{-}0.1)}{18{,}000\ \text{mg/l}}$$

Fluoride Feed Rate = 0.009 gpm

To convert to ml/min, multiply by 3785 ml/gal

Fluoride Feed Rate = 0.009 gpm × 3785 ml/gal

Fluoride Feed Rate = 34 ml/min

So, 34 ml/min of sodium fluoride solution must be fed into the water to obtain 1.0 mg/l of fluoride.

It should be noted that this problem is the same as problem No. C page 66. To compare how much sodium fluoride (dry) is used, change the 0.009 gpm of sodium fluoride solution to lb/hr. of sodium fluoride. There are 18.8 lbs of sodium fluoride in 55.6 gallons of saturated sodium fluoride solution.

$$\text{Fluoride Feed Rate (lb/hr)} = \frac{0.009\ \text{gal/min} \times 60\ \text{min/hr} \times 18.8\ \text{lb}}{55.6\ \text{gal}}$$

Fluoride Feed Rate = 0.18 lb/hr

This is the same amount as shown in example in problem No. *C* page 66.

4.2.10 Calculated Dosage

Some States require that records of the amount of chemical used be kept, and that the theoretical concentration of chemical in the water be determined mathematically. In order to find the theoretical concentration of fluoride, the calculated dosage must be determined. Adding the calculated dosage to the natural fluoride level in the water supply will yield the theoretical concentration of fluoride in the water. This number, the theoretical concentration, is calculated as a safety precaution to help ensure that an overfeed or accident does not occur. It is also an aid in solving trouble-shooting problems. If the theoretical concentration is significantly higher or lower than the measured concentration, steps should be taken to determine the discrepancy.

The fluoride feed rate formula can be changed to find the calculated dosage as follows:

$$\text{Dosage (mg/l)} = \frac{\text{Fluoride Feed Rate (lbs/day)} \times \text{AFI} \times \text{chemical purity}}{\text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}$$

When the Fluoride Feed Rate is changed to fluoride fed and the Capacity is changed to Actual Daily Production of Water in the water system, then the dosage becomes the Calculated Dosage: The units remain the same, except that Fluoride Feed goes from lbs/day to lbs and Actual Production goes from MGD to MG (million gallons) (the ''day'' units cancel).

$$\boxed{\text{Calculated Dosage (mg/1)} = \frac{\text{fluoride fed (lbs)} \times \text{AFI} \times \text{chemical purity}}{\text{actual production (MG)} \times 8.34\ \text{lbs/gal}}}$$

The numerator of the equation gives the pounds of fluoride ion added to the water while the denominator gives million pounds of water treated. Pounds of fluoride divided by million pounds of water equals ppm or mg/l.

The formula for calculated dosage for the saturator is as follows:

$$\boxed{\text{Calculated Dosage (mg/1)} = \frac{\text{solution fed (gal)} \times 18{,}000\ \text{mg/l}}{\text{actual production (gal)}}}$$

Determining the calculated dosage for an unsaturated sodium fluoride solution is based upon the particular strength of the solution. For example, a 2 percent strength solution is equal to 9,000 mg/l, a 1 percent strength solution is equal to 4500 mg/l, or a 1.9 percent strength is equal to 8,550 mg/l. The percent strength is based upon the pounds of sodium fluoride dissolved into a certain amount of water.

For example:

Find the percent solution if 6.5 lbs of sodium fluoride are dissolved in 45 gallons of water:

45 gal × 8.34 lbs/gal = 375 lbs. of water

$$\frac{6.5 \text{ lbs NaF}}{375 \text{ lbs } H_20} = 1.7\% \text{ NaF solution}$$

This means that 6.5 lbs of fluoride chemical dissolved in 45 gallons of water will yield a 1.7 percent solution.

To find the solution concentration of an unknown sodium fluoride solution, use the following formula:

$$\boxed{\text{Solution concentration} = \frac{18{,}000 \text{ mg/l} \times \text{solution strength (\%)}}{4\%}}$$

For example, assume that 6.5 lbs of NaF is dissolved in 45 gallons of water, as previously given. What would be the solution concentration?

Solution strength is 1.7% (see above).

$$\text{Solution concentration} = \frac{18{,}000 \text{ mg/l} \times \text{solution strength (\%)}}{4\%}$$

$$\text{Solution concentration} = \frac{18{,}000 \text{ mg/l} \times 1.7\%}{4\%}$$

Solution concentration = 7,650 mg/l

The calculated dosage formula for an unsaturated sodium fluoride solution is:

$$\text{Calculated Dosage (mg/l)} = \frac{\text{solution fed (gal)} \times \text{solution concentration (mg/l)}}{\text{actual production (gal)}}$$

(Note: CDC recommends against the use of unsaturated sodium fluoride solution in water fluoridation.)

4.2.11 Calculated Dosage Problems

A. Sodium Silicofluoride

EXAMPLE 1. A plant uses 65 lbs. of sodium silicofluoride in treating 5,540,000 gallons of water in one day. What is the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{fluoride fed (lbs)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34 \text{ lbs/gal}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{65 \text{ lbs} \times 0.607 \times 0.985}{5.540 \text{ MG} \times 8.34 \text{ lbs/gal}}$$

Calculated Dosage = 0.84 mg/l

EXAMPLE 2. A plant uses 26 lbs. sodium silicofluoride in treating 1,756,000 gallons of water. What is the calculated dosage for this plant?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{fluoride fed (lbs)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34 \text{ lbs/gal}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{26 \text{ lbs} \times 0.607 \times 0.985}{1.756\,\text{MG} \times 8.34\,\text{lbs/gal}}$$

Calculated Dosage = 1.06 mg/l

EXAMPLE 3. A water plant has an actual production rate of 0.8 MGD. When 10 lbs of sodium silicofluoride was fed in one day, what was the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{fluoride feed rate(lbs)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34\,\text{lbs/gal}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{10 \text{ lbs x } 0.607 \text{ x } 0.985}{0.8 \text{ MG} \times 8.34 \text{ lbs/gal}}$$

Calculated Dosage = 0.90 mg/l

B. Hydrofluosilicic Acid

EXAMPLE 1. A plant uses 43 lbs. of hydrofluosilicic acid in treating 1,226,000 gallons of water. Assume the acid is 23 percent purity. What is the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{fluoride fed (lbs)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34\,\text{lbs/gal}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{43 \text{ lbs} \times 0.792 \times 0.23}{1.226\,\text{MG} \times 8.34\,\text{lbs/gal}}$$

Calculated Dosage = 0.77 mg/l

The calculated dosage is 0.77 mg/l. If the natural fluoride level is added to this dosage, then it should equal what the actual fluoride level is in the drinking water.

EXAMPLE 2. A plant uses 898 lbs of 23 percent hydrofluosilicic acid in treating 17,058,000 gallons of water. What is the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{fluoride fed (lbs)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34\,\text{lbs/gal}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{898 \text{ lbs} \times 0.792 \times 0.23}{17.058\,\text{MG} \times 8.34\,\text{lbs/gal}}$$

Calculated Dosage = 1.15 mg/l

Therefore, the calculated dosage is 1.15 mg/l.

EXAMPLE 3. A water plant uses a total of 2,800 lbs. of 28 percent hydrofluosilicic acid during 4 days to fluoridate 52 million gallons of water. What would be the calculated dosage? The natural fluoride level is 0.2 mg/l.

$$\text{Calculated Dosage (mg/l)} = \frac{\text{fluoride fed (lbs)} \times \text{AFI} \times \text{chem purity}}{\text{actual production (MG)} \times 8.34\,\text{lbs gal}}$$

$$\text{Calculated Dosage (mg/1)} = \frac{2800\,\text{lbs} \times 0.792 \times 0.28}{52 \text{ MG} \times 8.34 \text{ lbs/gal}}$$

Calculated Dosage = 1.43 mg/l

Thus, the calculated fluoride level is 1.4 mg/l, plus the natural fluoride level, 0.2 mg/l or 1.6 m/l. Of course, this is too high, and if the measured fluoride level in the drinking water is 1.0 mg/l, then the cause for the discrepancy must be found.

C. Sodium Fluoride (dry)

EXAMPLE 1. A water plant feeds sodium fluoride in a dry feeder. They use 5.5 lbs of the chemical to fluoridate 240,000 gallons of water. What is the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{fluoride fed (lbs)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34\ \text{lbs/gal}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{5.5\ \text{lbs} \times 0.45 \times 0.98}{0.24\ \text{MG} \times 8.34\ \text{lbs/gal}}$$

Calculated Dosage = 1.21 mg/l

D. Sodium Fluoride - Saturator

EXAMPLE 1. A plant uses 10 gallons of sodium fluoride from its saturator in treating 200,000 gallons of water. What is the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{solution fed (gal)} \times 18{,}000\ \text{mg/l}}{\text{actual production (gal)}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{10\ \text{gallons} \times 18{,}000\ \text{mg/l}}{200{,}000\ \text{gallons}}$$

Calculated Dosage = 0.9 mg/l

EXAMPLE 2. A plant uses 19 gallons of solution from its saturator in treating 360,000 gallons of water. What is the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{solution fed (gal)} \times 18{,}000\ \text{mg/l}}{\text{actual production (gal)}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{19\ \text{gallons} \times 18{,}000\ \text{ppm}}{360{,}000\ \text{gallons}}$$

Calculated Dosage = 0.95 mg/l

EXAMPLE 3. A small water plant uses sodium fluoride from a saturator at a rate of 1.0 gallon per day, and the plant treats 4,500 gallons per day. What is the calculated dosage?

$$\text{Calculated Dosage (mg/l)} = \frac{\text{solution fed (gal)} \times 18{,}000\ \text{mg/l}}{\text{capacity (gal)}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{1.0\ \text{gal} \times 18{,}000\ \text{mg/l}}{4{,}500\ \text{gal}}$$

Calculated Dosage = 4.0 mg/l

E. Sodium Fluoride - Unsaturated Solutions

EXAMPLE 1. A water plant adds 93 gallons per day of a 2 percent solution of sodium fluoride to fluoridate 800,000 gal/day. What is the calculated dosage?

$$\text{Solution concentration (mg/l)} = \frac{18{,}000\text{ mg/l} \times \text{solution strength (\%)}}{4\%}$$

$$\text{Solution concentration (mg/l)} = \frac{18{,}000\text{ mg/l} \times 0.02}{0.04}$$

$$\text{Solution concentration} = 9{,}000\text{ mg/l}$$

$$\text{Calculated Dosage (mg/l)} = \frac{\text{solution fed (gal)} \times \text{solution conc (mg/l)}}{\text{actual production (gal)}}$$

$$\text{Calculated Dosage (mg/l)} = \frac{93\text{ gal} \times 9{,}000\text{ mg/l}}{800{,}000\text{ gal}}$$

Calculated Dosage = 1.05 mg/l

4.3 Costs

4.3.1 General

As in all engineering, costs play a very important role in the selection of the fluoridation system to be installed. Higher initial equipment costs can sometimes be justified by lower operating (chemical) costs. This is often the case in larger communities where dry feeders or bulk acid installations can be justified by the lower cost of sodium silicofluoride or hydrofluosilicic acid in bulk quantities. Conversely, in smaller systems using relatively small amounts of chemicals, the cost of more expensive chemicals, such as sodium fluoride or hydrofluosilicic acid in small quantities, is not as significant as initial installation costs, and saturators or acid feed from carboys are advantageous.

In order to make a preliminary cost estimate for a fluoridation system, it is necessary to know the number and arrangement of sources supplying water to the system, the annual average water production of each source, the natural fluoride content of each source, and whether or not flow pacing is required. From this information, the number of injection points, equipment, and chemical type can he selected, and preliminary designs and cost estimates prepared.

A strong word of caution is necessary at this point. Costs and cost estimates are highly variable factors. Especially variable are "rules of thumb" and "national figures." Costs vary widely depending on local conditions, shipping, availability, and many other factors (some of which may be unknown, except locally). Thus, the cost information given here is intended to be a rough guideline and must be used carefully. The State fluoridation engineer/technician should become the "expert" on costs in his/her State. Those individuals at the national level should look to State personnel for the latest cost data in their respective States. With this information in mind, the following sections will describe some typical fluoridation costs.

CDC is presently conducting a study evaluating the cost of fluoridating water systems of various sizes. The cost study includes equipment costs, chemical costs, and installation costs.

4.3.2 Chemical Costs

Fluoride chemical costs will vary greatly (especially the hydrofluosilicic acid) because of shipping costs. Shipping charges can double or even triple chemical costs, and in the case of hydrofluosilicic acid (23-30 percent) the transportation charges may represent the major portion of the cost. It is also very important that local personnel be consulted, as they may have information that will affect costs.

A list of chemical prices is given in Table 4-1 below. Prices listed are F.O.B. with January 1986 references. Sodium fluoride generally costs from 50¢ to 55¢ per pound in the North East. In the South West, it will cost from 65¢ to 90¢ per pound. Sodium silicofluoride will cost 20¢ to 25¢ per pound in larger communities in the North Central (Great Lakes) part of the United States. In the West, it will cost 30¢ to 50¢ per pound. Hydrofluosilicic acid, in bulk, will cost from 3¢ to 15¢ per pound in most parts of the United States. It will cost up to 50¢ per pound in carboy or drum lots. A rule of thumb is that chemical costs increase as the purchaser goes West. The highest costs tend to be on the West Coast.

Over the years, fluoride chemical prices have been the most variable items in the cost of fluoridation systems. Many times communities will not "shop around" when they purchase new chemicals, but will go to their regular supplier and pay his price. Frequently, when the costs are dropping, these prices may be 50 to 100 percent higher than the prices a competitor will be charging.

In summary, fluoride chemical costs given in this manual must be updated frequently. The State or local engineer/technician should be consulted for the latest information.

TABLE 4-1

FLUORIDE CHEMICAL COSTS*

Items	**Cost (Dollars/lb)**
1. Sodium fluoride	$0.60 - $0.90
2. Sodium silicofluoride	$0.25 - $0.50
3. Hydrofluosilicic acid	
a. Bulk purchases	$0.04 - $0.15
b. Carboys (varies)	$0.20 - $0.50
c. Drums (55 gallon)	$0.12 - $0.35

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*As of July 1986

4.3.3 Equipment Costs

Local availability, projected capacity, etc., make exact equipment cost projections very difficult. An estimate of expenses, however, is given on Table 4-2 on page 74. These costs are current as of July 1986. Volumetric feeders are preferred over gravimetric feeders because of cost. Gravimetric feeders will cost two to three times as much as volumetric feeders and are not necessary for feeding fluoride chemicals. A volumetric feeder will cost from $3,000 to $8,000 depending on the size (capacity), the manufacturer, and the geographic location of the community.

Upflow saturator units, without the metering pump, will cost from $500 to $1,000, but this price will vary according to manufacturer, size, and State requirements. In some States, State personnel make their own saturators, and these will cost as little as $50. In some western States, prices of saturators are very high because of lack of competition. Presently, no manufacturers produce the downflow saturators.

The cost of metering pumps for fluoridation, as with most fluoridation equipment, varies greatly. Piston pumps are by far the most expensive and may cost several thousand dollars depending on the size and manufacturer. However, they may be required if it is necessary to discharge into a water line that has high pressure (over 150 psi). Otherwise, piston pumps should be avoided because of their high cost. Mechanical diaphragm metering pumps can range from $500 to $1,500 or more depending on size, manufacturer, and/or special conditions (such as requirements for hydrofluosilicic acid). The most popular metering pumps are the diaphragm electronic pumps. They will range in price from $300 to $2000 or more. Again, the price depends on the size, manufacturer, and/or special conditions. One of the reasons for its popularity is its low cost.

Pacing meters are considered very expensive and require regular maintenance. The pacing meter must go in the main line, not a makeup water line, thus it usually is several inches in diameter at the very least. The price will range from several hundred dollars for a meter under 1 inch in size to over several thousand dollars for a meter several inches in diameter. Pacing meters should be avoided, if possible, because of the high cost.

All the appurtenances for a fluoridated water system vary greatly depending on the types of system. It is almost impossible to estimate what they will cost. Generally, they will not exceed the cost of the fluoride feeder, saturator, or metering pump. Appurtenances really must be priced on a case by case basis.

TABLE 4-2

FLUORIDATION EOUIPMENT COSTS*

Items	Cost (Dollars)
1. Feeders	
Volumetric (including solution tank)	$4,000-10,000
Gravimetric (including solution tank)	8,000-20,000
Saturator	500-1,000
2. Scales	500-1,000
3. Piston pumps	2,000-4,000
4. Mechanical-diaphragm pumps	500-1,500
5. Electronic-diaphragm pumps	300-800
6. Pacing meters (3/4"-3")	500-2,000
7. Miscellaneous (Piping, etc.)	300-2,000
8. Acid Storage (per gallon of storage)	1.00-2.00
9. Consulting Engineers Fees	Up to 15% of Total Costs

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*As of July 1986

4.3.4 Chemical Storage Costs

Fluoride compounds should be stored in dry, well ventilated areas inaccessible to unauthorized personnel. For some installations, additional storage space maybe required. Costs for storage installations range from a low of about $2 per square foot for unheated metal buildings, to about $10 per square foot (1986 reference) for conventional brick masonry structures.

Bulk purchases require bulk storage. The bulk storage tank cost for hydrofluosilicic acid will depend mostly on costs for shipping. Most bulk storage tanks are manufactured in the Mid West, primarily around St. Louis, Missouri. If the water system which is purchasing the bulk storage tank is located close to the manufacturing plant, the cost of the tank will be approximately 1 dollar per gallon of storage. The minimum size is generally about 4,500 gallons, thus the minimum cost will be approximately $4,500. If the city that is purchasing the bulk storage tank is located a long distance from the factory, the cost of the tank (because of shipping costs) may double. In some of the western parts of the United States where the tanks will be shipped long distances, the cost of the tank will be approximately $2.00 per gallon of storage. These prices have been relatively stable the past few years.

4.3.5 Test Equipment Costs

From Table 4-3 in page 75, it is apparent that test equipment costs are dependent upon the method selected. Costs are listed with 1986 references. In general, the cost of the SPADNS equipment is much less than the cost of the ion electrode equipment, which is the most accurate; however, there are many more interferences in the SPADNS method of testing. The cost of the SPADNS colorimetric equipment is generally about $200 to $400, with some of the equipment costing up to $1,600. The spectrophotometers generally range from $800 to $1,000, with one popular model costing $3,000. The ion electrode equipment will cost about $1,200.

The type of testing equipment (SPADNS versus ion electrode) selected should depend on cost and type of water treatment facilities. In general, ground water (wells) type systems can use colorimetric SPADNS equipment, while surface water treatment plants (or water softening plants) should use the ion electrode equipment. If there are interferences in the ground water, they will be constant and thus corrected for the final fluoride analysis. In surface water plants, there are fluctuating interferences (alum, for example) thus the ion electrode method should be used. The size of the water system is not that important. For example, a large city with many wells can still use the colorimetric equipment.

The magnetic stirrer is recommended for operating the ion electrode method of fluoride analysis. Distillation is not required or recommended by CDC in the SPADNS analysis method for daily monitoring results at water plants.

The ion electrode method requires two electrodes, the reference electrode, and the fluoride electrode. Generally, the reference electrode will last several years, whereas the fluoride electrode may not. Depending on the user or the lab involved, the fluoride electrode will last from 6 months to 5 years. In general, it will last about 1 year to 18 months. Keep in mind, then, the cost of replacing this electrode.

Communities which fluoridate should have their daily tests verified in either local or State laboratories.

State labs need to maintain a greater degree of accuracy than do the fluoridated communities doing daily testing; therefore, the State labs may use the ion electrode method, which is more accurate than the SPADNS method for testing for fluorides.

TABLE 4-3

TEST EQUIPMENT COSTS*

Items	Cost (Dollars)
1. Specific Ion equipment	
a. Specific Ion meter	$600-3,000
b. Fluoride electrode	400-450
c. Reference electrode	100
d. Magnetic stirrer	50-100
2. SPADNS equipment	
a. Colorimetric	200-1,600
b. Spectrophotometer	800-3,000

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*As of July 1986

4.3.6 Installation Costs

Installation costs are by far the most difficult to determine. Some States install most of the equipment themselves; others contract for the entire installation. Local installation costs vary greatly and must be determined individually, based on local practices, regulations and codes, labor, and material costs. As a general rule, in smaller installations, equipment costs will approximately equal installation costs. For example, if a small acid system is to be installed and the equipment costs $1,200, the installation costs should not exceed $1,000. For larger systems, consult with your local equipment manufacturer.

4.4 Selection of Fluoridation Systems

4.4.1 General

While there is no specific type of fluoridation system which is solely applicable to a specific situation, there are some general limitations imposed by the size and type of water facility. For example, a large metropolitan water plant would hardly be likely to consider a fluoridation installation involving the manual preparation of sodium fluoride solution—nor would a small facility consisting of one unattended well consider the use of a gravimetric dry feeder installation.

For the smaller water plant, some type of solution feed is almost always selected. There is almost no lower limit to the ranges of the small metering pumps. Conversely, there is almost no upper limit to the capacity of volumetric or gravimetric dry feeders.

4.4.2 Chemical Selection

4.4.2.1 General

Prior to the actual design of a fluoridated system, a decision must be made on the type of chemical to be used. This will largely determine the type of fluoridated water system that will be designed.

To determine the type of fluoride chemical to use and thus the type of fluoridation system to be designed, the following items must be considered:

1. Chemical availability
2. Water usage
3. Type of existing facilities
   a. Compatibility with proposed system
   b. Space available
   c. Number of treatment sites required (fluoride injection points)
4. Characteristics of the water
   a. Natural fluoride and optimal fluoride levels
   b. Type of flow (variable or steady state)
   c. Pressure (discharge)
5. Estimated overall cost
   a. Capital (initial) cost
   b. Operation and maintenance costs
   c. Chemical costs
6. Operator preference and skill
7. State rules, regulations, and preference

For the smaller water systems, the amount of chemical used is small enough so that the cost per pound of chemical is not as important as the equipment costs. Thus, either sodium fluoride or hydrofluosilicic acid, even though relatively expensive in small lots, can be used. The decision of whether to use a saturator or hydrofluosilicic acid depends on the quantities to be fed, the skill of the operator, the availability and desirability of acid, and personal preference.

Perhaps the simplest fluoridation installation is one based on the use of hydrofluosilicic acid. The acid is supplied in carboys or drums which are placed on a platform scale. A metering pump, mounted on a shelf above the carboy, draws acid and injects it into a water main in proportion to the water flow.

Acid in carboys is usually around a 23.0% concentration; in very small water supplies this may be too concentrated to feed without dilution. Dilution feed would add a mixing tank and method of accurately transferring acid to the above system. This is generally undesirable due to increased operator time potential for dilution errors, and increased safety hazard in extra handling of acid.

As an alternative, a sodium fluoride saturator may be used. This system is a relatively simple means of solution feed with only limited attention required. The operator should daily read gallons fed (after the tank is filled), make periodic chemical additions (no weighing), and clean the saturator every 6 months to a year (depending on water quality).

Sodium silicofluoride is limited to water plants large enough to accommodate a volumetric or gravimetric feeder. It is always fed as a dry feed. In general, sodium silicofluoride is used in surface treatment plants of 4 MGD or larger. The discharge from a dry feeder should be to a non-pressurized injection point (gravity flow).

Fluoride chemicals are plentiful, but having the right one in the right place at the right time may not be as simple as it might seem. The availability of compounds derived from phosphate fertilizer production, hydrofluosilicic acid, sodium fluoride, and sodium silicofluoride is tied in with fertilizer sales, so if there is a decline in such sales, there is also a decline in recovery of the fluoride compounds. Such occurrences are rare and can be circumvented, in large measure, by purchasing these chemicals on a contract basis. The critical instance of availability is the large user of hydrofluosilicic acid. Purchases of lots of 5,000- to 10,000-gallon tank car loads can rapidly deplete a supplier's inventory. (Note: CDC recommends having a minimum storage of 3 months' supply of fluoride chemical on hand.)

It would be wise to investigate the availability of fluoride chemicals through a local supplier before making a choice. Ordinarily, stocks of chemicals on hand at local distributors' warehouses are sufficient for the smaller water plants even if there is a temporary shortage. The large user of hydrofluosilicic acid must be assured of an ample supply before committing to an installation designed around the use of the acid for fluoridation. An on-site visit is necessary, especially if the design is really an extension of an existing system.

The selection of the chemical is a judgment made after considering some or all of the above items. Keep clearly in mind that different people may make somewhat different judgments. While in many cases the facts will clearly favor one chemical, sometimes they will not; therefore, well-informed, knowledgable persons could come to different conclusions.

In demonstrating how to select the correct fluoride chemical to use for a particular water system, this manual will consider different actual situations. (The names have been changed to protect the innocent.) The selection process will be illustrated in the given problems. It is important that the student follow the problems and solutions carefully.

Other considerations may be necessary in particular situations—for example, the technical issues that may surface in a fluoridation referendum.

The problems and solutions make certain assumptions for the sake of simplicity. If these assumptions are incorrect, the solution could change.

4.4.2.2 Problems (Chemical Selection)

The following examples will illustrate how the fluoride chemical selection should be made.

PROBLEM 4-1

The Town of Pelion, Iowa (population 525), has decided to fluoridate its water supply system. The water system also serves a large rural school (population 2,000). Pelion's water system consists of two city wells that are not attended on a full-time basis. The average daily production rate is 0.2 MGD. The optimal fluoride level for this community's water system is 0.8 mg/l. All three fluoride chemicals are readily available from a nearby chemical supplier.

Well No. 1 has a maximum pumping rate (capacity) of 290 gpm (417,600 gpd) and a discharge pressure of 65 psi. Well No. 2 has a capacity of 250 gpm (360,000 gpd) and a discharge pressure of 60 psi. The natural fluoride level in the water from both wells is 0.1 mg/l.

The wells are located approximately 1 mile apart. Both wellhouses are large and contain equipment for feeding chlorine, polyphosphate, and soda ash. Also, the wellhouses contain electricity and the necessary piping. What type of fluoride chemical should be used in this community?

SOLUTION 4-1

As the town has two relatively small unattended wells, the use of sodium silicofluoride for dry feeders should be ruled out immediately. Thus, the choice is to use sodium fluoride and a saturator or hydrofluosilicic acid in carboys and a metering pump.

A saturator will require slightly more space, but that is not a problem here. Both the acid system and the saturator system are compatible with the water system. There will be two fluoride injection points, one at each well, because of the location of the wells. There is a steady flow and adequate pressure at each well.

While the chemicals are readily available, there will be a difference in cost, both chemicals and capital. These costs should be estimated, compared, and evaluated:

Data Known:

Average daily production rate = 0.2 MGD

Dosage (mg/l) = optimal fluoride level (mg/l) – natural fluoride level (mg/l)

Dosage = 0.8 mg/l – 0.1 mg/l
Dosage = 0.7 mg/l

Amount of sodium fluoride (saturator) needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate} = \frac{0.7\ \text{mg/l} \times 0.2\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.45 \times 0.98}$$

Fluoride Feed Rate = 2.65 lbs/day

NaF needed/yr = 2.65 lbs/day × 365 days/yr

NaF needed = 967.3 lbs/yr

Note: A shortcut can be used to determine the amount of chemical used per year. From page 14 it is stated that 19 lbs. of sodium fluoride will fluoridate 1 million gallons of water to 1.0 ppm of fluoride. Thus:

$$\text{NaF needed/yr} = \frac{19\ \text{lb}}{1\ \text{MG} \times \text{ppm}} \times 0.7\ \text{ppm} \times 0.2\ \text{MD} \times 365\ \text{days/yr} = 970.9\ \text{lbs/yr}$$

Amount of hydrofluosilicic acid (23%) needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{0.7\ \text{mg/l} \times 0.2\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.79 \times 0.23}$$

Fluoride Feed Rate = 6.4 lbs/day

Acid (23%) needed/yr = 6.4 lbs/day × 365 days/yr

Acid (23%) needed = 2,336 lbs/yr

From Section 4.3, assume the cost for a consulting engineer will be 15% of the total costs; a saturator will be $1,500; the acid metering pump and equipment will be $1,000; and installation costs will be 90% of the capital cost. Also assume the colorimetric test equipment will cost $350.

CHEMICAL COSTS COMPARISON

CHEMICAL (ITEM)	COST (¢/LB)	CHEMICAL USED (LBS/YR)	CHEMICAL COST ($/YR)	DIFFERENCE ($)
NaF	90	966	870	170
Acid	30	2,345	703	0

CAPITAL COSTS COMPARISON

CHEMICAL (ITEM)	EQUIP ($/EACH)	INSTALL ($)	TEST EQUIPMENT ($)	TOTAL CAPITAL ($)	CONSULT ENG ($)	TOTAL ($)	DIFFERENCE ($)
NaF	1,500	1,350	350	6,050	907	6,957	2,200
Acid	1,000	900	350	4,150	622	4,772	0

There is approximately a $170 difference in yearly chemical costs between using hydrofluosilicic acid and sodium fluoride. Also, there is a difference of approximately $2,200 in capital costs. As the acid installation and yearly chemical costs are cheaper, a judgment can be made that the acid system is preferred. (The fact that the Pelion water system also serves a large rural school is not a factor which will influence the selection of the fluoride chemical. Note: It is generally best to base the decision on which chemical to use on the costs.) *Thus, in this problem, the best judgment is to use hydrofluosilicic acid.*

Many other intangible factors usually will be considered. The State drinking water program may prefer using acid dilution in smaller fluoridated systems while the city does not want to use dilution. If dilute acid is used, the capital and operational costs of the acid system will probably increase only by a small amount. The State may have a strong bias against the use of acid and prefer the use of a saturator. All or any of these factors could change the decision to use acid.

As the project develops and specific kinds of equipment are selected, rough designs are made, and additional information is gathered, the estimated costs may become very inaccurate. If this happens, another cost comparison should be made to insure that it is still more economical to use the acid.

PROBLEM 4-2

The town of Cripple Creek, West Virginia (population 1,220), recently voted to fluoridate its water supply system. They have one city well which has a maximum pumping rate of 352 gpm and a discharge pressure of 60 psi. The natural fluoride level of the water is less than 0.1 mg/l and the State recommends an optimal fluoride level of 1.0 mg/l. The average daily production rate is 0.15 MGD. The wellhouse is large, and has electricity and necessary piping. The city presently is only chlorinating the water from the well. The State recommended that similar-sized communities in West Virginia use sodium fluoride saturators when they fluoridated. Also, the State provides funds for the equipment and 2 years' supply of chemicals. What type of fluoride chemical should Cripple Creek use to fluoridate its water system?

SOLUTION 4-2

The Cripple Creek well is obviously not attended full-time, thus the use of sodium silicofluoride should be ruled out immediately. The choice is between sodium fluoride and a saturator or hydrofluosilicic acid in carboys and a metering pump.

Space is not a problem. There is a steady flow and adequate pressure at the well. Both chemicals are readily available, but shipping costs can be high. The difference in costs should be estimated and compared.

Data known:

Average daily production rate = 0.15 MGD

Dosage (mg/l) = optimal fluoride level (mg/l) – natural fluoride level (mg/l)

Dosage = 1.0 mg/l – 0.0 mg/l

Dosage = 1.0 mg/l

Amount of sodium fluoride (saturator) needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\,\text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate} = \frac{1.0\,\text{mg/l} \times 0.15\,\text{MGD} \times 8.34\,\text{lbs/gal}}{0.45 \times 0.98}$$

Fluoride Feed Rate = 2.83 lbs/say

NaF needed/yr = 2.83 lbs/day x 365 days/yr

NaF needed = 1,033 lbs/yr

Amount of hydrofluosilicic acid (23%) needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\,\text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{1.0\,\text{mg/l} \times 0.15\,\text{MGD} \times 8.34\,\text{lbs/gal}}{0.79 \times 0.23}$$

Fluoride Feed Rate = 6.9 lbs/day

Acid (23%) needed/yr = 6.9 lbs/day × 365 days/yr

Acid (23%) needed = 2,519 lbs/yr

From Section 4.3, assume the cost for a consulting engineer will be 15% of the costs; a saturator will be $1,400; the acid metering pump and equipment will be $1,200; and the installation costs will be 85% of the capital costs. Also assume the colorimetric test equipment will cost $350.

CHEMICAL COSTS COMPARISON

CHEMICAL (ITEM)	COST (¢/LB)	CHEMICAL USED (LBS/YR)	CHEMICAL COST ($/YR)	DIFFERENCE ($)
NaF	80	1,033	826	0
Acid	45	2,519	1,134	308

CAPITAL COSTS COMPARISON

CHEMICAL (ITEM)	EQUIP ($/EACH)	INSTALL ($)	TEST EQUIPMENT ($)	TOTAL CAPITAL ($)	CONSULT ENG ($)	TOTAL ($)	DIFFERENCE ($)
NaF	1,400	1,190	350	2,940	441	3,381	425
Acid	1,200	1,020	350	2,570	386	2,956	0

It costs approximately $300 per year more to feed acid but it is approximately $425 cheaper to buy the equipment and install it. For this particular community these cost differences are relatively insignificant but, in general, when the chemical costs favor one chemical and the capital costs favor another, the lowest priced chemical is the chemical of choice. Obviously, this is a judgment that can vary with even knowledgably trained engineers or technicians.

In this case, there is an additional factor involved. The State seems to have a preference for the use of sodium fluoride and the saturator. As the cost differences are small, *Cripple Creek should use sodium fluoride as their chemical to fluoridate.*

PROBLEM 4-3

The community of Greenrule, S.C. (population 39,000), has decided to fluoridate its water supply system. Greenrule has a surface water treatment plant with a full-time staff of operators. The plant has a capacity of 12 MGD with an average production rate of 9 MGD. The lake which is the water source for Greenrule has a natural fluoride level of 0.1 mg/l. The State recommends an optimal fluoride level of 1.0 mg/l. There is a large amount of space available with an unused extra room that was originally designed for feeding chlorine. The plant has two injection points with variable flow. The treated water from the filters flows by gravity to the clearwells. The plant has two identical separate systems that are mirror images of each other. What would be the preferred fluoride chemical?

SOLUTION 4-3

Of the three fluoride chemicals available, sodium fluoride and the use of a saturator can be eliminated. (Note: the maximum flow that can be treated with a saturator is 2.6 MGD. See Table 4-4 on page 86.) It is possible to use sodium fluoride with the dry feeder, although CDC does not recommend it. Therefore, theoretically, any of the fluoride chemicals could be used and a cost comparison needs to be made.

Data Known:

Average daily production rate = 9 MGD

Dosage (mg/l) = optimal fluoride level (mg/l) – natural fluoride level (mg/l)

Dosage = 1.0 mg/l – 0.1 mg/l

Dosage = 0.9 mg/l

Amount of sodium fluoride (dry feeder) needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{0.9\ \text{mg/l} \times 9\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.45 \times 0.98}$$

Fluoride Feed Rate = 153 lbs/day

NaF needed/yr = 153 lbs/day × 365 days/yr

NaF needed = 55,845 lbs/yr

Amount of hydrofluosilicic acid (23%) needed;

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{0.9\ \text{mg/l} \times 9\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.79 \times 0.23}$$

Fluoride Feed Rate = 372 lbs/day

Acid (23%) needed/yr = 372 lbs/day × 365 days/yr

Acid (23%) needed = 136,000 lbs/yr

Amount of sodium silicofluoride needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{0.9\ \text{mg/l} \times 9\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.607 \times 0.98}$$

Fluoride Feed Rate = 113 lbs/day

Sodium Silicofluoride
~~Acid (23%)~~ needed/yr = 113 lbs/day × 365 days/yr
" "
~~Acid (23%)~~ needed = 41,250 lbs/yr

From Section 4.3, assume the cost for the equipment for the sodium silicofluoride will be:

One volumetric feeder (including solution tank)		$7,500
One scales		500
	TOTAL	8,000

The cost for the acid equipment will be $8,000, which includes two metering pumps and appurtenances. Assume a specific ion test kit at $1,500 and consulting engineering costs of 15% of the capital costs.

CHEMICAL COSTS COMPARISON

CHEMICAL (ITEM)	COST (¢/LB)	CHEMICAL USED (LBS/YR)	CHEMICAL COST ($/YR)	DIFFERENCE ($)
NaF	85	55,845	47,500	35,100
Acid	10	136,000	13,600	1,200
Na_2SiF_6	30	41,250	12,400	0

The cost of sodium fluoride is obviously too high, so it can be eliminated as one of the fluoride chemicals that could be used to fluoridate Greenrule.

CAPITAL COSTS COMPARISON

CHEMICAL (ITEM)	EQUIP ($)	BULK STOR-AGE*	INSTALL ($)	TEST EQUIPMENT ($)	TOTAL CAPITAL ($)	CONSULT ENG ($)	TOTAL ($)	DIFFER-ENCE ($)
Na_2SiF_6	16,000	—	11,000	1,500	28,500	4,275	32,775	1,150
Acid	8,000	8,000	10,000	1,500	27,500	4,125	31,625	0

* Including cost for a transfer pump

The capital costs are essentially the same, *thus, based on chemical costs, sodium silicofluoride would be preferred.*

PROBLEM 4-4

Assume that a city in Colorado with a population of 20,500 is going to fluoridate its water system. The city has five wells. Well No. 5 is only used during the summer months during the tourist season. The wells have a capacity and fluoride level as follows:

WELL NO.	FLUORIDE LEVEL	CAPACITY (gpm)
1	0.4	400
2	0.4	400
3	0.2	550
4	0.2	550
5	0.1	300
		2,200 gpm

The optimal fluoride level is 1.0 ppm, with a discharge pressure at each well of 100 psi. The average water use is 1.8 MGD. The water is not treated except for chlorine. (There are no dry feeders in the plant.) It is generally hard water. The characteristics of the water should be no problem. There is a steady state flow for each well, but when the lines are combined, there will be a variable flow. The discharge pressure at each well is 60 psi. The discharge lines from the wells can be combined. What type of fluoride chemical should be used?

SOLUTION 4-4

This is a middle-sized town and, theoretically, any of the three fluoride chemicals could be used, but there is no treatment plant and no dry feeders are used. Thus, sodium silicofluoride should be eliminated as one of the fluoride chemicals. Both the acid and the sodium fluoride in a saturator are compatible with the water system.

The cost of five individual installations will have to be compared to the cost of one common installation. Also, the cost of the acid versus the sodium fluoride must be evaluated. The amount of chemicals used is as follows: (Assume an average of 0.3 natural fluoride for comparison costs only.)

Data Known:

Average daily production rate = 1.8 MGD

Dosage (mg/l) = optimal fluoride level (mg/l) – natural fluoride level (mg/l)

Dosage = 1.0 mg/l – 0.3 mg/l

Dosage = 0.7 mg/l

Amount of sodium fluoride (saturator) needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{0.7\ \text{mg/l} \times 1.8\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.45 \times 0.98}$$

Fluoride Feed Rate = 23.8 lbs/day

NaF needed/yr = 23.8 lbs/day × 365 days/yr

NaF needed = 8,690 lbs/yr

Amount of hydrofluosilicic acid (23%) needed:

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\ \text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{0.7\ \text{mg/l} \times 1.8\ \text{MGD} \times 8.34\ \text{lbs/gal}}{0.79 \times 0.23}$$

Fluoride Feed Rate = 57.8 lbs/day

Acid (23%) needed/yr = 57.8 lbs/day × 365 days/yr

Acid (23%) needed = 21,100 lbs/yr

From Section 4.3, assume the following costs:

CHEMICAL COSTS COMPARISON

CHEMICAL (ITEM)	COST (¢/LB)	CHEMICAL USED (LBS/YR)	CHEMICAL COST ($/YR)	DIFFERENCE ($)
NaF	85	8,690	7,386	3,166
Acid	20	21,110	4,220	0

A comparison of the costs for the five injection points is as follows. Assume a saturator will cost $1,600 each and installation of each saturator will cost $1,500. Also, assume the equipment for the acid feed (pumps, piping, valves, etc.) will coxt $1,000, with installation costs of $1,200. A colorimetric test kit costing $300 will be used. The cost of a consulting engineer will be 15% of the capital costs.

CAPITAL COSTS COMPARISON

CHEMICAL (ITEM)	EQUIP ($)	INSTALL ($)	TEST EQUIPMENT ($)	TOTAL CAPITAL ($)	CONSULT ENG ($)	TOTAL ($)	DIFFERENCE ($)
NaF	1,600	1,500	300	15,800	2,370	18,170	5,170
Acid	1,000	1,200	300	11,300	1,700	13,000	0

A comparison of the costs for the one injection point follows. Assume costs for equipment, installation, etc., will be slightly higher for one injection point. A pacing meter, piping change, and bulk storage must be added. Assume the bulk storage tank is 5,000 gallons in size.

CAPITAL COSTS COMPARISON

CHEM (ITEM)	EQUIP ($)	BULK STORAGE ($)	INSTALL ($)	PACING METER ($)	PIPING CHANGE ($)	TEST EQUIPMENT ($)	TOTAL CAPITAL ($)	CONSULT ENGR ($)	TOTAL ($)	DIFFERENCE ($)
NaF	1,800	—	1,600	2,500	3,000	300	9,200	1,380	10,580	0
Acid	1,200	5,000	1,400	2,500	3,000	300	13,400	2,010	15,410	4,830

The chemical costs favor the installation of hydrofluosilicic acid. There is a difference between capital costs of five injection points versus one injection point, with the one injection point being the cheapest. Thus, based on capital costs, the use of sodium fluoride and one injection point would be the cheapest. But the savings is approximately $5,000, and the cost of the acid over a 2-year period would result in a savings of approximately $6,000. Therefore, based on all costs, the preferred chemical would be the acid and five injection points. The cost difference between the acid and five injection points and the acid and one injection point is not large (approximately $2,500), thus, the city may prefer acid and one injection point to minimize the labor required to operate the equipment.

However, remember that each well has different fluoride levels. Thus, if one injection point was used, each time the combination of wells changed, the level of natural fluoride could change. Again, a judgment must be made. If a certain combination of wells was used for long periods of time, then a single injection point could be used. In this case, the change in wells would have to accompany a manual change in the fluoride feeder setting. If there were frequent changes, then each well should have its own feeder. In this example, it is assumed that frequent changes would not be necessary, thus one injection point could be easily used.

Based on the above and the costs, the final choice should be the use of hydrofluosilicic acid and one injection point.

Remember that selection of the type of chemical to be used is very important because it usually dictates the type of equipment to be used. Considerable thought should be given to this selection. Unfortunately, in many instances, the chemical selection is based solely on tradition.

4.4.3 Fluoride Feeder Selection

4.4.3.1 General

Once the fluoride chemical to be used has been decided, the choice of the fluoride feeder will be limited. If hydrofluosilicic acid is to be used, then a metering pump will be required. If a saturator (with sodium fluoride) is to be used, a metering pump is necessary. If sodium fluoride (as a dry chemical) or sodium silicofluoride is to be used, then a dry feeder is required. Only the specific type of each general type of feeder will need to be determined after the chemical has been selected. See Table 4-4 on page 86.

The type of feeder chosen for a particular fluoride installation is determined by cost (primarily), availability, service reputation of the manufacturer or sales representative, and, again, personal preference. The types of metering pumps include piston, mechanical-diaphragm, hydraulic-diaphragm, electronic-diaphragm, and peristaltic.

If the decision is made to use a saturator, then the only other choice is whether to use an upflow or a downflow saturator. The saturator is nothing more than a special application of a solution feeder. The upflow saturator has become more popular recently and generally is the preferred type.

TABLE 4-4
COMPARISON OF FLUORIDATION SYSTEMS

Chemical And System		Sodium Fluoride		Hydrofluosilicic Acid 23–35%	Sodium Silicofluoride Dry Feeder	
		Sodium Fluoride[1] Manual Preparation	Automatic Preparation (Upflow Saturator)		Volumetric	Gravimetric
Treated water flow rate[2]	Max.	175 gpm (.25MGD)	1,800 gpm.[3] (2.6MGD)	18,050 gpm (26 MGD)	unlimited	unlimited
	Min.	12 gpm	6 gpm	7.6 gpm	16 gpm	1,400 gpm (2MGD)
Population served[4] (each well or system)	Max.	1,700	17,333	173,000	unlimited	unlimited
	Min.	500[5]	500[5]	500[5]	500[5]	15,000[5]
Equipment required		-metering pump -mixing tank -scales -mechanical mixer	-metering pump -saturator -water meter	-metering pump -day tank -scales	-volumetric dry feeder -scales -hopper -solution tank	-gravimetric dry feeder -hopper -solution tank
Physical characteristics		-white solid -powder -crystalline	-white solid -fine crystalline -coarse crystalline	-straw-colored liquid	-white solid -powder -crystalline	
Shipping containers		-50 lb bags -100 lb bags -125 lb drums	-50 lb bags -100 lb bags -125 lb drums	-tank cars -tank trucks -drums -carboys	-50 lb bags -100 lb bags -125 lb drums -400 lb drums	
Handling requirements		-weighing -mixing -measuring (manually)	-dumping whole bags only -emptying drums	-all handling by pump	-bag loaders or bulk -handling equipment required	
Other requirements		-solution water may require softening	-solution water may require softening	-acid-proof storage tank -vent to atmosphere	-dry storage area -dust collectors -solution tank -mixers	
Hazards		-dust -spillage -solution preparation error	-dust -spillage	-corrosion (especially electrical parts & glass -leakage -fumes	-dust -spillage -arching & flooding in hopper -corrosion	

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[1] Based on maximum strength of 2% NaF, 50 gallon tank, every other day preparation.
[2] Based on equipment operating at mid-range capacity.
[3] Based on adding no more than 100 lbs of sodium fluoride every other day.
[4] Population served correlates with maximum flow rates—based on 150 gallons per person per day.
[5] When population is less than 500, maintaining optimal fluoride level becomes more difficult.

The choice of dry feeders is one between the volumetric or gravimetric feeders. Almost always, the volumetric feeder is the best choice because of cost. The gravimetric feeder is the most expensive and the most accurate, but the accuracy of the volumetric feeder is sufficient for fluoridation.

Determination of the type of volumetric feeder to be used is dependent only on personal preference and availability of the equipment. Some volumetric dry feeders are capable of feeding at very low rates, and some of the smallest disc types, such as those used for pilot plant installations, are able to handle water rates as low as 16 gpm. But, it is not recommended that a dry feeder for fluoridation be used for flows under 25 gpm. If an open channel for feeding by gravity (from the solution tank) is not available, a centrifugal feed pump can be used for injecting fluoride solution into a water main. Any of the dry feeders can be used for sodium fluoride, as well as for sodium silicofluoride.

4.4.3.2 Problems (Feeder Selection)

Again, the selection of the equipment will be illustrated by examples. The problems in the previous section will be used to show how to select a specific type feeder. The fluoride chemical has been selected; now the feeder will be selected.

PROBLEM 4–5

In Problem 4–1 on page 77, hydrofluosilicic acid (23%) was selected as the chemical to be used in a small town in southern Iowa. Select and size an acid system for this town. There are two wells supplying water to the town.

SOLUTION 4–5

In the design of an acid system, the key is to select the proper metering pump. The selection of scales, pipe size, and other details is similar to any other design at the water plant and will not be covered in this manual.

As there are two city wells, there will be two injection points and thus, two metering pumps required. There are several manufacturers of fluoridation equipment, but assume that the Precision Company is selected.

Well Number One

$$\text{Fluoride Dosage} = 0.8 \text{ mg/l} - 0.1 \text{ mg/l}$$

$$\text{Fluoride Dosage} = 0.7 \text{ mg/l}$$

$$\text{Pumping Rate}_1 = 290 \text{ gpm} = 417{,}600 \text{ gal/day}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34 \text{ lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate}_1 = \frac{0.7 \text{ mg/l} \times .417 \text{ MGD} \times 8.34 \text{ lbs/gal}}{0.79 \times 0.23}$$

$$\text{Fluoride Feed Rate}_1 = 13.4 \text{ lbs/day}$$

Thus, the fluoride feed rate for Well Number One would be 13.4 lbs/day.

Assume that the Precision metering pump is desirable because the chlorinators are all Precision metering pumps. All manufacturers publish specifications or design data for their equipment. See Table 4–5 for the Precision data sheet on page 89. (Note: The capacities of the pumps are given in gallons per hour and the discharge pressure must be known.) For this problem, the discharge pressure would be a maximum of 65 psi. The capacity would be:

$$\text{Fluoride Feed Rate} = \frac{13.4 \text{ lbs/day}}{24 \text{ hr/day} \times 10 \text{ lbs/gal}}$$

Fluoride Feed Rate = 0.059 gal/hr

From Table 4–5, a capacity of 0.12 gal/hr should be found and the maximum pressure checked.

The Electronic Pump Series No. 10001-32 would probably be the best choice, based on the cost, the capacity, and the discharge pressure.

Well Number Two

Fluoride Dosage = 0.8 mg/l – 0.1 mg/l

Fluoride Dosage = 0.7 mg/l

Pumping Rate$_2$ = 250 gpm = 360,000 gal/day

Fluoride Feed Rate$_2$ (lbs/day) =

$$= \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34\,\text{lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate}_2 = \frac{0.7\,\text{mg/l} \times 0.36\,\text{MGD} \times 8.34\,\text{lbs/gal}}{0.79 \times 0.23}$$

Fluoride Feed Rate = 11.6 lbs/day

The Fluoride Feed for Well Number Two is 11.6 lbs/day. But this needs to be converted to gallons per hour.

$$\text{Fluoride Feed Rate}_2 = \frac{11.6\ \text{lbs/day}}{24\,\text{hr/day} \times 10\ \text{lbs/gal}}$$

Fluoride Feed Rate$_2$ = 0.048 gal/hr

From table 4-5 on page 89, using 0.10 gallons/hours, an Electronic Pump Series No. 10001-32 could probably be used. (Note: This capacity is almost too large. If the metering pump size had been smaller, then probably, a different company should be considered.) If possible, when there are multiple wells, it is best to use the same kind of metering pump for the convenience of the water plant operator.

PROBLEM 4–6
In Problem 4–2, the town of Cripple Creek, West Virginia, decided to use sodium fluoride with a saturator. They have only one city well. Select and size a saturator unit for this community.

SOLUTION 4–6
In the design of a saturator fluoridation system, there is the choice of an upflow or a downflow system. The upflow is always preferred. Many companies sell upflow saturators, but, based on the community's preference, the company selected is Liquid Metronics, Incorporated (LMI). To size a saturator, the size of the metering pump should first be determined.

Fluoride Dosage = 1.0 ppm

Pumping Rate = 352 gpm = 506,900 gal/day

$$\text{Fluoride Feed Rate (gpm)} = \frac{\text{capacity (gpm)} \times \text{dosage (mg/l)}}{18{,}000\ \text{mg/l}}$$

TABLE 4–5
TECHNICAL DATA — PRECISION PUMP CAPACITY

Pump Series	Pressure		Pump Output					Max CC/ Stroke	Shipping Weight Lbs (Approx)	Dimensions Inches (Approx)		
	Max PSI	Max kg/cm²	Max GPH	Max LPH	Max GPM	Max CC/Min	Max SPM			W	L	H
H1□□1-12□	600	42.2	5.6	21.2	.09	350	60	5.9	140	8	17½	18
H1□□1-14□	600	42.2	11.2	42.4	.18	700	120	5.9	140	8	17½	18
H2□□1-12□	400	28.1	8.8	33.3	.15	560	60	9.3	140	8	17½	18
H2□□1-14□	400	28.1	17.6	66.6	.30	1,120	120	9.3	140	8	17½	18
H3□□1-12□	125	8.8	30	113.5	.50	1,890	60	30.3	140	9	18½	18
H3□□1-14□	125	8.8	60	227	1.00	3,780	120	30.3	140	9	18½	18
H4□□1-1R□	50	3.5	110	416	1.83	6,930	60	115.5	145	9	26½	18
H4□□1-14□	35	2.4	220	832	3.67	13,860	120	115.5	145	9	26½	18
5□□1-11□	150	10.5	5.0	18.9	.08	315	37.5	8.4	45	17	15	10
5□□1-12□	150	10.5	10.0	37.8	.16	630	75	8.4	45	17	15	10
5□□1-13□	150	10.5	13.5	51.1	.22	850	101	8.4	45	17	15	10
6□□1-1□F	60	4.2	2.5	9.4	.04	160	36	4.4	21	12½	9	7
6□□1-2□F	60	4.2	5.0	18.9	.08	315	72	4.4	21	12½	9	7
7□□1-1R□	1200	84.4	5.0	18.9	.08	315	60	8.4	100	20	26	14
7□□1-14□	1200	84.4	10.0	37.8	.16	630	120	8.4	100	20	26	14
8□□1-1□	100	7.0	.83	3.1	.01	50	36	1.45	17	8½	9½	8
8□□1-2□	60	4.2	1.6	6.1	.03	100	72	1.45	17	8½	9½	8
9□□1-1□	125	8.8	2.5	9.4	.04	160	36	4.4	18	8½	10	9
9□□2 1□	125	8.8	5.0	18.9	.08	315	36	4.4	21	8½	14	9
9□□1-2□	60	4.2	5.0	18.9	.08	315	72	4.4	18	8½	10	9
9□□2 2□	50	3.5	10.0	37.8	.16	630	72	4.4	21	8½	14	9
10□□1-32□	75	5.3	.14	.53	.002	9	15	0.6	8	4½	7	9
10□□1-36□	75	5.3	.57	2.2	.009	35	60	0.6	8	4½	7	9
11□□1-32□	45	3.1	25	.95	.004	15	15	1.05	9	4½	9	7
11□□1-36□	45	3.1	1.0	3.8	.016	60	60	1.05	9	4½	9	7
12□□1-1□	80	5.6	1.6	6.1	.03	100	72	1.4	15	7½	10	12
12□□2-1□	80	5.6	3.2	12.1	.06	200	72	1.4	15	7½	10	12
13□□1-1□	150	10.5	1.6	6.1	.03	100	72	1.4	22	7½	11	12
13□□1-1□HO	90	6.3	4.0	15.1	.07	250	72	3.5	25	7½	15	12
14□□1-11□	35	2.4	10.0	37.8	.16	630	72	8.4	30	7½	15½	11½
15□□1-1□	500	35	.25	.95	.004	15	72	.22	15	7½	13	9½
16□□1-1□	900	63	.25	.95	.004	15	72	.22	20	7½	14	9½
17□□1-58□	75	5.3	.79	3.0	.01	50	83	0.6	13	4½	11½	12½

PSI	Pounds per square inch
kg/cm²	kilograms per square centimeter
GPH	gallons per hour
LPH	liters per hour
GPM	gallons per minute

CC/Min. = cubic centimeter per minute

SPM = strokes per minute

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$$\text{Fluoride Feed Rate} = \frac{506{,}900 \text{ gal/day} \times 1.0 \text{ ppm}}{18{,}000 \text{ ppm}}$$

Fluoride Feed Rate = 28.2 gal/day

Look at Table 4–6 on page 91. Either a series "B" or "D" electronic metering pump would pump 28 gallons per day, but a metering pump that will operate in the middle range should be selected. Thus, the maximum range should be about 56 gal/day. A model B72 pump would be selected. There is a maximum discharge pressure of 100 psi. LMI has only one saturator tank that can be used with these electronic pumps—a Model 28850. This is a 50-gallon polyethylene tank.

PROBLEM 4–7

In Problem 4–3, a community in South Carolina with a surface water treatment plant has decided to use sodium silicofluoride to fluoridate their water supply system. They wish to design a fluoridation system.

SOLUTION 4–7

In using sodium silicofluoride, a volumetric feeder should be chosen, as the cost of the gravimetric feeder is not warranted. The plant has two identical injection points, with a flow of 6 MGD at each location. Problem 4–3 has already stated that the plant has variable flow—this is because of the several low service pumps used. The city has decided that the water plant operator can make manual adjustments with the volumetric dry feeders when the flow changes. Thus, if the size of the volumetric feeders is determined, the fluoridation design can be made.

Fluoride Dosage = 1.0 mg/l – 0.1 mg/l

Fluoride Dosage = 0.9 mg/l

Pumping Rate = 6 MGD

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34 \text{ lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{0.9 \text{ mg/l} \times 6 \text{ MGD} \times 8.34 \text{ lbs/gal}}{0.607 \times 0.98}$$

Fluoride Feed Rate = 75.7 lbs/day

Use a screw-type volumetric feeder made by Wallace and Tiernan. (See Table 4–6 on page 79). These capacities are given in cubic feet per hour. The density of sodium silicofluoride is approximately 65 lb/cf.

$$\text{Fluoride Feed Rate} = \frac{75.7 \text{ lbs/day}}{65 \text{ lbs/cf} \times 24 \text{ hr/day}}$$

Fluoride Feed Rate = 0.05 cfh

A Wallace and Tiernan volumetric feeder will be selected. Remember that 0.05 cfh is the average capacity, and the technical data gives the maximum capacity. Thus, use a value of 0.10 to select a feeder. From Table 4–7, the high gearbox, Step 1, and 3/4-inch screw size would be the best choice. Therefore, the volumetric feeder for each of the two identical plants should be a Wallace and Tiernan Model Series 32–055, with a high-speed gearbox and a 3/4-inch screw.

PROBLEM 4–8

In Problem 4–4, a community in Colorado is going to fluoridate its water system, using hydrofluosilicic acid and one injection point.

TABLE 4-6
TECHNICAL DATA—LMI
SPECIFICATIONS—SERIES A

SERIES	A14 A74		A34		A15 A75		A16 A76	
OUTPUT CAPACITY	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**
Gallons per day	.14	14.0	.04	14.0	.24	24.0	.48	48.0
Gallons per hour	.006	.6	.002	.6	.01	1.0	.02	2.0
Liters per hour	.023	2.19	.008	2.19	.038	3.79	.076	7.57
ML or CC per min.	.80	38.0	.13	38.0	.63	63.0	1.26	126.0
Output per stroke ML or CC	.08	.38	.08	.38	.13	.63	.26	1.26
Maximum injection pressure	250 PSI (17.5 kg/cm²)		250 PSI (17.5 kg/cm²)		110 PSI (7.7 kg/cm²)		55 PSI (3.85 kg/cm²)	

SPECIFICATIONS—SERIES B

SERIES	B11 B71 BE1		B12 B72 BE2		B13 B73 BE3	
OUTPUT CAPACITY	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**
Gallons per day	.19	38.5	.31	60.0	.50	108.0
Gallons per hour	.008	1.6	.012	2.5	.022	4.5
Liters per hour	.03	6.0	.05	9.5	.085	17.0
ML or CC per min.	.50	100.0	.79	158.0	1.42	284.0
Output per stroke ML or CC	.10	1.0	.16	1.58	.28	2.84
Maximum injection pressure	150 PSI (10.5 kg/cm²)		100 PSI (7 kg/cm²)		50 PSI (3.5 kg/cm²)	

SPECIFICATIONS—SERIES D

SERIES	D10 D70 DE0		D11 D71 DE1		D12 D72 DE2		D13 D73 DE3		D14 D74 DE4	
OUTPUT CAPACITY	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**
Gallons per day	.16	31.0	.30	60.0	.48	96.0	1.2	240.0	2.4	480.0
Gallons per hour	.006	1.3	.012	2.5	.02	4.0	.05	10.0	.1	20.0
Liters per hour	.024	4.9	.047	9.5	.076	15.2	.19	38.0	.379	76.0
ML or CC per min.	.4	82.0	.783	158.0	1.26	253.0	3.16	631.0	6.3	1262.0
Output per stroke ML or CC	.1	1.02	.20	1.98	.32	3.16	.79	7.9	1.6	15.8
Maximum injection pressure	300 PSI (21 kg/cm²)		150 PSI (10.5 kg/cm²)		100 PSI (7 kg/cm²)		35 PSI (2.45 kg/cm²)		20 PSI (1.4 kg/cm²)	

SPECIFICATIONS—SERIES S

SERIES	S11		S12		S13		S14	
OUTPUT CAPACITY	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**
Gallons per day	6.0	60.0	12.0	120.0	19.0	190.0	31.0	312.0
Gallons per hour	.25	2.5	.50	5.0	.79	7.9	1.3	13.0
Liters per hour	.95	9.5	1.9	19.0	3.0	30.0	5.0	50.0
ML or CC per min.	16.0	160.0	31.5	315.0	50.0	500.0	82.0	820.0
Output per stroke LM or CC	.10	1.03	.21	2.06	.33	3.26	.54	5.36
Maximum injection pressure	300 PSI (21 kg/cm²)		150 PSI (10.5 kg/cm²)		90 PSI (6.3 kg/cm²)		60 PSI (4.2 kg/cm²)	

SPECIFICATIONS—SERIES L

SERIES	L11 L71 L41 L81		L12 L72 L42 L82	
OUTPUT CAPACITY	**MIN.**	**MAX.**	**MIN.**	**MAX.**
Gallons per day	84.0	840.0	168.0	1680.0
Gallons per hour	3.5	35.0	7.0	70.0
Liters per hour	13.25	132.5	26.5	265.0
ML or CC per min.	221.0	2208.0	442.0	4416.0
Output per stroke ML or CC	3.0	30.0	3.0	30.0
Maximum injection pressure	150 PSI (10.5 kg/cm²)		150 PSI (10.5 kg/cm²)	

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SOLUTION 4–8

The design of the metering pump for the acid system would be similar to that discussed in Problem 4–5. The selection of the proper metering pump would have to take into consideration the highest possible flow rate, using the various fluoride levels. Therefore, the highest and the lowest fluoride feed rates must be found. There would be a manual change in the setting every time a well pump was turned off or on, thus, a pacing meter is not required.

The highest fluoride feed rate would occur when all wells are turned on.

Fluoride natural level$_h$

$$= \frac{0.4 \times 400}{2{,}200} + \frac{0.4 \times 400}{2{,}200} + \frac{0.2 \times 550}{2{,}200} + \frac{0.2 \times 550}{2{,}200} + \frac{0.1 \times 300}{2{,}200}$$

Natural fluoride level$_h$ = 0.25 mg/l

Fluoride Dosage$_h$ = 1.0 mg/l – 0.25 mg/l = 0.75 mg/l

Pumping Rate$_h$ = 2,200 gpm = 3,168,000 gal/day

$$\text{Fluoride Feed Rate}_h \text{ (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34 \text{ lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

TABLE 4-7

TECHNICAL DATA - W. & T

Maximum volumetric capacities (cu ft/hr)

LOW SPEED GEARBOX

4-STEP DRIVE PULLY		SCREW SIZE			
STEP	RATIO	3/4″	1-1/2″	2-1/2″	4″
1	12:1	0.03	0.2	1.0	4
2	8:1	0.04	0.3	1.4	6
3	5.3:1	0.06	0.45	2.2	9
4	4:1	0.08	0.6	3.0	12

HIGH SPEED GEARBOX

4-STEP DRIVE PULLEY		SCREW SIZE			
STEP	RATIO	3/4″	1-1/2″	2-1/2″	4″
1	12:1	0.10	0.8	4	16
2	8:1	0.16	1.2	6	24
3	5.3:1	0.24	1.8	9	36
4	4:1	0.32	2.4	12	50

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$$\text{Fluoride Feed Rate (lbs/day)}_h = \frac{0.75 \text{ mg/l} \times 3.17 \text{ MGD} \times 8.34 \text{ lbs/gal}}{0.79 \times 0.23}$$

$\text{Fluoride Feed Rate}_h = 109 \text{ lbs/day}$

The lowest fluoride feed rate would be either with Well Number 1 or Well Number 5.

$\text{Fluoride Dosage}_1 = 1.0 \text{ mg/l} - 0.4 \text{ mg/l} = 0.6 \text{ mg/l}$

$\text{Pumping Rate}_1 = 400 \text{ gpm} = 0.57 \text{ MGD}$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34 \text{ lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)}_1 = \frac{0.6 \text{ mg/l} \times 0.57 \text{ MGD} \times 8.34 \text{ lbs/gal}}{0.79 \times 0.23}$$

$\text{Fluoride Feed Rate}_1 = 15.7 \text{ lbs/day}$

$\text{Fluoride Dosage}_5 = 1.0 \text{ mg/l} - 0.1 \text{ mg/l}$

$\text{Fluoride Dosage}_5 = 0.9 \text{ mg/l}$

$\text{Pumping Rate}_5 = 300 \text{ gpm} = 0.43 \text{ MGD}$

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{dosage (mg/l)} \times \text{capacity (MGD)} \times 8.34 \text{ lbs/gal}}{\text{AFI} \times \text{chemical purity}}$$

$$\text{Fluoride Feed Rate (lbs/day)}_5 = \frac{0.9 \text{ mg/l} \times 0.43 \text{ MGD} \times 8.34 \text{ lbs/gal}}{0.79 \times 0.23}$$

$\text{Fluoride Feed Rate}_5 = 17.76 \text{ lbs/day}$

Therefore, the fluoride feed rate when Well Number 1 (or Well Number 2) is on by itself would be the lowest.

$$\text{Fluoride Feed Rate (lbs/day)}_h = \frac{109 \text{ lbs/day}}{10 \text{ lbs/gal}} = 10.9 \text{ gal/day}$$

$$\text{Fluoride Feed Rate (lbs/day)}_L = \frac{15.7 \text{ lbs/day}}{10 \text{ lbs/gal}} = 1.57 \text{gal/day}$$

A metering pump that will handle a range of 3 to 20 gallons/day must be selected, remembering it is best to operate the metering pump in the mid-range. Using an LMI electronic metering pump (from Table 4–6) the ''A'' series pump, Model A74 would be the best choice. Checking the discharge pressure of 100 psi, it is satisfactory. (Note: At low flow, the metering pump will be operating above the manufacturer's minimum of 0.24, but is lower than generally recommended by CDC.)

CHAPTER FIVE
INSTALLATION OF FLUORIDATION SYSTEMS

5.1 General

It is impossible to discuss installation of fluoridation equipment without some basic knowledge of water treatment systems. While detailed descriptions are beyond the scope of this manual, some basic facts can be presented. There has been some necessary simplification in the interest of clarity. This chapter shall use some terms, such as rapid sand filters, clearwells, flocculation basins, solid contact basins, etc. without detailed explanations. The reader is referred to a good text book on water treatment plant design for additional information.

There are no national laws, regulations, or requirements governing the design or installation of fluoridation equipment. The U.S. Environmental Protection Agency does set standards for the maximum amount of natural fluoride which can be in drinking water (MCL's), but these standards do not apply to adjusted fluoridation.[1] The laws, regulations, and requirements for water fluoridation come from the State drinking water programs. The U.S. Centers for Disease Control has been the national focus for water fluoridation and has developed many recommendations concerning the engineering aspects of fluoridation. Most of these are contained in this manual.

In general, the following practices for the engineering aspects of fluoridation are followed by the State drinking water program:

1. A permit from the State is almost always required before the community (or school) can fluoridate.

2. Plans and specifications must be prepared (in many States by a licensed engineer) and submitted to the State for approval prior to construction.

3. Safety devices are required. These vary greatly from State to State, but they generally include vacuum breakers, anti-siphon devices, and bypass lines.

4. In many States, a fluoridation system can't be started up until they have been inspected and approved by the State engineers. In some States, the operators are also required to have some formal training prior to startup.

5. Most States require equipment for the safety of the water plant operator, such as long gauntlet gloves, chemical aprons, respirators, goggles, showers, eye wash facilities, etc. These requirements need more attention and better enforcement after the final inspection of the construction.

6. Almost all States now require some level of operator certification prior to the operation of the fluoridation system.

7. Almost all States require daily sampling for fluorides. Many States require daily sampling from each individual source (well).

8. Generally, all States require certain records to be kept, such as daily sample results, daily weights of chemicals, calculation of fluoride levels, etc.

Most States do not strongly enforce their rules and regulations concerning fluoridation. Water fluoridation is not covered under the Safe Drinking Act of 1974, and thus is given a lower priority than items covered in the Act. While those involved in fluoridation tend to disagree with that position, it is a fact of life and probably will remain so.

5.2 Types of Water Plants

The installation of the fluoridation equipment, especially the point of injection, depends greatly on the type of water system or water treatment plant. While the classification of water plants can be confusing even to engineers, broad general types of systems can be identified. See Table 5–1 below.

The three major types of water systems are the single well, surface treatment plant, and the water softening treatment plant. The multiple well water system is a complex single well system. The solid contact process is a form of the water softening plant. It combines the rapid mix, flocculation, and setting basins into one unit. The iron and manganese removal treatment plant is an aeration system and is a form of well system. Also, aeration treatment plants can be used for the removal of hydrogen sulfide (H_2S). See Figures 5–1, 5–2, 5–3 on pages 96 and 97.

Of course, there are many combinations of the above. For example, a large water system may include a well field and a city reservoir, thus combining surface treatment and water softening. Sometimes it is hard to type cast a particular water plant because it will contain several types within its system. A water system can be as simple as a one distribution water line to a complex multiple type treatment system. Fortunately, most of the 60,000 water systems in this country will clearly be one type of water system.

5.3 Chemicals Used in Water Plants

The number and kind of chemicals used in a water treatment plant vary widely. See Table 5–2 page 98. In general, the chemicals used depend on the characteristics of the water to be changed rather than the type of

TABLE 5–1

TYPES OF WATER SYSTEMS

Type of System	Source of Water	Chemicals Commonly Used*
Distribution	Other Systems	Chlorine
Single Well	Ground	Chlorine, Fluoride, Polyphosphate
Multiple Wells	Ground	Chlorine, Fluoride, Polyphosphate
Surface Treatment Plant	Surface (Lake, River)	Chlorine, Fluoride, Lime, Alum, Activated Carbon, Potassium Permanganate, Polyelectrolyte
Water Softening Plant	Ground	Chlorine, Fluoride, Alum, Lime, Polyphosphate, Carbon Dioxide
Solid Contact (Water Softening) Plant	Ground	Chlorine, Fluoride, Alum, Lime, Polyphosphate, Carbon Dioxide
Iron/Manganese Removal Plant	Ground	Chlorine, Fluoride, Potassium Permanganate, Manganese Greensand
Ion Exchange	Ground/Surface	Chlorine, Fluoride, Zeolite, Polystyrene Resins

*There are many other chemicals that can be used depending on the characteristics of the water—see Table 5–2.

water plant. For example, chlorine is used for disinfection, fluorides for fluoridation, activated carbon for taste and odor control, etc. The specific type of chlorine or fluoride chemical used may depend upon the type of water plant—for example, sodium fluoride in a single well system or gas chlorination in a surface treatment plant.

In order to make the pipes easier to identify, painting the pipes in the pipe galleries of water treatment plants is a good practice. Color coding helps to prevent possible errors when taking samples or performing maintenance. The color scheme is recommended in the 1982 Recommended Standards for Water Works-A Report of the Committee of the Great Lakes-Upper Mississippi Board of State Engineers.[2] For all fluoride lines the pipes should be light blue with red bands. Also, the name "fluoride" and the direction of flow should be printed on the pipe.

5.4 Fluoride Injection Point

The first consideration in selecting the fluoride injection point is that it must be a point through which all the water to be treated passes. In a water plant, this can be in a channel where the other water treatment chemicals are added, in a main coming from the filters, or in the clear well. If there is a combination of facilities, such as a treatment plant for surface water plus supplemental wells, it must be at a point where all water from all sources passes. If there is no such common point, it means that separate fluoride feeding installations will have to be made for each water facility.

Another consideration in selecting a fluoride injection point is the question of fluoride losses in filters. Whenever possible, fluoride should be added after filtration to avoid the substantial losses which can occur, particularly with heavy alum doses or when magnesium is present and the lime-soda ash softening process is being used. There can be up to a 30 percent loss if the alum dosage rate is 100 ppm of alum. On rare occasions, it may be necessary to add fluoride before filtration, such as in the case where the clearwell is not inaccessible or so far away from the plant that moving chemicals would not be economical.

FIGURE 5-1
SINGLE WELL WATER SYSTEM

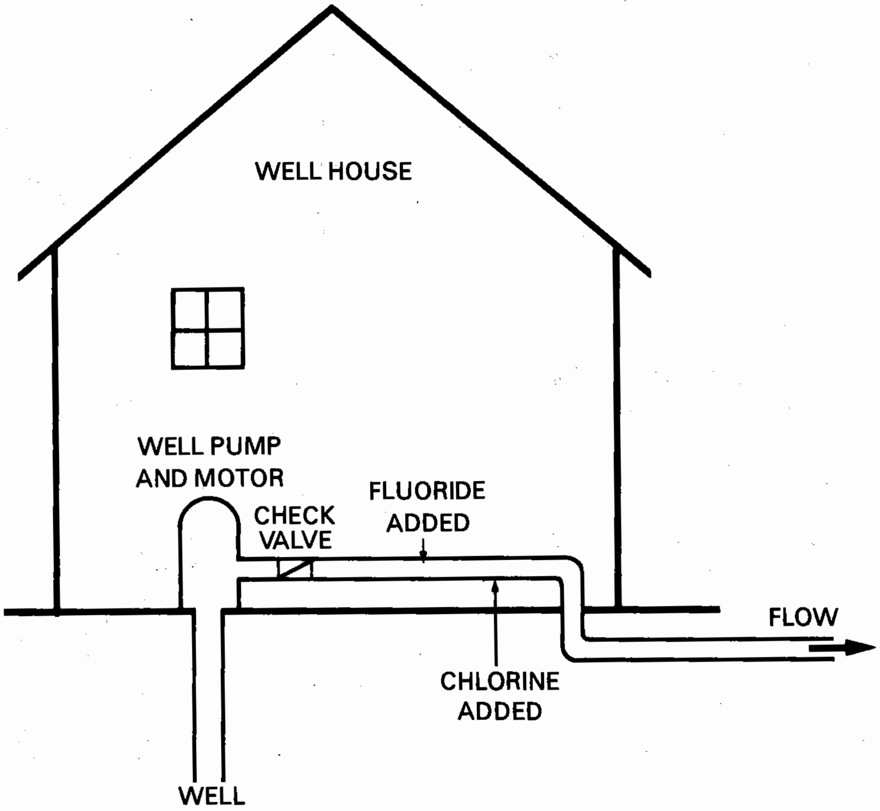


FIGURE 5-2
WATER SURFACE TREATMENT PLANT DIAGRAM

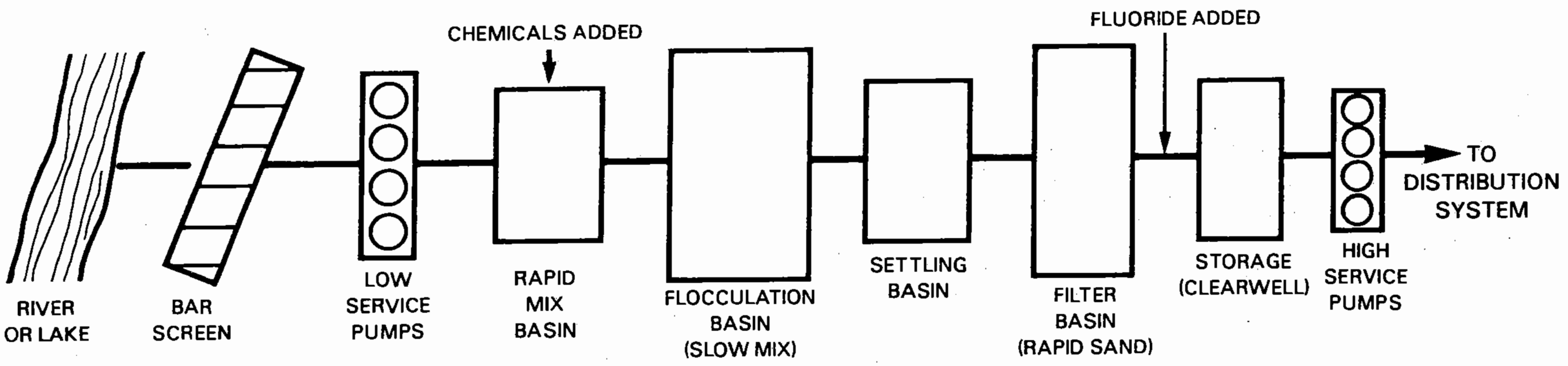


FIGURE 5-3
WATER SOFTENING PLANT DIAGRAM

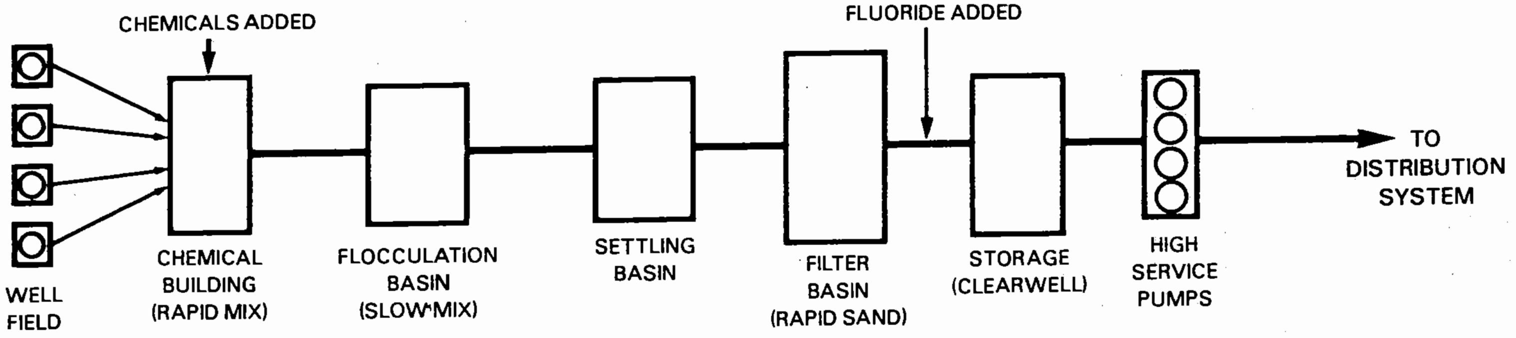


TABLE 5-2

CHEMICALS COMMONLY USED IN A WATER TREATMENT PLANT

NAME	USE
* 1. Ammonia (anhydrous)	Disinfection
* 2. Hydroxide ammonium	Disinfection
3. Ammonium sulfate	Disinfection
4. Bromine	Disinfection
* 5. Chlorine (gas)	Disinfection, oxidation agent
6. Chlorine dioxide	Disinfection
7. Hydrochlorites	
- Calcium hypochlorite (HTH)	Disinfection
- Sodium hypochlorite (household bleach)	Disinfection
- Lithium hypochlorite	Disinfection
* 8. Ozone	Disinfection
9. Silver nitrate	Disinfection - home units
10. Ultraviolet light	Disinfection
11. Activated carbon	Absorption material
12. Charcoal (carbon)	Absorption material
13. Aluminum ammonium sulfate	A Metal coagulant, dechlorinator
14. Sulfur dioxide	Dechlorination agent
15. Sodium sulfite	Dechlorination agent
16. Sodium bisulfite	Dechlorination agent
17. Sodium thiosulfate	Dechlorination agent
18. Ion - exchange resins	Water softener media
19. Sodium chloride (salt)	Water softener media
20. Glauconite (greensand)	Water softener media
21. Silica sand	Filter media
22. Anthracite coal	Filter media
23. Aluminum sulfate (alum)	A Metal coagulant
24. Ferric sulfate	A Metal coagulant
25. Ferrous sulfate	A Metal coagulant
* 26. Ferric chloride	Coagulant
27. Sodium aluminate	Coagulant, pH control
28. Aluminum potassium sulfate	Coagulant
* 29. Calcium oxide (quick lime)	pH control, coagulant
30. Calcium hydroxide (hydrated lime)	pH control, coagulant
31. Clay (Bentonite)	Coagulant aid
32. Calcium carbonate	Coagulant aid, pH control
33. Activated silica	Coagulant aid
34. Sodium silicate	Coagulant aid
35. Sodium carbonate (soda ash)	pH control, coagulant
36. Carbon dioxide (gas)	pH control
* 37. Hydrochloric acid	pH control
* 38. Sodium hydroxide	pH control, corrosion control
* 39. Sulfuric acid	pH control
40. Potassium permanganate	Disinfection, remove color, oxident
41. Polyelectrolytes	Coagulant aid
42. Polyphospates	
- Calcium polyphosphate	Corrosion control, Iron control
- Zinc polyphosphate	Corrosion control, Iron control
- Sodium tri-polyphosphate	Corrosion control
- Sodium hexa-metaphosphate	Corrosion control
43. Sodium fluoride	Fluoridation
44. Sodium silicofluoride	Fluoridation
* 45. Hydrofluosilicic acid	Fluoridation
46. Copper sulfate	Algae control

* Very hazardous material for plant operator

When other chemicals are being fed, the question of chemical compatibility must be considered. If any of these other chemicals contain calcium, the fluoride injection point should be as far away as possible in order 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 but at another point, or it can be added to the clearwell. If the lime is being added to the clearwell, the fluoride should be added to the opposite side. If it is not possible to separate injection points, an in-line mixer must be used.

In a single well system, the fluoride injection point will be in the discharge line of a pump. If there is more than one pump, it can be in the line leading to the elevated tank or other storage facility. In the surface water treatment plant and the water softening plant, the ideal location of the fluoride injection point is in the line from the rapid sand filters to the clearwell. This will provide maximum mixing. Sometimes the clearwell is located directly below the rapid sand filter, and discharging any chemicals directly to the clearwell is difficult.

At the fluoride injection point, the location of the chemical line should be 45 degrees from the bottom of the pipe and protrude 1/3 of the pipe diameter into the pipe. This will allow better mixing without sediments collecting around the injection point. The fluoride injection point should never be located at the top of the line because of the air binding problems. A valve or corporation cock should be part of the installation. It is strongly recommended that an anti-siphon device always be included. See Figure 5–4 on page 100.

5.5 Equipment Installation

5.5.1 General

Fluoridation installation should be considered during the design stage. The decisions made during the design phase will greatly affect the installation. The best installation is one that incorporates as many of these factors as possible:

1. Simple, accurate feeding equipment
2. Minimum chemical handling
3. Consistent with the above two factors, the lowest overall cost based on amortization of equipment and cost of chemical
4. Ease in collecting reliable records
5. Minimum maintenance of feeder, piping, and injector equipment

A thorough knowledge of the types of equipment available is a must in order to determine the best installation.

Before a type of feeder can be selected, sufficient and appropriate space for its installation must be provided. If there is an existing water plant where other water treatment chemicals are being fed, usually space for an additional feeder is no problem. If there is no treatment plant, as is often the case with well systems, then there may be a well house, or perhaps even some type of shelter, near an elevated storage tank. The feeder must be placed in a dry, sheltered area, near the point of fluoride injection, and preferably in a place which has storage space for chemicals. There must be electrical power available (in most cases) and a water line for solution preparation. The location must be accessible for chemical replenishment and maintenance. Other than these basic requirements, consideration should be given to the desirability of isolation of chemical storage from other materials for adequate ventilation and general convenience.

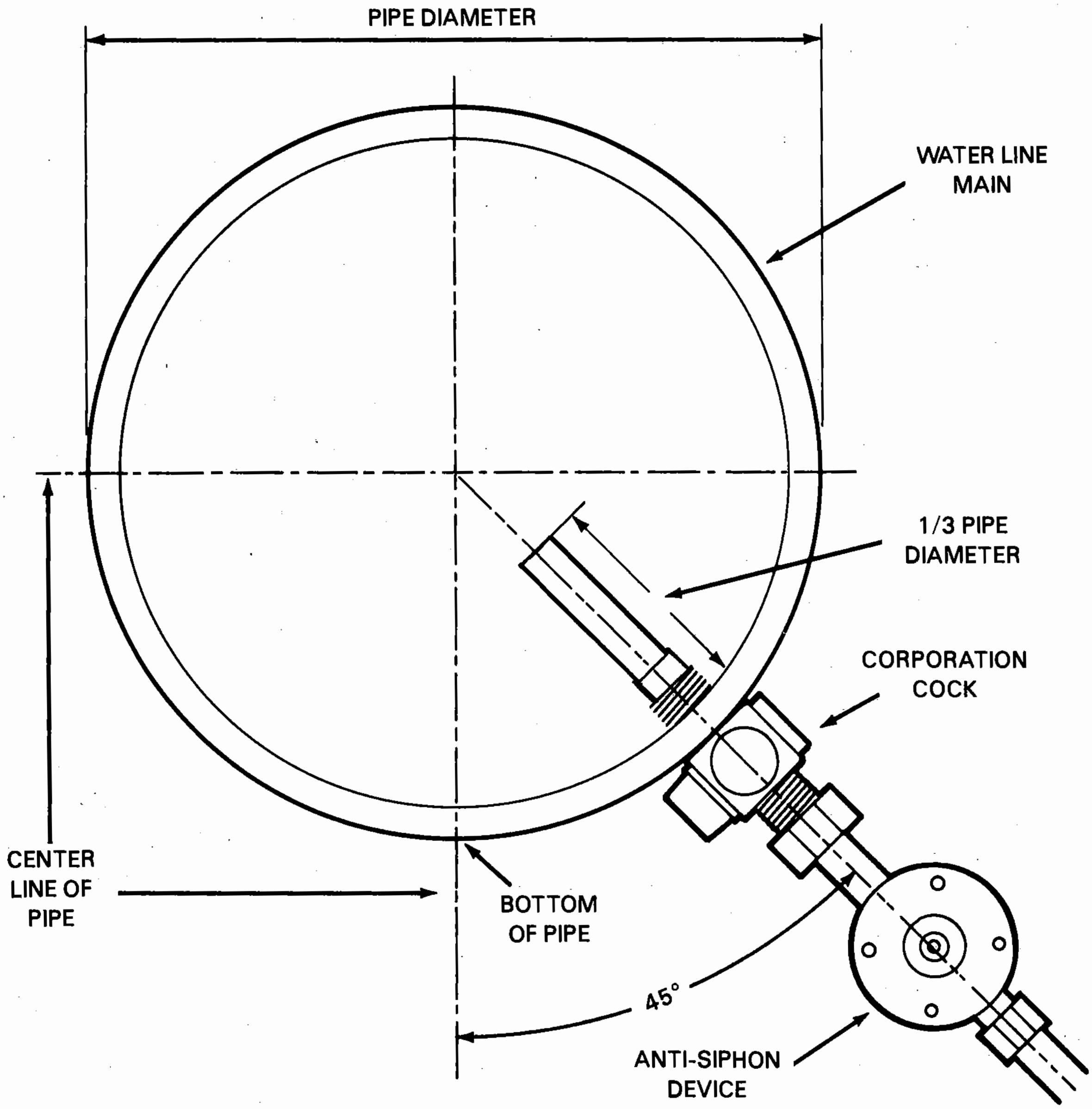
When the fluoridation system is tied electrically to the well pump, it should be physically impossible to plug the fluoride metering pump into any "hot" electrical outlet. The pump should be plugged only into the circuit containing the overfeed protection. One method of insuring this is to provide a special plug on the metering pump which is compatible only with a special outlet on the appropriate electrical outlet. This special plug should be clearly labeled. This recommendation is true for both acid feed and saturator systems.

5.5.2 Hydrofluosilicic Acid Installation

The simplest and easiest fluoridation installation is an acid feed system with a single well. The typical installation would include a carboy of acid (or drum), small metering pump, and scales. See Figure 5–5 on page 101. The carboy (or drum) should be vented to the outside and sealed around the pump intake line and vent line. If the room where the fluoride equipment is located is exposed to strong direct sunlight, the tubing pigment should be black. The black color screens out the ultraviolet rays, which can cause cracking of the translucent tubing.

The metering pump should be located on a shelf not more than 4 feet above the carboy or solution container, if possible. Note: Many manufacturers recommend that the pump be located so that it has a flooded suction line (low). This is not recommended in fluoridation. The suction line should be as short and straight as possible, and there should be a foot-valve and strainer at the bottom and, if necessary, a weight to hold it down.

FIGURE 5-4
FLUORIDE INJECTION POINT



The discharge line from the metering pump should be as short and straight as possible. Avoid sharp curves or loops in the line. Injecting solution into the top of a pipe should be avoided, since air collects there and can work its way into the metering pump check valve or the discharge line and cause air-binding. It is recommended that an anti-siphon valve be installed at the injection point.

Many metering pumps come equipped with, or have available as an accessory, an anti-siphon discharge valve. This may be mounted directly on the pump head. If solution is to be fed into an open channel or a low-pressure pipeline, a "loaded" discharge valve should be used. This is a spring-loaded check or diaphragm valve which will not open until the pump discharge pressure exceeds a certain fixed value. A common setting is about 15 psi.

As mentioned above, the carboy of acid should be completely sealed. This is a major problem at many fluoridation sites. Several kinds of carboys are used as containers for acid. The most common (and the latest style) is a flat top. An example of how the carboy or drum container can be sealed is shown in Figure 5–6 on page 102.

Many States are concerned about the possibility of an overfeed because of adverse publicity. If this becomes a major consideration, a physical break box can be used. See Figure 5–7 on page 103. The break box reduces the chance for an overfeed from siphoning, with only a marginal increase in cost. Only the amount of acid in the break box can be siphoned into the main water line. Even in very small installations, this amount would be relatively insignificant. This rather ingenious installation was developed by the State of Minnesota. The major difference in cost is the dual head metering pump instead of a single head metering pump.

The installation of an acid feed system in a larger water plant that uses bulk storage is similar to the simple well installation with some exceptions. See Figure 5–8 on page 104. A day tank is necessary instead of a carboy. Under normal operating conditions, the day tank *should not contain* over 2 days' supply of acid. The day tank must also be sealed around the outer lip of the container, the vent hole, and the pump suction line opening.

FIGURE 5-5
HYDROFLUOSILICIC ACID INSTALLATION — CARBOY (DRUM) STORAGE

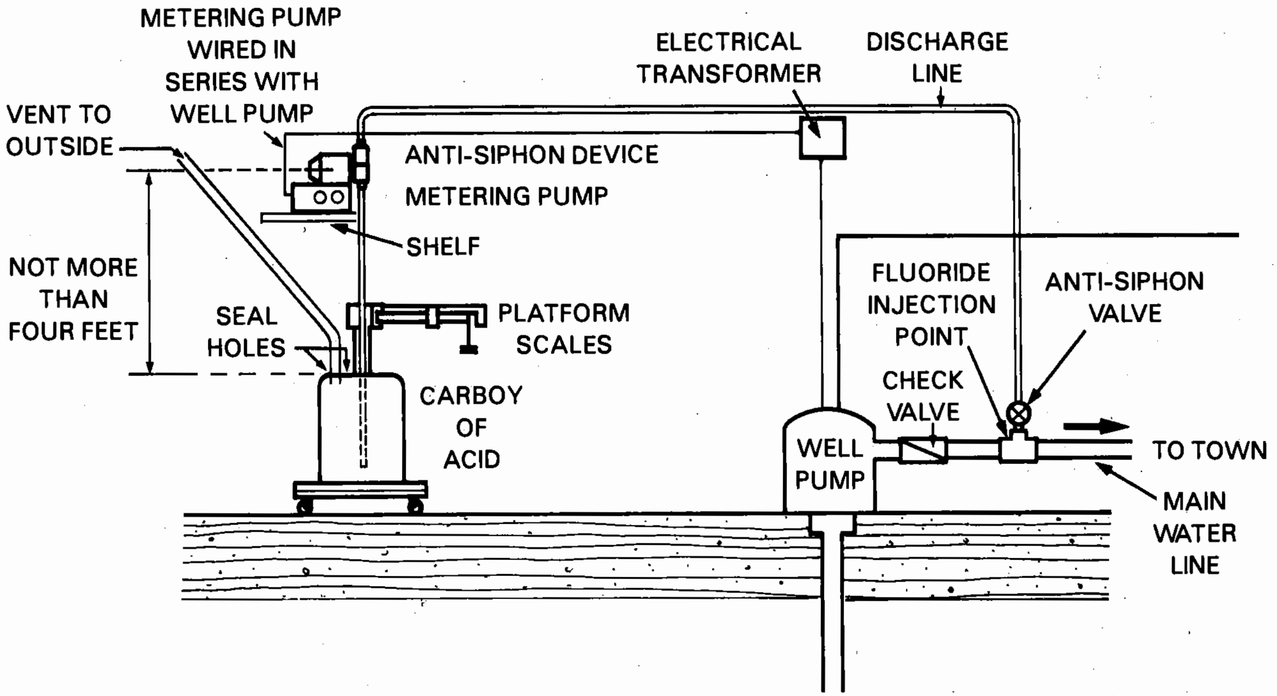


FIGURE 5-6
CONNECTION TO H_2SiF_6 ACID CARBOY (DRUM)

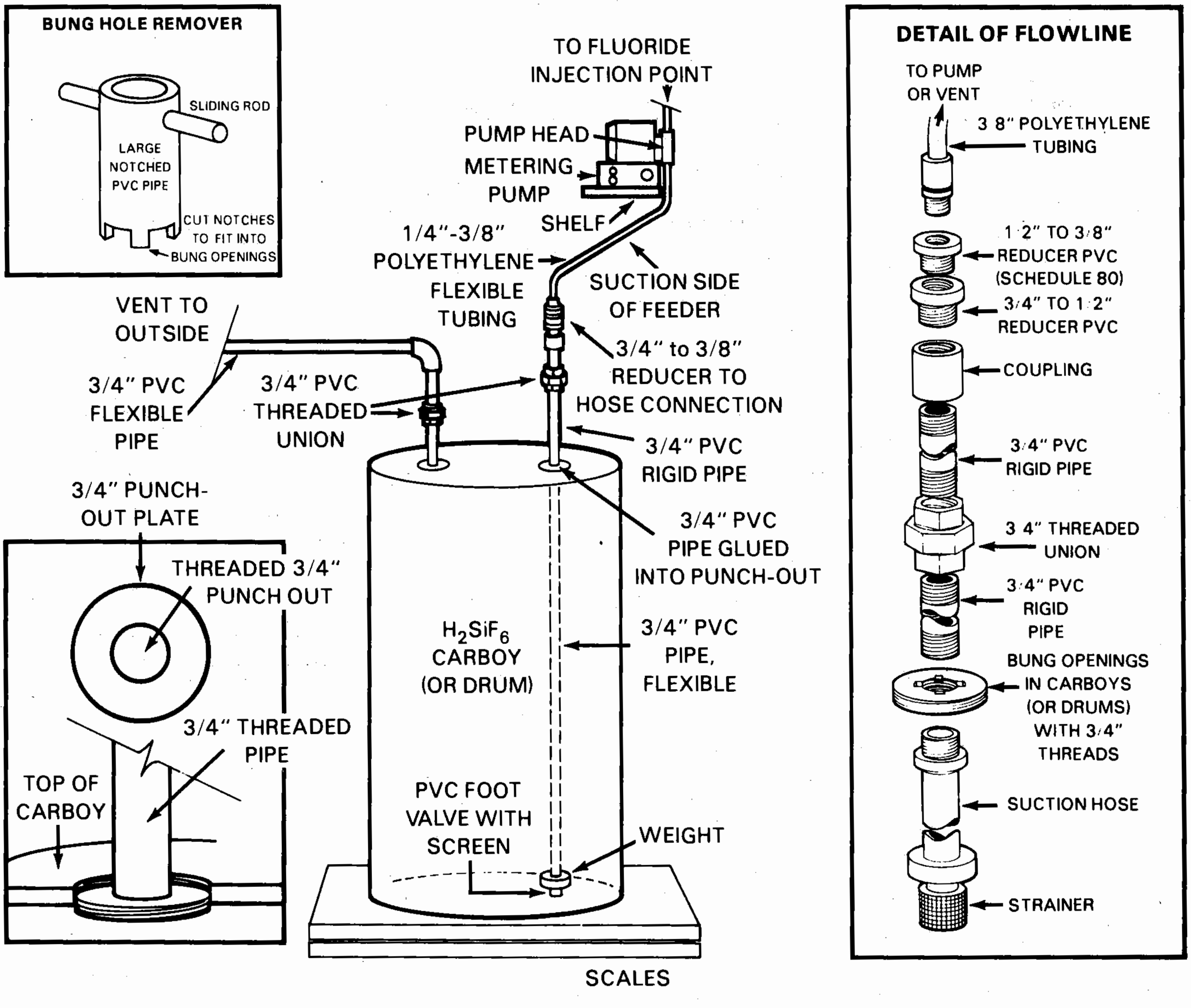
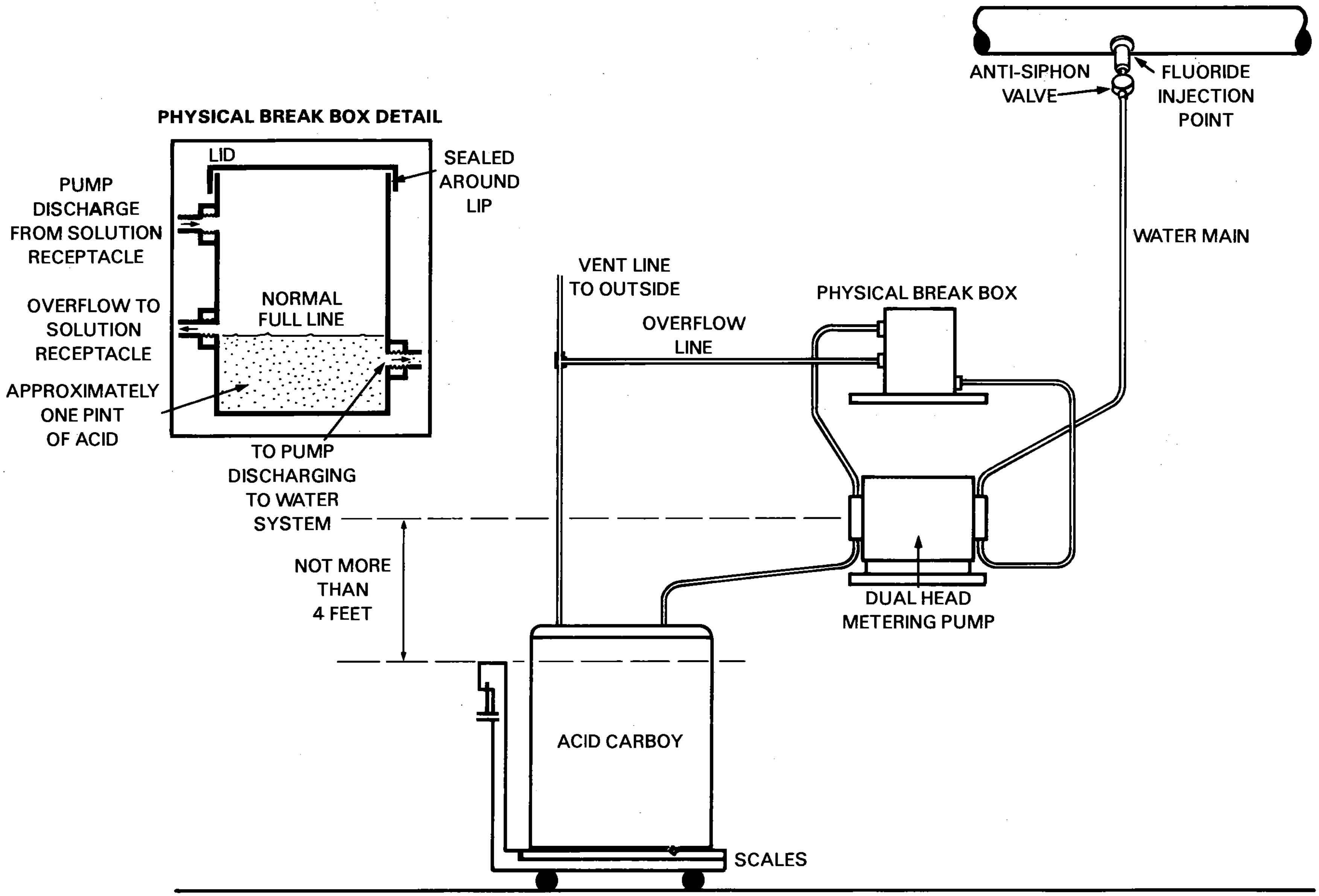
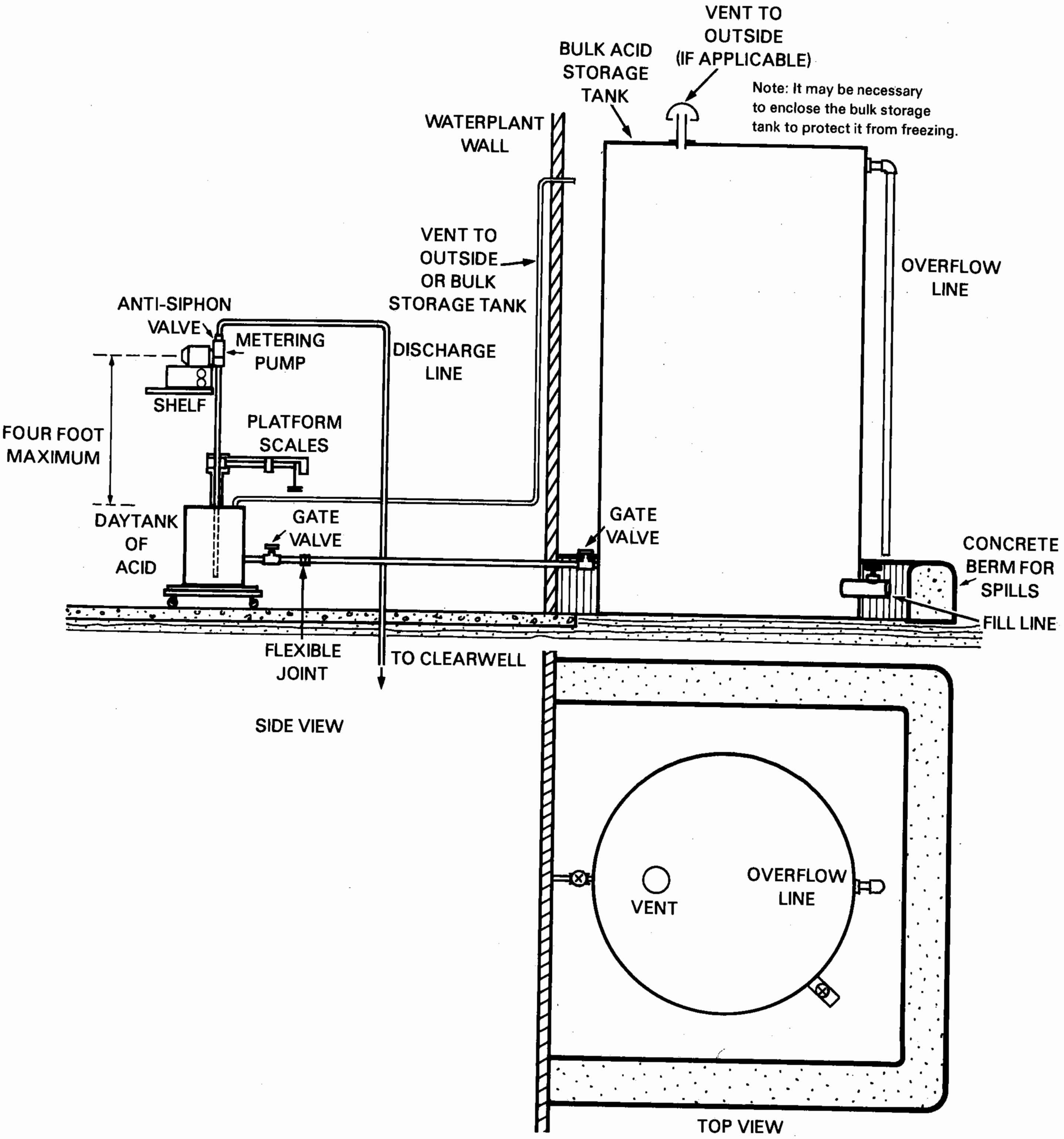


FIGURE 5-7
BREAK BOX INSTALLATION



*Courtesy of Minnesota State Department of Health

FIGURE 5-8
HYDROFLUOSILICIC ACID INSTALLATION — BULK STORAGE



There should be flexible connections in the bulk storage line and in the pump suction line (if it is not flexible tubing). This is to prevent inaccurate reading on the scales. The vent line should go from the day tank to the bulk storage tank (near the top), instead of just to an outside wall. The metering pump should discharge the acid into the line going into a clearwell. If the discharge is directly into the clearwell, the anti-siphon device is not needed at this discharge point.

The bulk storage tank must be vented on top and, when located outside, should be surrounded by a berm to contain any spills. The acid will freeze if exposed to sustained temperatures at or below 4 degrees F. Therefore, in northern climates, the bulk storage tank must be protected from freezing.

Generally, the metering pumps in these types of large fluoridation installations are *not* tied electrically to the high or low service pumps. The settings on the metering pumps are made manually. For example, if the acid is added in the clearwell, the change in the number of high service pumps in use would result in a manual change in the metering pump setting.

5.5.3 Sodium Fluoride Installation (Saturators)

The sodium fluoride saturator is a very simple fluoridation system. It requires only a little more space and piping than the straight acid feed. Many of the same comments made on the acid feed installations apply to the saturator installations. The metering pump should be located not more than 4 feet over 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 anti-siphon valve. There also should be an anti-siphon valve at the fluoride injection point if the fluoride solution is injected into a water main.

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 feed water 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 off-set it sufficiently to permit access to the container for filling and cleaning. It is not recommended to mount the metering pump on the lid of the saturator.

The saturator capacities are based on the make up water temperature. The maximum withdrawal rates are given in Table 5-3 below. Note, in theory it is possible to fluoridate at the maximum withdrawal rate at the minimum bed level of 12 inches at 7.93 gallons per hour. This would fluoridate a flow of up to 3.4 MGD.

TABLE 5–3

SATURATOR CAPACITIES * (MAXIMUM WITHDRAWAL RATE)
(gallons per hour)

Wet Bed Depth (Inches)	Water Temperature 60 F	50 F	40 F
12″	7.93	7.53	7.14
13	8.72	8.33	7.94
14	9.51	9.13	8.73
15	10.31	9.92	9.53
16	11.10	10.72	10.32
17	11.89	11.51	11.12
18	12.69	12.31	11.91
19	13.48	13.10	12.71
20	14.27	13.90	13.50
21	15.07	14.69	14.30
22	15.86	15.49	15.09
23	16.65	16.28	15.89
24	17.45	17.08	16.68

*Approximations—not based on actual data

But a saturator should never be pushed to its limit for any length of time. When a saturator's capacity is approached, then another method of fluoridation should be considered, such as the use of hydrofluosilicic acid.

The downflow saturator, as explained before, is not as popular as the upflow. In time it may be phased completely out, but, many of them are still in use. See Figure 5–9 on page 107. The following information is given to prepare a downflow saturator for use:

A. 1. With the manifold in place, carefully place by hand a 2 to 3″ layer of coarse, clean gravel (1 to 2″ size) in the saturator tank around the manifold or cone and over the manifold or over the lower edge of the cone. Then place another 2 to 3″ layer of finer gravel (1/2 to 1″ size) over the coarse gravel.

   2. Place a 6 to 9" layer of clean, sharp, filter sand over the gravel. (Do not use beach sand, "clayey" sand, or ordinary soil.) Level the sand surface. (A 12″ layer of 1/8″ to 1/4″ filter gravel can be substituted for the sand and coarse gravel layers.)

B. Add 200 lbs. of coarse crystalline sodium fluoride. (Do not use powered NaF or fine crystal.) Add water to keep down the dust and to assist in leveling the fluoride surface.

C. Check to see if the float has room to operate. If necessary, make a depression in the fluoride surface to provide clearance for the float and float rod.

D. If you have not already done so, connect a cold-water supply line to the water intake of the saturator. The line should contain a small water meter for use in calculating the feed rate, and there should be a shut-off valve between the meter and the saturator.

E. Turn on the water supply and adjust the float position if necessary. The low-water level should be no less than 2″ above the fluoride surface, and the high-water level should be just below the overflow outlet.

F. Insert the metering pump suction line into the pipe leading to the inner cone or manifold as the case may be. Adjust the length of the suction line so that the foot-valve and strainer are 2 to 3″ above the bottom of the saturator tank. The saturator is now ready for use.

G. By looking through the translucent wall of the saturator tank, the layers of fluoride, sand, and gravel should be distinguishable. When the thickness of the fluoride layer decreases to 12″, add another 100 lbs. of fluoride. It would be wise to add the fluoride when the water level is at its lowest level, or if necessary, to shut off the water temporarily until there is enough room for the fluoride without causing water to come out of the overflow opening.

H. Before more fluoride is added to the saturator, the surface of the fluoride layer in the saturator should be scraped free of accumulated dirt, insoluble material, or the slimy film of fine particles that sometime forms. Such routine maintenance permits better percolation of water through the fluoride layer and extends the length of time between clean-outs.

I. At regular intervals, usually on an annual basis, but depending on the severity of use, the saturator will have to be cleaned out. A typical schedule calls for a clean-out every 3 months or when the quantity of water being treated is in excess of 1500 gpm and the accumulation of dirt in the saturator is moderate.

The upflow saturator installation is very similar to the downflow saturator installation, with some exceptions. See Figure 5–10 on page 108. If a liquid level switch is used, CDC recommends that there be a solenoid valve and a vacuum breaker installed. The vacuum breaker must be between the solenoid valve and the water inlet. Also, CDC recommends that a flow restrictor with a maximum flow of 2 gallons per minute be installed. (Note: Many States allow flow restrictors of up to 4 gpm.) There must be a minimum water pressure in the inlet line of 20 psi.

FIGURE 5-9
SODIUM FLUORIDE INSTALLATION – DOWNFLOW SATURATOR

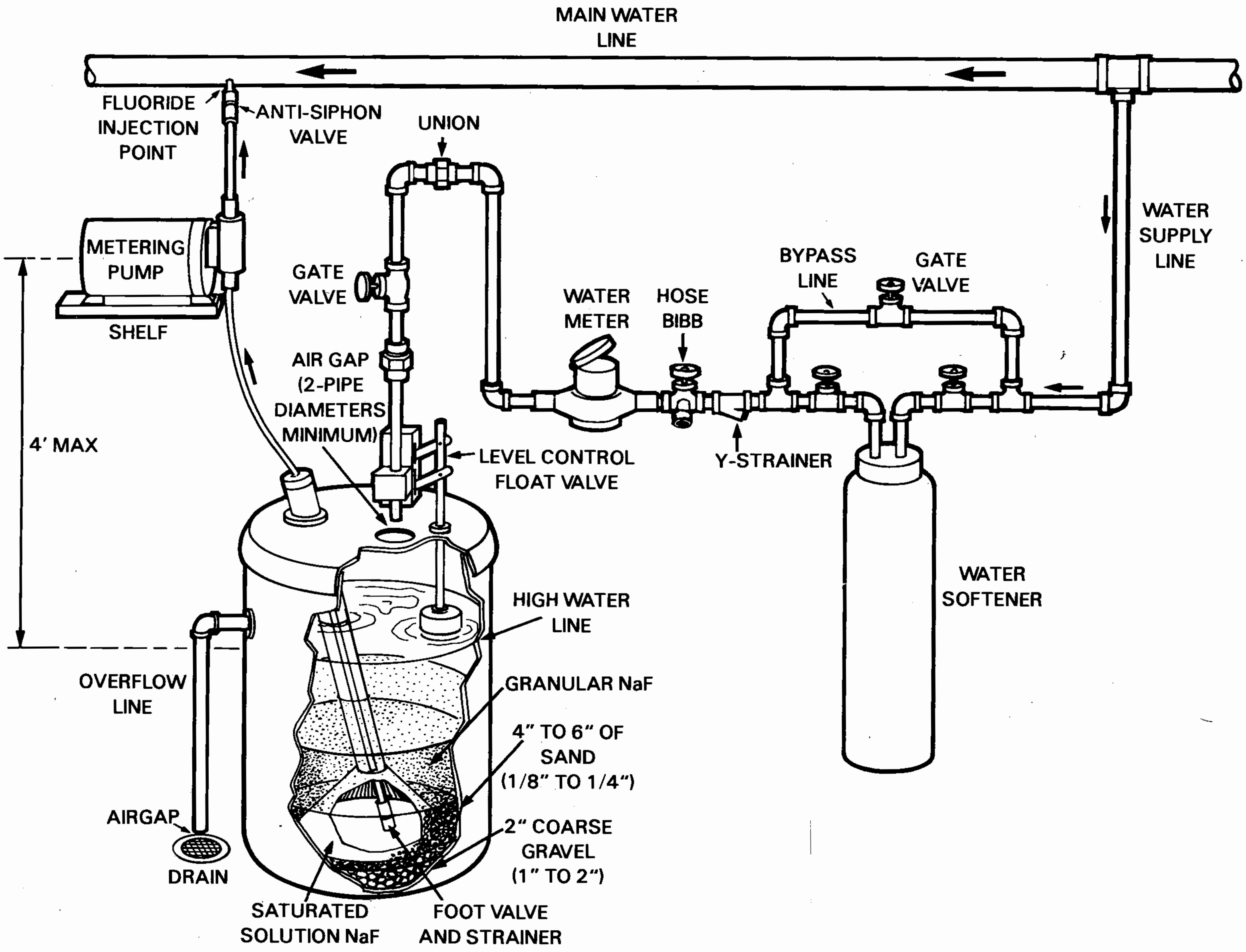
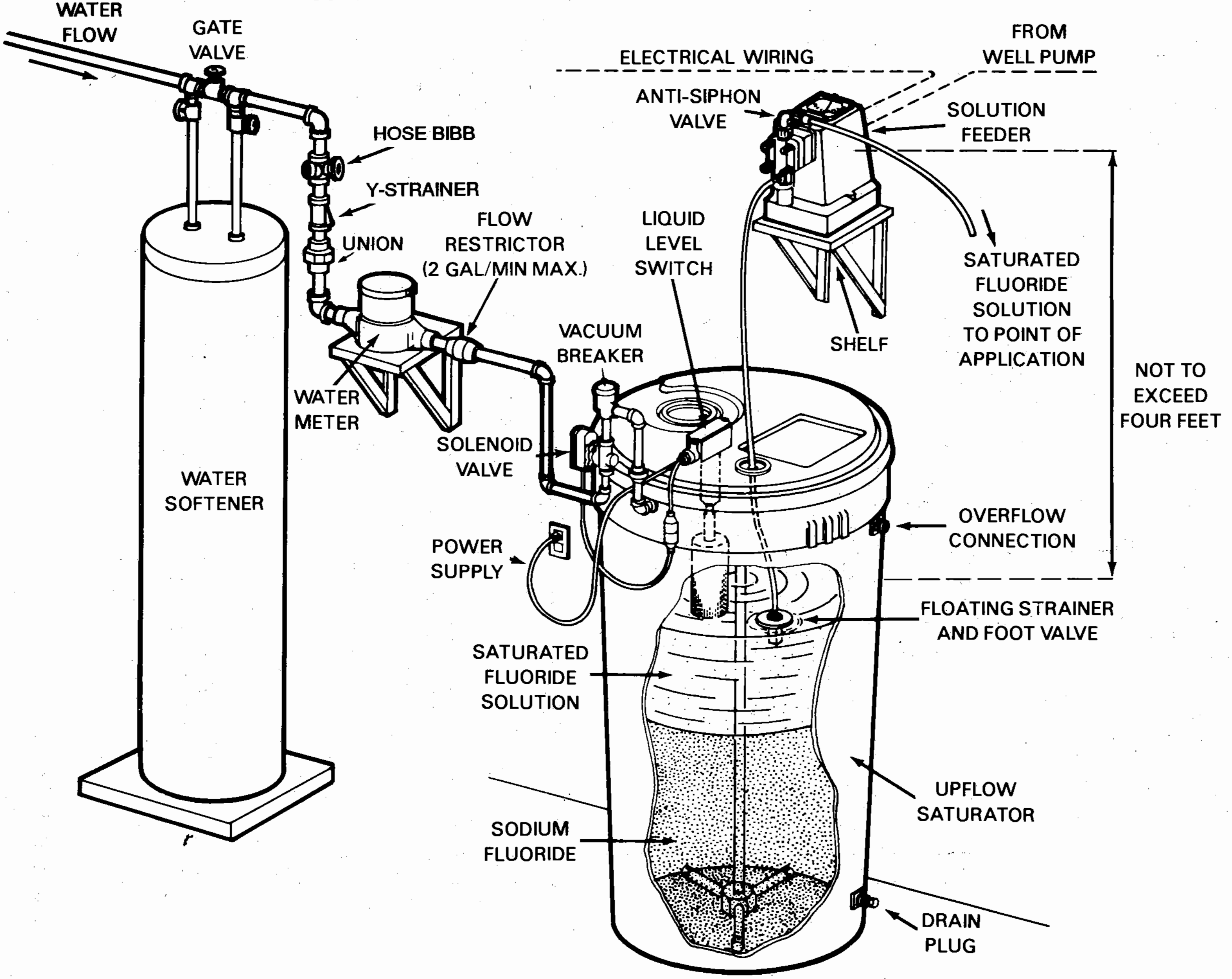


FIGURE 5-10
SODIUM FLUORIDE INSTALLATION – UPFLOW SATURATOR



The recommendation for a different kind of metering pump plug to prevent connecting the metering pump into a "hot" electrical outlet is especially important with an upflow saturator installation. This is because a solenoid valve requires the "hot" electrical connection, and, it thus becomes easy to make a mistake.

To prepare an upflow saturator for use, the following steps should be taken:

A. With the distributor tubes in place, and the floating suction device removed, add 200 to 300 pounds of sodium fluoride directly to the tank. Any type of sodium fluoride can be used, from coarse crystal to fine crystal, but fine crystal will dissolve better than coarse material. Powder can be used, but is not as desirable as a crystal form of sodium fluoride.

B. 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.

C. Replace the intake float and connect it to the feeder intake line. The saturator is now ready to use.

D. By looking through the translucent wall of the saturator tank, the level of undissolved sodium fluoride can be determined. Whenever the level is low enough, another 100 pounds of fluoride should be added.

E. The water distributor slits are supposed to be essentially self-cleaning, and the accumulation of insolubles and precipitates does not constitute as serious a problem as it does in a downflow saturator. However, periodic cleaning is still required. Frequency of cleaning is dictated by the severity of use and the rate of accumulation of debris.

F. Because of the thicker bed of sodium fluoride attainable in an upflow saturator, higher withdrawal rates are possible. With 300 pounds of sodium fluoride in the saturator tank, more than 15 gallons per hour of saturated solution can be fed—a rate sufficient to treat about 5,000 gallons per minute of water to a fluoride level of 1.0 ppm.

G. The method for calculating the amount of fluoride feed is the same for both types of saturators. The fixed water inlet rate of 2 gpm should register satisfactorily on a 5/8" meter.

5.5.4 Sodium Silicofluoride Installation (Dry Feeders)

Only the installation of the volumetric dry feeder will be discussed because it is the most typical one used. See Figure 5-11 on page 110. The gravimetric feeder installation would be, in essence, the same. When installing a dry feeder, placement should be so that the solution from the solution tank can fall directly into the chemical feed channel, if possible. If other considerations dictate that the feeder be placed some distance from the point of application, the drain line should be as direct as possible, with adequate slope and sufficient size to preclude precipitation build-ups and subsequent stoppages.

Obviously, the dry feeder installation must be on a firm, level foundation if the scales are expected to perform satisfactorily. If there is a small hopper on the feeder, it must be readily accessible for filling, and if an extension hopper is used, it should extend vertically upward to the filling area, without angles which could trap material. For the water supply line to a volumetric feeder, there must be a section of flexible hose between the solution tank 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 or mechanical vacuum-breaker, or some other type of anti-siphon device. The air gap is the most positive protection against the dangers of a 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 vacuum breaker must be placed between the point of entry to the solution tank and any restrictive device in the pipeline, and must be installed in an elevated location.

5.6 Maintenance

To realize the full benefits of fluoridation, it is very important that the optimal fluoride content be consistently maintained in the drinking water supply. To ensure constant fluoride feed, proper maintenance of the fluoridation equipment is essential. Experience has shown that the basic reason for low or erratic fluoride levels is due to poor operation and maintenance.

It is difficult to include a comprehensive chapter for operation and maintenance in this manual. It would take one complete manual to accomplish that task. Therefore, the information given here is, at best, incomplete. The reader is directed to the manufacturers' literature and to any good text book on operation and maintenance. Only the very basic information on maintenance is presented in this manual.

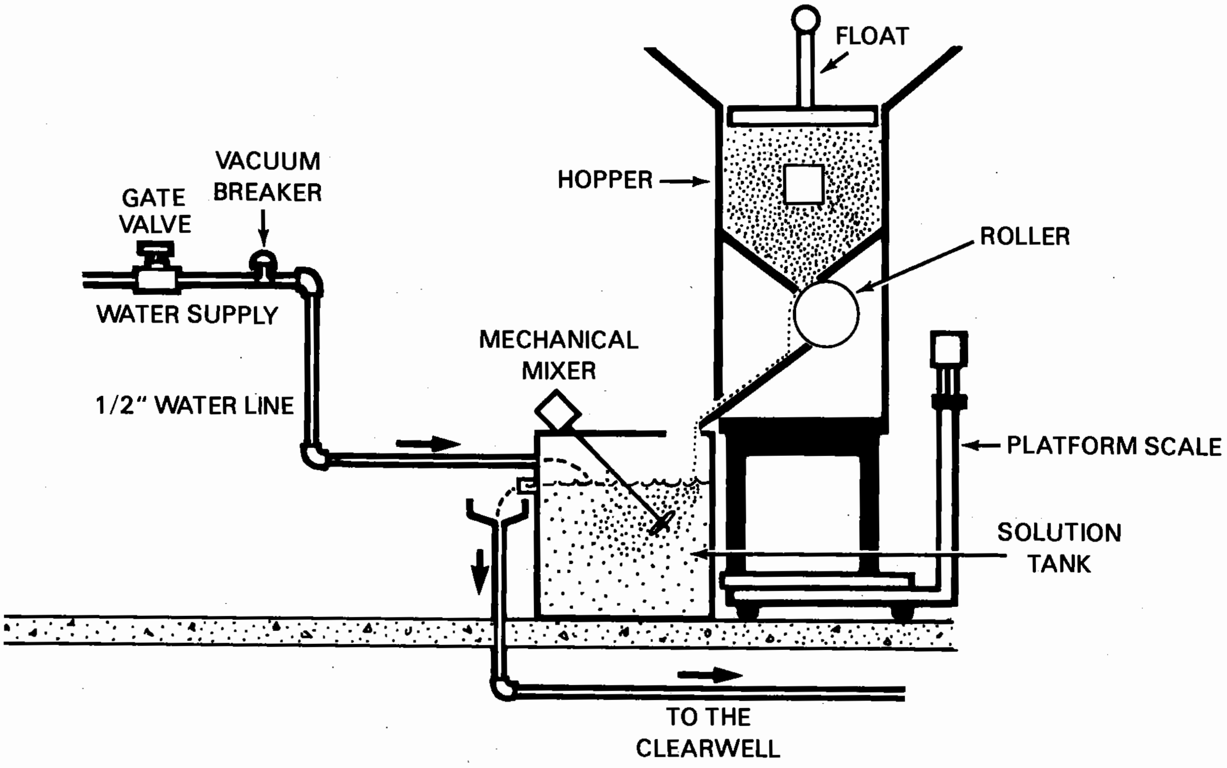
Like any other mechanical device, fluoride feeders must be kept clean and lubricated if they are expected to function efficiently. A regular program of maintenance will also minimize costly break-downs and ensure long life for the equipment. Electric motors usually come with a prescribed schedule for lubrication—the right type, amount, and frequency of lubrication are all important. Gear boxes 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 greasing should be observed.

Fluoride feeders and related equipment, when purchased, usually are accompanied by an instruction booklet and/or parts list. The instruction booklet will contain information on maintenance and repairs, and the parts list will enable the operator to select replacement parts when needed.

If booklets or lists have been lost, copies can usually be obtained through the manufacturer of the equipment or his representative. The equipment representative will also be happy to suggest a list of spare parts to be kept on hand. Having parts available can greatly minimize the length of shut-downs due to equipment failure. In the larger water plants, having an entire spare feeder available may prove to be prudent.

The best fluoride feeders will operate as intended only if the measuring mechanism is kept clean and operative. Thus, the mechanisms of both types should be regularly inspected for signs of wear or damage, and repairs or replacement should be made before the machine actually breaks down.

FIGURE 5-11
VOLUMETRIC FEEDER INSTALLATION



Leaks in and around the discharge line of a metering pump are an annoyance and can affect the quantity of solution delivered and thus result in low fluoride levels. Leaks are corrosive, and can result in damage in 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 metering pump, will be immediately apparent and will adversely affect delivery and can eventually lead to air-binding and cessation of feed.

Any time strong solutions are used, the possibility of precipitation build-up is present. In a solution feed system, precipitates in the feeder pumping chamber or on the check-valves will affect delivery rate or even stop the pump entirely. Deposits in the suction or feed lines can build up until flow stops, and a coating of insoluble matter on a saturator bed can prevent water from percolating through. If the deposits are the result of water hardness, softening the make-up 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.

CHAPTER SIX

SCHOOL FLUORIDATION

6.1 General

Children who live in areas of our country not served by community water supplies are often deprived of the benefits of drinking water that has been optimally fluoridated. Currently, about 26 million people (11.4 percent of the U.S. population) reside in areas which lack central water systems.[1,2] Because community fluoridation is not feasible for these areas, other ways of preventing dental caries must be developed if adequate natural fluorides are not present in the water supply. Several other methods have been suggested—among them are individual home fluoridators, fluoride tablets, and the fluoridation of the water supplies of rural schools. The latter method seems particularly appealing since it would reach sizeable numbers of children with minimal demands on personnel, equipment, and funds. Early work was done with school fluoridation by Dr. Joseph A. Yacovone in Rhode Island[3], and later by Drs. H. S. Horowitz and Stanley Heifetz.[4,5]

Schools not on a municipal water system usually have private wells, and the water from these can easily be fluoridated. In the United States, nearly all school-age children annually spend from 20 to 25 percent of their total waking hours in school. A similar percentage of the total water consumed by these children is probably drawn from the schools' water supplies.

The most obvious limitation of school water fluoridation is that children are approximately 6 years old before they begin attending school, whereas maximum dental benefits occur when fluoridated water is consumed from birth. However, data obtained from communities with adjusted fluoridation indicate that children who are 6 years of age or older at the time fluoridation is initiated do derive dental benefits.[4,5] These findings are not surprising considering that, at age 6, there is still a significant amount of calcification which will occur in the later-erupting permanent teeth. In addition, considerable fluoride uptake occurs between the completion of permanent tooth calcification and eruption. Evidence also indicates that the topical action of fluoridated water will confer some caries protection to erupted teeth.

A second factor limiting the effectiveness of having only the school water supply fluoridated is that the exposure to fluoridated water in school is intermittent, since children attend school only five days a week for only part of the day for only part of the year.

6.2 Optimal Fluoride Level

The fluoride level in the school system should be maintained at 4.5 times the recommended optimum for community fluoridation. Studies in Pike County, Kentucky, and Elk Lake, Pennsylvania, have shown that there is about a 35 to 40 percent reduction in tooth decay at this level.[6,7]

Since some studies have indicated that the raising of the fluoride level in schools resulted in greater decay reduction, it has been theorized that still higher levels might impart even greater benefits. However, a 12 year study at a school near Seagrove, North Carolina, where fluoride was being added at 7 times the recommended community optimal level, showed that additional benefits were slight, thus the higher levels are not recommended.[8,9]

When discussing school fluoridation (4.5 times optimum), the question of safety must always be considered, since it is known that full-time exposure to fluoride levels, as low as twice the optimum, can cause some degree of dental fluorosis. Yet, findings of early epidemiological studies have shown that children who consumed water that was virtually fluoride-free at home, but who, when at school, drank water with natural fluoride at levels of 6 ppm and 14 ppm, were uniformly free of any objectionable signs of dental fluorosis.[5] Because fluorosis is a developmental disturbance that can be produced only at the initial stage of enamel formation, the teeth of school-age children may be too advanced to be adversely affected by higher levels of fluoride. Other epidemiologic findings support this evidence. Thus, the level of 4.5 times the optimum for communities will cause no objectionable fluorosis.

6.3 Criteria for Fluoridation

Normally, a school served by a community water supply is not recommended for fluoridation. If there is any possibility of fluoridating the community supply, it is more advantageous to work toward this end than to fluoridate the school. Also the engineering problems involved in fluoridating a single building or group of buildings already on a municipal water supply are difficult. An individual well supply for a school is more desirable from an engineering standpoint.

An evaluation of the fluoride content of the water consumed at home by students attending a school being considered for fluoridation must be made. If none of the children attending a school drink adequately fluoridated water (natural or adjusted) at home, that school is a candidate for fluoridation. However, situations often occur where only some of the children attending a school consume fluoridated water at home. Such situations can occur when children from both a community and the surrounding rural area attend a school and either (1) the community is fluoridated and the rural homes are not; or (2) some of the rural homes have adequate natural fluoride and the community is not fluoridated. Such situations need to be evaluated carefully, taking into account the relative number of children not consuming fluoridated water at home, the economics of fluoridating a school for only a portion of the children, and potential physiological effects. In general, if more than 25 percent of the children attending the school already receive fluoridated water at home, the school should not be fluoridated.

6.4 CDC Recommendations for School Fluoridation

The following recommendations incorporate the experience of several States with large school fluoridation programs and also represent the ''state-of-the-art'' of school fluoridation. Several of the recommendations address the need for overfeed protection in school fluoridation systems.

6.4.1 Administrative

1. School personnel should be relied upon only for the most cursory operation and maintenance of equipment and for monitoring. The primary burden of operating and maintaining school fluoridation equipment must fall upon the State. Regular visits to each school system are necessary, as well as a thorough annual (usually during summer recess) overhaul and inspection of all equipment. A school fluoridation program should not be undertaken unless resources are identified and available at the State level to undertake these operation and maintenance responsibilities. Exact requirements vary from State to State, primarily because of geographic factors, but normally one full-time technician should be assigned to each 25–35 schools.

2. School officials should be provided with an operating procedure to follow, should an overfeed occur. This should include procedures to shut the equipment down, prevent consumption of superfluoridated water, and notify appropriate State personnel.

6.4.2 Monitoring and Surveillance

1. Sampling and analysis should be conducted at each school before the beginning of each school day. No new school fluoridation system should be installed unless an agreement to this effect has been made with the appropriate school officials. Sampling before each school day will not prevent overfeeds, but will prevent anyone from consuming high levels of fluoride in their drinking water.

2. Check samples should be analyzed for each system at least weekly by the State in order to confirm the use of proper analytical techniques at each school. Results should be compared to results obtained at the school.

6.4.3. Equipment and Installation

1. The use of saturators and sodium fluoride is recommended. See Figures 6–1 and 6–2 on pages 114 and 115. Manual preparation of batches of sodium fluoride solution is not recommended because of problems in maintaining a uniform feed solution strength and because manual solution preparation often requires that unskilled personnel become involved. In schools with relatively low water usages, manual filling of the saturator tanks by State personnel may warrant consideration. This allows for a uniform saturated solution, but is better from an overfeed protection standpoint because only a finite amount of solution is available and because no ''live'' electrical outlet is necessary for the liquid

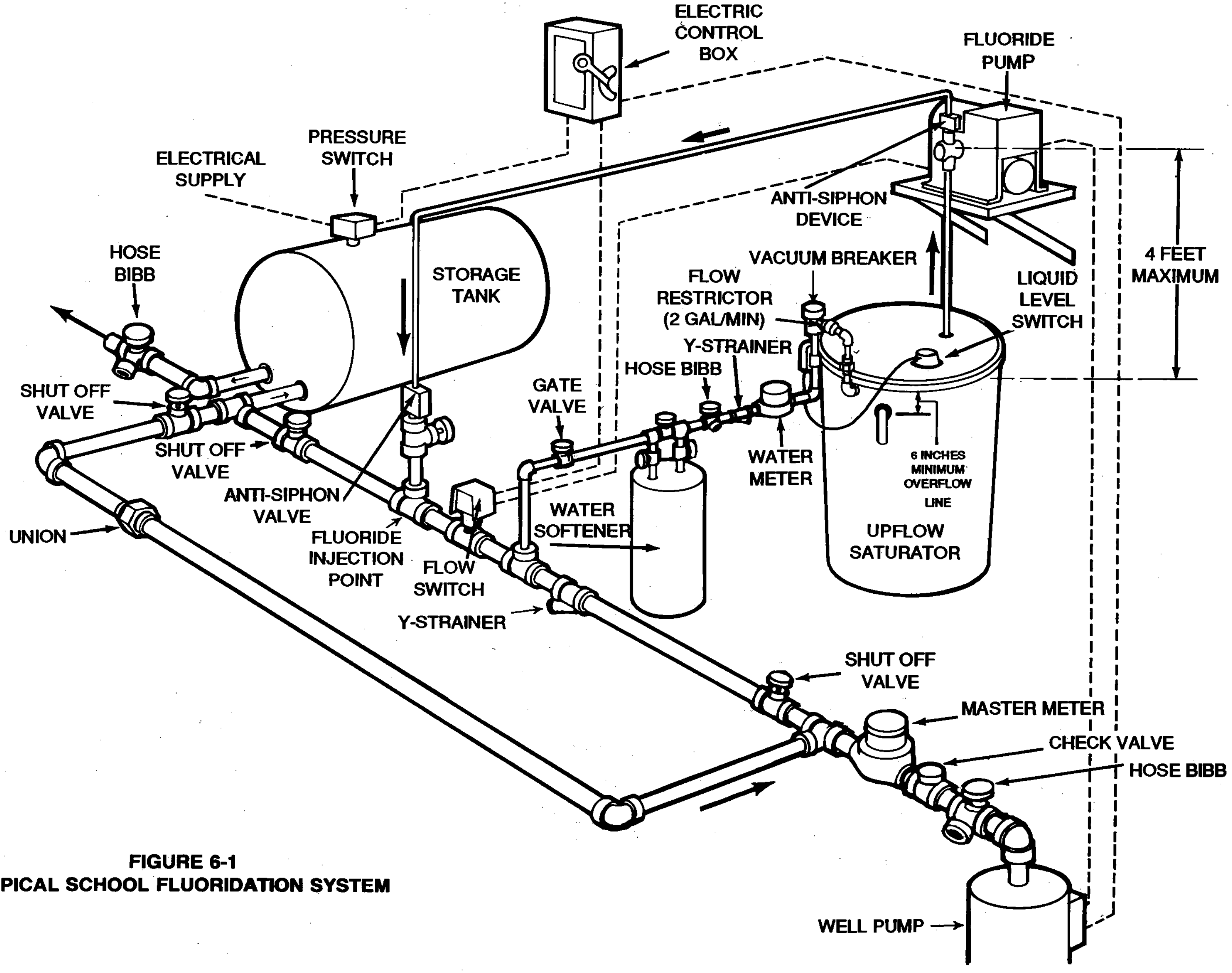


FIGURE 6-1
TYPICAL SCHOOL FLUORIDATION SYSTEM

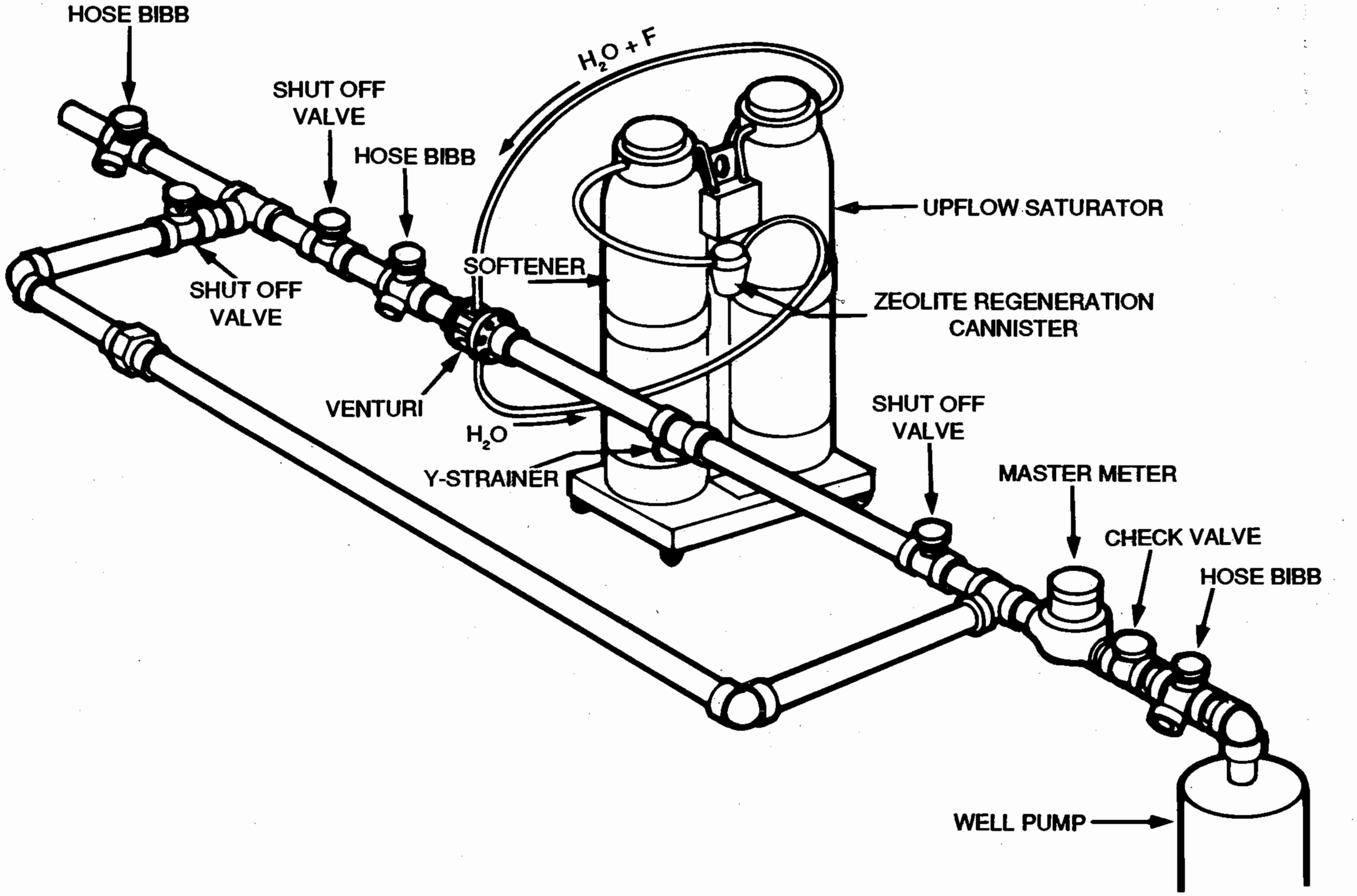


FIGURE 6-2
TYPICAL VENTURI SCHOOL FLUORIDATION SYSTEM

level control switch (see equipment recommendation 5). Potential problems with sticking solenoid valves are also eliminated.

2. Fluoridation systems should be installed only where the water is supplied by a well pump with a fairly uniform flow. Therefore, the practice of installing fluoridation systems in schools on a municipal water supply line should be discouraged.

3. In general, school systems should avoid using pacing meters in variable flow situations. However, it is sometimes impossible to install fluoridation equipment in a school without a pacing meter to control the solution feed pump. In such cases, "electronic" flow meters with magnetically operated contactors are the preferred equipment. Where pacing meters are necessary, they should be used with a flow switch wired in series with the pacing meter. Also, precautions (such as a double check valve) should be taken to ensure that no backflow can cause the contact meter to rotate backward.

4. The metering pump should be wired electrically in series with the flow switch and the main well pump.

5. The metering pump should be equipped with a spring-loaded, diaphragm type, anti-siphon device on the discharge site.

6. An anti-siphon device should be installed at the fluoride injection point. The valve should use a diaphragm that is spring-loaded in the closed position. Also, a corporation cock valve should be used in the line at the fluoride injection point.

7. There should be a check valve in the main water line near the well head. The check valve should be tested frequently for leakage.

8. There should be a vacuum breaker installed in the water line supplying the saturator. It should be installed at the high point between the solenoid valve and the saturator tank.

9. A flow restrictor, with a maximum flow of 2 gallons/minute, should be installed on the saturator inlet line so that the tank does not fill too fast to provide a saturated solution.

10. Metering pumps should be sized so as to feed near the mid-point of their range where they are most accurate. Care should be taken to avoid greatly oversized feed pumps which could seriously overfeed if accidently set too high.

11. It should be physically impossible to plug the solution feed pump into any "hot" electrical outlet. The pump should be plugged only into the circuit containing the overfeed protection. One method of ensuring this is to provide a special plug on the feed pump compatible only with a special outlet on the appropriate electrical outlet.

12. System should be built with some form of bypass arrangement so that the fluoridation equipment may be totally isolated during service and inspection periods. By using such an arrangement, the equipment can be taken out of service without shutting off the school's water supply. A corporation stop is used in some States to provide a portion of this function. Others use a pipe loop with gate valves isolating the injection point, meters, strainers, check valves, make-up water, take-off fittings, etc.

13. The use of a master meter on the school water service line and a make-up water meter is encouraged so that calculations can be made to confirm that the proper amounts of fluoride solution are being fed. These meters should be read periodically and the results recorded. Records should also be kept on the amount of sodium fluoride used at each school in the preparation of the feed solutions.

14. A flow switch should be installed, electrically, in series with the metering pump and the well pump. Flow switches should be properly sized and installed to operate at the flow ranges encountered in each school. They should be installed "upstream" above the fluoride injection point.

15. Some electronic meter-paced solution feed pumps have switches to allow for manual priming. Such switches should be spring-loaded to prevent the pump from continuously feeding if erroneously put into service with the switch in the manual position.

16. The fluoridation equipment must be placed in an area which is secure from tampering and vandalism.

17. A routine maintenance schedule should be set up and specify intervals at which various activities are to be performed. Some recommended items to be checked include: pump diaphragm, check valve, Y-strainers, injection points (for clogging), flow switch contact and paddles, saturator drum (for cleaning), pressure switch, solenoid valve, float switch, and foot valve.

18. Adequate provisions for cross-connection control, in conformance with State regulations and national standards, must be provided.

CHAPTER SEVEN

FLUORIDE ANALYSIS

7.1 General

It is important that fluorides be fed accurately at the water treatment plant. Frequent determination of the fluoride content of water samples is one way to confirm the adequacy of fluoridation. The results of such laboratory testing for fluorides reveal the concentration at the instant the sample was collected. This chapter will discuss the optimal fluoride levels recommended for community and school fluoridation and will address the methods that can be used for analyzing for fluoride.

7.2 Chemistry of Fluoride Analysis

7.2.1 Introduction

The analysis of fluoride in water involves the determination of the quantity of fluoride present in solution, irrespective of the source of that ion. There is no method capable of distinguishing natural fluoride from added fluoride, thus the fluoride test results will be in terms of total fluoride. (But remember that the test for total fluoride does not include insoluble fluorides or the organic fluorides.)

Because the recommended concentrations of fluoride in potable water are so small, the analytical method must be precise and highly selective. Methods based on classic gravimetric or volumetric techniques are generally not applicable.

Years ago, only the colorimetric methods were suited to the measurement of minute quantities of fluoride. Today the analyst may elect to use the fluoride specific ion electrode test rather than the traditional colorimetric fluoride test (SPADNS). Either method has the required sensitivity—the electrode method, however, has far fewer interferences and is generally more accurate.

Under the Safe Drinking Water Act, rigorous analytical requirements must be met for fluoride analysis. These tests are for the natural fluoride in the drinking water to determine long-term health effects. However, daily testing of adjusted fluoride levels are operational or monitoring tests and do not need to be as precise. For example, under the Safe Drinking Water Act, samples to be analyzed via colorimetric analyses must be distilled prior to color development. Daily operational tests need not he distilled.

7.2.2 Interferences with Fluoride Analysis

The substances which interfere with the analysis of the fluoride ion are shown in Table 7–1 page 119.[1] As can be seen, some of the interferences for the colorimetric (SPADNS) method occur at quite low concentrations. These low concentrations are definitely within the range that occurs in water plants during normal operation. However, most of the interfering substances will be fairly constant in ground water systems, so it is quite easy to account for this interference in the daily monitoring results. It's only when the interfering substance fluctuates widely, as in surface water systems, that either the distillation step or the use of the specific ion electrode method needs to be considered for daily monitoring of the fluoride level.

7.2.3 Fluoride Sampling Collection

The reliability of an analysis of the concentrations of fluoride in a water sample depends upon the sampling method. The water samples must be representative of the water to be examined. In other words, water samples must be collected at a point where the fluoride has become completely mixed with the entire volume of water entering the distribution system. Otherwise, the results will have no significance.

If a sample is collected from a tap, the water should first be run long enough to empty the service pipe and thus obtain a sample representative of the water in the main.

It is not possible to specify the sampling points in general that would be applicable to a particular water supply. The important point is that the samples for analysis show the fluoride content of the water delivered

TABLE 7-1

INTERFERING SUBSTANCES[5]

Concentration of substance, in mg/l, required to cause error of plus or minus 0.1 mg at 1.0 mg/l fluoride

Interfering Substances	SPADNS	Electrode
Alkalinity ($CaCO_3$)	5,000 (-)	7,000 (+)
Aluminum (Al)	0.1 (-)*	3.0 (-)
Chloride (Cl)	7,000 (+)	20,000 (-)
Iron (Fe)	10 (-)	200 (-)
Hexametaphosphate ($[NaPO_3]$)	1.0 (+)	50,000
Phosphate (PO_4)	16 (+)	50,000
Sulfate (SO_4)	200 (-)	50,000 (-)
Chlorine	Must be completely removed with arsenite	5,000
Color & Turbidity	Must be removed or compensated for	—

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*Above figure is for immediate reading

to the consumer. A possible sampling point could be from a water tap in the home of the plant operator, if the operator's house is served by the distribution system being tested.

Water samples should be taken and tested for fluoride at least daily by the plant operator. In some locations the operator may be required to test more than once a day. Consult the State drinking water program to determine how often samples should be collected for testing.

The State may require a certain number of water samples to be submitted each month for fluoride analysis. These are called check samples. (At least one check sample should be taken per month.) When collecting such water samples, it is good practice to collect two samples at the same time: one for submission to the State laboratory and one for analysis by the plant operator. Comparison of these two results can verify the accuracy, or point out any discrepancy, in the results of the tests.

7.2.4 SPADNS Method for Fluoride Analysis

The colorimetric method, or SPADNS photometric method, is based on a reaction in which a dye lake (a deep color) is formed with zirconium and SPADNS dye.[2] (SPADNS is sodium 2-(parasulfophenylazo) -1,8-dihydroxy- 3,6-naphthalene disulfonate.) Any fluoride present in the water sample removes zirconium from the reaction, thus decreasing the intensity of color present. The color of the reaction mixture (water sample plus reagent) varies from very deep red in the absence of fluoride to light red when the concentration of fluoride is high.

The colors produced by different concentrations of fluoride ions are all shades of red, and it is almost impossible to detect the difference in these colors by eye. It is necessary to use a photometer to detect the color differences and therefore determine the concentration of fluoride in a water supply. A photometer is an instrument for detecting differences in color, and consists of a light source, a filter for producing monochromatic light, and a photocell for measuring the intensity of the light transmitted through the sample.

The procedures for using the photometer for analysis of the fluoride concentration in a sample of water consist of adding a measured volume of reagent to a measured volume of the water sample, placing a portion of the mixture in a cell or curvette, placing the cell in the instrument, and determining the fluoride concentration in parts per million (ppm) from the instrument scale.

The fluoride analysis of water is a comparatively delicate operation, as the quantities involved are minute, and the greatest possible accuracy is desirable. For these reasons, the following special precautions should be taken with any of the SPADNS procedures:

- Ensure that the temperature of the standard sample and the water sample is the same, preferably approximately 20 degrees (± 1 degree) C. If the temperatures of the standard and the unknown are different, then the results will not give a correct reading of the fluoride content.

- Ensure that glassware is clean. In the fluoride test, the concentration of fluoride being determined is extremely small. Any fluoride test is very sensitive to small amounts of various chemicals that can interfere. Therefore, *it is absolutely necessary that the colorimeter bottles and all other glassware be clean*. To make sure of the accuracy of the test, it is strongly recommended that the fluoride test be repeated as a check, using the same graduated cylinders and colorimeter bottles. Repeating the test will ensure that the glassware is free of interfering chemicals.

- Measure the reagent accurately.

- If chlorine is present, it should be eliminated, using arsenite solution.

- The glassware should be periodically checked for scratches or chips. The readings can be affected by any obstructions in the glassware.

- To standardize the test equipment, use a standard fluoride solution that has a fluoride content close to what the fluoride content should be for the sample being tested. For example, if the routine test samples have about 1.5 ppm fluoride, it is recommended that a 1.5 ppm standard fluoride solution be bought and used rather than the 1.0 ppm solution.

- Perhaps the most important source of error is the presence of interfering ions in the water sample. None of the colorimetric methods are entirely specific for fluoride, and, to varying degrees, many of the other ions found in water affect the fluoride analysis. The reagents are designed to eliminate the effects of these interfering ions, or to minimize the effects as much as possible. However, if a water supply contains a large quantity of interfering ions, the reagent may not be able to minimize the effects of the interfering ions enough to get an accurate determination of the quantity of fluoride in the water. If the interferences become a problem, the ion electrode method should be considered.

The SPADNS method of fluoride analysis is directly applicable to fluoride samples in the range of 0.1 to 2.0 ppm. Beyond this range, dilutions must be made using deionized water to obtain accurate measure of the fluoride concentration.

7.2.5 Electrode Method for Fluoride Analysis

The electrode method is capable of measuring fluoride concentrations from 0.1 to 10 ppm.[3] A major advantage of the electrode method is that samples generally do not require distillation to eliminate the interferences.

The basis for this method is in the fluoride electrode itself. Most electrodes contain a fluoride solution; at the tip of the electrode is a crystal doped with fluoride ions. The crystal acts as an ionic conductor, so that when the fluoride concentration outside of the electrode is higher than that inside, ions move toward the inside, setting up a voltage potential proportional to the difference in fluoride concentration. Conversely, when the fluoride concentration on the outside is lower than that on the inside, a proportional potential or opposite sign is set up. In most fluoride electrodes, the internal solution is about 10^{-3} molar in fluoride, so concentrations below 19 ppm result in positive voltage readings. Some electrodes contain no internal solution, but the principle of operation is similar.

CHAPTER EIGHT

CENTERS FOR DISEASE CONTROL'S PROGRAM

8.1 General

The Centers for Disease Control (CDC) has been charged with the responsibility for the implementation of a P.H.S. initiative for the promotion of oral health including water fluoridation. This policy states that by 1990 nearly all of the citizens in the United States who are served by community public water supply systems shall obtain the benefits of water fluoridation.[1] This goal of near-universal fluoridation will also be accompanied by strong emphasis on monitoring and surveillance to insure that those who are on fluoridated water systems are receiving optimal levels of fluoride in their drinking water.

During the Federal fiscal years of 1977 to 1981, CDC provided categorical project grants assistance to 36 States, Guam, and 18 communities to expand the availability of optimally fluoridated water. A total of $10,950,000 was awarded during that time, resulting in the fluoridation of 681 community and school water supplies serving over 7,700,000 people.[2] The categorical grants for fluoridation now are included in the State Prevention Health Block Grants.

CDC remains the national focus for the control and prevention of dental and oral diseases, including fluoridation. Specifically, CDC has the following fluoridation activities:

1. Functions for the preparation and dissemination of educational and research material relating to dental disease prevention and water fluoridation.

2. Provides training seminars, both basic and advanced, for State engineers and technicians to assure standardized surveillance, maintenance, and monitoring of fluoridated water systems.

3. Provides and administers a home study course on the engineering aspects of fluoridation for water plant operators.

4. Continues the "Fluoridated Water Proficiency Testing Program" for State labs to insure the accuracy of their fluoride testing programs.

5. Maintains, on an on-going basis, the status of water fluoridation in the U.S.

6. Provides general and specialized technical consultation and assistance to State and local health agencies and private organizations. This includes liaison with other Federal and international agencies and institutions.

7. Serves as a national advocate for, and identifies problems with, the programs for the prevention of dental and oral diseases.

8.2 State Monitoring and Surveillance Program

The need for a good monitoring and surveillance program is essential if fluoridated communities are to provide the optimum level of fluoride to their consumers. It is necessary to define monitoring and surveillance. Monitoring means to test for a particular substance. When a community tests for fluoride in its drinking water, it is monitoring for fluoride. Surveillance means to review the monitoring results. When a State reviews the daily anaylsis of fluoride over a period of time for a community, it is providing surveillance of the fluoride in that community's water system. If the State reviews the monitoring data for all the fluoridated communities within that State, it is providing surveillance of fluoride for the entire State.

The elements of a good monitoring and surveillance program, with some exceptions, will be similar for most States. These elements should include the following items:

1. **State Fluoridation Specialist**
   When a State has a sufficient number of communities or schools fluoridated, there should be at least one technical person responsible for the monitoring and surveillance portion of the fluoridation program. This person should be technically competent (either an engineer or an engineering technician) to assist the fluoridated communities/schools and to review the monitoring data from the communities/schools. It is strongly recommended that this responsibility not be divided among several persons, such as State regional engineers. (Experience has shown that when this responsibility is added to other regional engineering activities, program inconsistencies develop.) If the State has a school fluoridation program, then additional technical personnel will be required. (See Chapter 6.)

2. **Monitoring Data**
   There should be a method of receiving and reviewing monitoring data from all fluoridated water systems. This method should include (1) a system for obtaining the data from the daily analysis of the community/school system and the data from the State monthly check sample; (2) a plan for posting the results; (3) a system for reviewing and analyzing the information. The monitoring data should consist of all daily fluoride analyses from all fluoridated communities and all daily (school days) analyses from all fluoridated school systems.

3. **Follow-up Procedures**
   After the data from all fluoride analyses have been reviewed, a system to follow-up and correct problems must be developed. This procedure is very important since it is the key to any good monitoring and surveillance program. The follow-up procedures may include phone calls, visits, letters, and in extreme cases, enforcement actions.

4. **Operator Training**
   A program for operator training is essential to insure that the consumers of the water from a fluoridated community/school are receiving the optimal level of fluoride. This training course should be one- or two-days' duration; be accessible to all interested operators; and be routinely conducted. One objective of this manual is to provide State personnel with the information and knowledge to conduct such courses.

5. **Technical Assistance**
   The State fluoridation specialist should provide routine technical assistance (including routine visits) to all fluoridated water systems. If there is no State fluoridation specialist, the person responsible for the fluoridation program in the State should obtain the part-time services of technically competent persons within other State programs or outside the State.

6. **Emergency Procedures** A plan should be developed for the reaction of community/school officials and State officials in the case of a serious overfeed. While there is usually a very small chance for such an overfeed, all those involved should be prepared to act.

The lack of good monitoring and surveillance programs in States with fluoridated communities has been a concern of State dental directors and CDC for some time. One complaint raised about efforts to strengthen the States' monitoring and surveillance efforts in fluoridation was that good standards or guidelines were not available. Therefore, CDC and the State dental directors, through ASTDD, has tried to develop such standards. CDC has assembled a task force of national experts to develop those guidelines.

The efforts of the CDC task force and the ASTDD special committee on fluoridation resulted in a set of voluntary guidelines for the establishment of a good State monitoring and surveillance program in fluoridation.[3] The goal of these guidelines is to achieve quality water fluoridation within the United States through the establishment of voluntary State monitoring and surveillance programs. These guidelines are included in the appendix.

8.3 Fluoride Overfeed Incidents

8.3.1 General

When a community is fluoridating its drinking water, there is always a potential for overfeeding. Most overfeeds are of no serious consequence (but should be corrected). For example, if the optimal level of fluoride for a community is 1.0 ppm, and an overfeed resulted in 2.0 ppm in the drinking water *for several years*, very mild fluorosis would result in a few persons. Higher levels of fluoride for shorter periods can be accepted with no adverse effects. See Table 8–1 below. As stated previously, at a rural school in Seabrook, North Carolina, the fluoride level had been adjusted to seven times the optimal level for 12 years with no unacceptable fluorosis. Thus, the danger of overfeed, while always present, should not be overemphasized.

Both community and rural school fluoridation systems can have fluoride overfeeds, but an occurrence in the rural system would have the most serious effects—because of the higher fluoride level maintained (4.5 times optimum); shorter distribution lines, size of the people involved (low body weight); and a lower level of technical expertise. The concern, of course, is for the "slug" of very high fluoride content that can cause fluoride poisoning.

TABLE 8-1

RECOMMENDED FLUORIDE OVERFEED ACTIONS

Fluoride Content (mg/l)	Recommended Actions
3.0 or lower	1. Leave the fluoridation system on. 2. Find what has malfunctioned and repair it.
3.0 to 5.0	1. Leave the fluoridation system on. 2. Notify your supervisor. 3. Report the incident to the county and State health departments. 4. Find what has malfunctioned and repair it.
5.0 to 10.0	1. Consider turning off the fluoridation system if the problem is not found and corrected quickly. 2. Notify your supervisor. 3. Take water samples at several points in the distribution system, and test the fluoride content. 4. Report the incident to the county and State health departments. 5. Find what has malfunctioned and repair it.
10.0 or higher	1. Cut off the fluoridation system immediately. 2. Notify your supervisor and your State health/State engineering departments immediately and follow their instructions. 3. Take water samples at several points in the distribution system, and test the fluoride content. Save part of the sample for the State lab to test. 4. Find what has malfunctioned and repair it.

With overfeeds, there are three very important points to remember. First, the number of overfeed incidents is very, very small when compared to the number of systems that are fluoridating, Since the mid '60's, there have been only 20 reported incidents. Second, all of the effects resulting from the overdose of fluoride have been mild and short-lived. Third, it is very difficult to swallow fluoride in large enough quantities to make a person very ill. One of the symptoms of fluoride poisoning is severe nausea; thus, in effect, people cure themselves by vomiting.

8.3.2 Specific Incidents - Schools

The following are brief descriptions of some of the overfeed incidents which have occurred in school fluoridation systems:

1. A school water supply was used during a picnic. The school employee (operator) "felt that the fluoride level in the water was not high enough" and ran the fluoride metering pump while the water supply was shut off. An overfeed resulted.

2. Water used to prepare orange juice at a morning recess was found to contain a high fluoride level. Earlier, when school was closed for a holiday, the fluoride metering pump fed fluoride while the well pump was not operating. (The fluoride metering pump had been operating sporadically for about a month.) A flow switch had been installed, but the metering pump was not wired in with the well pump circuit. When the metering pump malfunctioned and the flow switch failed, no backup system was available to prevent the overfeed.

3. Another incident occurred in a system where water from a well served two separate school buildings. The metering pump was wired into the well pump, but no flow switch had been installed. An overfeed occurred when the well pump malfunctioned, but continued to operate, while the metering pump continued to feed fluoride into the system.

4. Another incident occurred when an operator unplugged the metering pump for repair. He replugged it into a "live" electrical outlet nearby. This caused the metering pump to continuously, feed even though the well pump (which normally controlled the metering pump) was not on.

5. Vandals were responsible for an overfeed in which the well pump in a school failed and was not delivering water, even though the pressure switch was calling for water. A flow switch was wired into the system and normally would have prevented the overfeed, but the wires were cut on both sides of the flow switch.

8.3.3 Specific Incidents - Communities

The following are brief descriptions of overfeed incidents which have occurred in some community fluoridated water systems:

1. A well-meaning, but untrained, operator was responsible for an overfeed because he felt the solution strength in the saturator was too low and added a mixer, thus causing a slurry of fluoride chemical to be fed.

2. An overfeed occurred when a double check valve in the main water line apparently failed, allowing the flow to go both ways across a magnetically paced contact meter. The metering pump fed each time a magnetic contact was made, whether flow was forward or backward.

3. Another incident occurred when a mercury switch on an older meter failed. This resulted in the fluoride feeder continuously feeding fluoride, thus causing an overfeed.

4. The accident (reported overfeed) which occurred at Annapolis, Maryland, is a special case. This is the first instance of fluoride overexposure known to have caused serious illness in the 40 years since fluoridation of community water supplies has begun. The facts are summarized:[3]

(a) An Annapolis water plant employee left open a valve on the bulk storage tank and approximately 1,000 gallons of hydrofluosilicic acid spilled out before it was discovered the next morning.

(b) Eight dialysis patients at a nearby dialysis center received hemodialysis treatment and become ill. All patients exhibited unusal and severe symptoms (nausea, vomiting, diarrhea, chest pain, etc.) One patient went home and complained of feeling drowsy, but refused hospitalization when recommended by the dialysis center. He died the next morning.

(c) Eight days later, the county health department officials heard informally of the fluoride spill and asked the State to test fluoride taken from the clinic. The next day the first notice of the fluoride spill was reported to the State health officials. The autopsy report on the patient who died was made 17 days after the incident. It stated that the immediate cause of death was hypertensive and arteriocardiovascular disease, with a contributing cause of death being acute fluoride intoxication which occurred during hemodialysis.

There were no other reported serious illnesses related to fluoride intoxication in Annapolis. There was suggestive evidence of mild fluoride reaction among the office workers in the dialysis center building. It was estimated the fluoride level reached up to 36 ppm at some point in time in the drinking water. Annapolis continues to fluoridate.

The result of many of these overfeed incidents has been a tightening of State rules and regulations governing the engineering aspects of fluoridation. For example, the incident of a malfunctioning flow switch resulted in the State requiring two flow switches to be installed in all school fluoridation systems.

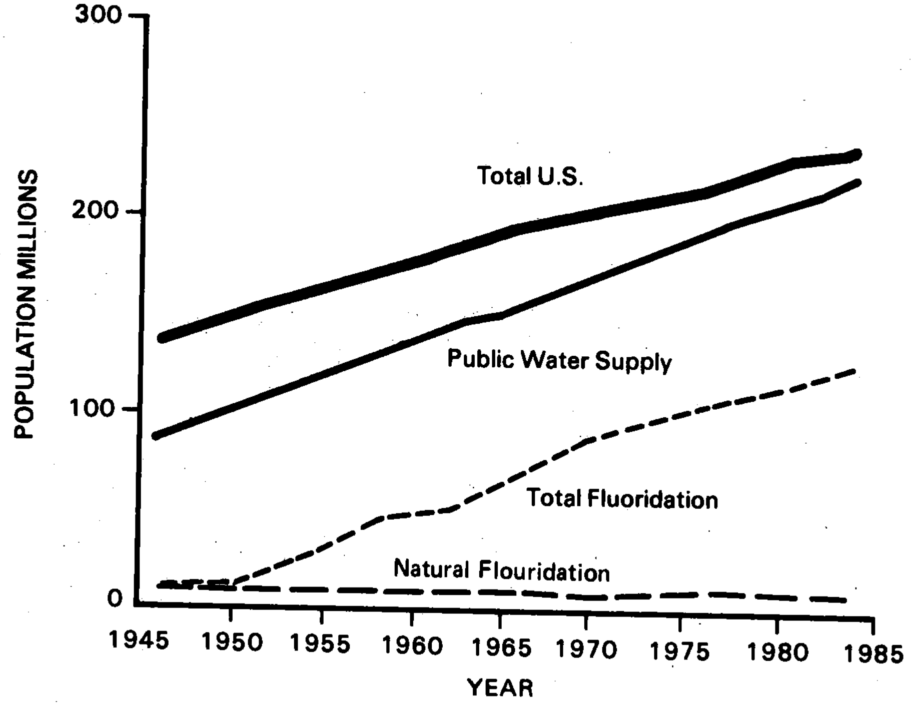
8.4 Present Status of Fluoridation

According to the 1980 CDC Fluoridation Census, as of January 1, 1980, approximately 116 million Americans, or about 56.5 percent of those on public water supplies, consumed fluoridated water daily.[4] Some 9.8 million of these are served by naturally fluoridated supplies. It is estimated that 131 million citizens are presently receiving the benefits of fluoridated water. In 1980, there were 4,846 water systems serving 8,278 communities which had adjusted the fluoride content of their water, and another 3,010 water systems serving 3,063 communities which received water naturally fluoridated at optimal or higher levels. Some 24 million people in over 100 cities, with populations of 50,000 or more, have had adjusted fluoridation for more than 20 years. Approximately 70 percent of all cities with populations of 100,000 or more have fluoridated water. More than 22 States, the District of Columbia, and Puerto Rico provide fluoridated water to over one-half of their population. The growth of the U.S. population served by fluoridated drinking water systems is shown in Figure 8–1 on page 126.[5]

In 1980, approximately 38 countries reported that community water fluoridation is benefiting approximately 208 million people. The U.S.S.R., United States, Canada, Brazil, Australia, Venezuela, and Chile have large populations consuming fluoridated water. The city-states of Hong Kong and Singapore are totally fluoridated. Fluoridation has been seriously hindered in Europe by the opponents of fluoridation. In fact, there may be very little progress toward fluoridation in Europe in the foreseeable future.

Considerable progress has been made toward community fluoridation in Central and South America, especially in Brazil, which now has a federal law requiring fluoridation for all communities over 50,000 population. Calcium fluoride has gained widespread use in Brazil, as well as in several other South and Central American countries. The Pan American Health Organization (a branch of the World Health Organization) has been very active in the promotion of fluoridation in Latin America. There has been very little activity by the opponents of fluoridation there.

FIGURE 8-1
FLUORIDATION GROWTH BY POPULATION – U.S., 1945-1985



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ABBREVIATIONS

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The following symbols and abbreviations are used throughout this manual.

AAP -American Academy of Pediatrics
AC -Alternating current
ADA -American Dental Association
AFI -available fluoride ion concentration
AWWA -American Water Works Association
C -Degrees Centigrade
cc -cubic centimeter
cc/min -cubic centimeter per minute
CDC -Centers for Disease Control
cf -cubic feet
cfh -cubic feet per hour
DC -Direct Current
DDPA -Dental Disease Preventi[illegible]
deg. -degree
DMF -Decayed, Missing, [illegible]
DMFT -Decayed, Missing, a[illegible]
EPA -U.S. Environmental Pro[illegible]
F -Degrees Fahrenheit
F$^-$ -Fluoride ion
FOB -Freight on Board
ft^3/day -cubic feet per day
ft^3/hr -cubic feet per hour
ft/sec -feet per second
gm -gram
gm/lb -gram per pound
gpd -gallons per day
gph -gallons per hour
gpm -gallons per minute
gal -gallons
HHS -U.S. Department of Health and Human Services
hr -hour
hr/day -hours per day
Hz -Hertz
in -inches
kg -kilogram
Kg/cm^2 -kilogram per square centimeter
l -liters
lbs -pounds
lbs/cf -pounds per cubic feet
lbs/day -pounds per day
lbs/ft^3 -pounds per cubic feet
lbs/gal -pounds per gallon
lbs/hr -pounds per hour
lbs/min -pounds per minute
LCI -Lucier Chemical Incorporated
l/min -liters per minute
lph -liters per hour
mA -milliamp
max -maximum
MCL -Maximum Contaminant Level
mg -milligram
mg/m^3 -milligrams per cubic meter
[illegible] -million gallons
[illegible] -million gallons per day
[illegible] -milligrams per liter
[illegible] -minute
[illegible] [illegible]inutes per day
[illegible] [illegible]liter
[illegible] [illegible]illiliter per gallons
[illegible] -milliliters per minute
[illegible] -millimeter
[illegible]A -Mine Safety and Health Administration
NIOSH -National Institute of Occupational Safety and Health
oz -ounce
pH -hydrogen - ion concentration
PHS -U.S. Public Health Service
ppm -parts per million
psi -pounds per square inch
pvc -polyvinyl chloride
rpm -revolutions per minute
SCR -stroke control rectifier
sec -second
SPADNS -sodium 2-(parasulfophenylazo)-1, 8-dihydroxy-3,6-naphthalene disulfonate
SPM -strokes per minute
SG -specific gravity
SRI Stamford Research Institute
SS -stainless steel
TLV -Threshold Level Valve
V -Volts