CHAPTER FIVE

OPERATION OF FLUORIDATION SYSTEMS

5.1 Introduction

It is important, in the proper operation of any fluoridation system that complete and accurate records should be kept on proper chemical storage and handling and fluoride analysis.

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 methods that can be used for analyzing fluoride.

5.2 Record Keeping

5.2.1 Introduction

Comprehensive record-keeping allows efficient operation and maintenance of the water supply system. Since the size and design of water supply systems vary, record keeping methods are best tailored to each design. Without permanent records describing the system, a community becomes dependant upon the memories of long-time employees. Valuable information can be lost with the retirement of each employee. Records demonstrate that an operator is attempting to maintain system reliability.

There are two types of records: those required by law and/or regulations and those required for operation.

5.2.2 Required Records

Most states require that certain records be kept. Generally, this includes the daily determination of fluoride concentration, daily weights (or volumes) of chemicals fed, and the volume of water treated. Some states also require the daily calculated chemical dosage. In fluoridation, the records required by law/regulations generally include:

1 Daily fluoride test',
2 Daily weight measurements (lbs);
3. For saturators - make-up water used daily (gallons);
4. Weekly/monthly check sample fluoride tests (split samples for state lab); and
5. Calculated dosage rates.

The required records for fluoride tests should be written, of course, and contain the following;

1 . The date, place, and time of sampling, and the name of the person who collected the sample;
2. Identification of the sample as to whether it was a routine distribution system sample, a check sample, a raw or processed water sample, or any other special purpose sample;
3. Dates of analyses;
4. Laboratory and person responsible for performing analysis;
5. The analytical technical method used; and
6. The results of the analysis (mg/L fluoride).

Copies of any written reports, summaries, or communications relating to required records should be mailed to the state, as required and should be kept for a period of at least ten years or as required by the state.

5.2.3 Operational Records

Obviously operational records are necessary to improve the operation of the fluoridation system. These records will vary greatly depending on the individual water system, state, and even the region of the United States. Generally, these records should include the chemical quality of the raw water (natural fluoride content, pH. etc.); the quantities of water pumped (from the master meter), and data on the maintenance of the fluoride metering pumps, motors, piping, etc. Records also should be maintained on the calibration curves made. Information from the vendors for parts, repairs, etc. should also be kept readily available. Additional information, such as when the equipment was last checked, repaired, and lubricated and when chemicals were added, should also be maintained. The state health department should be contacted to ascertain specific record-keeping requirements. Some kind of record should be kept of the work done on alt fluoridation equipment. Records can help remind the operator what maintenance has to be done and when it is time to do it again.

If the operator already keeps maintenance records on other equipment in the water plant, then the fluoridation equipment can be included in whatever record system is used.

There are many ways to keep maintenance records. Some operators make out a schedule for an entire year and post it on a wall. This schedule shows the maintenance jobs planned for each month and when a job is completed, the date is added. Other operators mark maintenance jobs on a calendar, a reminder of the work to do. A record of what they actually do is kept in another place such as in a card file (with a separate card for each piece of equipment) or in an equipment record book.

With experience, the operator will probably want to change the frequency of some maintenance jobs. For example, suppose the records showed that some part always wore out before it was scheduled to be replaced the operator would probably want to change the maintenance schedule and routinely replace the part more often.

Also, the maintenance schedule should be adjusted whenever equipment is taken apart to make a repair. For example, if the equipment has not received it's routine maintenance the routine maintenance of the equipment may be done while it is disassembled. The next routine maintenance can then be rescheduled starting from the date of the repair.

5.3 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; preferably they should 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 compounded i.e.,sodium fluoride and sodium fluorosilicate, 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. Do not re-use empty fluoride containers! The temptation to re-use fiber drums is strong, since the drums are convenient and sturdy. Paper bags are dusty and could cause a hazard if they are burned. The best approach is to rinse all empty containers with plenty of water-even the paper bags are strong enough to with- stand repeated rinses. After all traces of fluoride are removed, the bags should be disposed of in a proper manner. 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.

Fluorosilicic 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 fluorosilicic acid containers in the hot sun where the containers can build hydrostatic pressure, or in open areas subject to winter freezing.

Fuorosilicic 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 that may suffer leakage problems. Wash down all spills immediately.

When fluorosilicic 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 poly- ethylene should be manufactured from high density cross-linked material (cross-linked provides strength). The plastic should contain a minimum of 0.25 percent ultraviolet stabilizer to protect against sunlight. The polyethylene storage tanks are still relatively new so the longevity of the tank is yet to be determined. Fiberglass and rubber-lined steel tanks are used about equally for bulk storage of Fluorosilicic acid. Fiberglass tanks usually will last about 7-10 years. Several years ago, fiberglass tanks were the most popular; then, the steel tanks became 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, however, it's the most expensive. The steel-rubber-lined tanks will last about 20 years.

5.4 Calculations for Fluoridation Systems

5.4.1 General

Prior to the operation of any fluoridation system, some basic calculations should be made. While these calculations can be done several ways, the results should be the same. One method of the calculation is described in this manual, Ervin Bellack, in his "Fluoridation Engineering Manual" uses another. Many states have their own individual ways of doing the basic calculations, and all are usually correct. Some states use short cuts, such as homographs, 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.

5.4.2 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. 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 - 0F*	Recommended fluoride concentration In milligrams per Inter
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

5.4.3 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 (specific gravity) of l .0 grams per cubic centimeter (the specific gravity of water is 1.0). In this manual the terms ppm and mg, are used interchangeably. While mg/la 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 lmg/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/la - 0.2 mg/L
Dosage = 1.0 mg/L

5.4.4 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. Three terms 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 that 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 the 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 gpm x 1440 minutes/day = 1 ,008.000 gpd
1 ,008.000 gpd / l ,000,000 = l .008 MGD

5.4.5 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 (AHI) and is the most common purity for the three commonly-used chemicals for fluoridating water systems:

Chemical	Formula	Purity	Available Fluoride ton Concentration (AFI)
Sodium Fluoride	NaF	98%	0,452
Sodium Fluorosilicate	Na2SiF6	98.5%	0.607
Fluorosilicic Acid	H2Si%	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:

% available fluoride = *To* F^-x *%* commercial purity

% available fluoride = 0.45 x 0.98

% available fluoride = 0.44

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

5.4.6 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 5.4.3, mg/L is equal to ppm.). The formula for the fluoride feed rate (the amount of chemical required to raise the fluoride content to the optimal level) is as follows:

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

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 tile denominator. (Note the previous page where gpm is converted to MGD):

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

5.4.7 Problems (Fluoride Feed Rate)

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

A. Sodium Fluorosilicate

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?
2,000 gpm x 1440 minutes/day = 2,880,000 gpd
2,880,000 gpd / 1,000,000 = 2.88 MGD

$$\text{Fluoride Feed Rate (lb/day)} = \frac{\text{1.l mg/L x 2.88 MGD x. 8.34 lbs/gal}}{\text{0.607 x 0.985}}$$

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) = 44.19 lb/day /1440 min/day x 454 gm/lb
Fluoride Feed Rate = 1 3.9 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 fluorosilicate:

(a) Convert the plant rate to MGD

$$\frac{\text{695 gpm x 1440 min/day}}{\text{l , 000, 000}} = \text{l .0 MGD}$$

(b) Find the fluoride feed rate

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

$$\text{Fluoride Feed Rate (lbs/day)} = \frac{\text{1 .0 mg/L x MGD x 8.34 lbs/gal}}{\text{0,607 x 0.985}}$$

Fluoride Feed Rate = 13.95 lbs/day

Therefore, it takes about 14 lbs. of sodium fluorosilicate to treat 1.0 MG of water to a concentration of 1 .0 mg/La of fluoride.

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

Fluoride Feed Rate (ft^3/hr) = 1 3.95 lb/day + 75 lb/ft^3 /24 hrs/day

Fluoride Feed Rate = 0.0078 ft^3/hr

B. Fluorosilicic 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 for 23% fluorosilicic acid?

1,000 000 = 10^6

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

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

Fluoride Feed Rate = 0.147 Ib/min

A gallon of 23 percent fluorosilicic acid weighs 10 pounds (see Table 2-2 on page 19) and there are 3785 ml per gallon; thus the following formula can be used to convert the feed rate to mi/min:

Fluoride Feed Rate (ml/min) = 0. 147 lb/min / 10 lb/gal x 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 for
23% fluorosilicic acid?

$$\text{Fluoride Feed Rate (lb/day)} = \frac{\text{dosage (mg/L) x. capacity (MGD) x 5.34 lb/gal}}{\text{AFI x chemical purity}}$$

$$\text{Fluoride Feed Rate (1b/day)} = \frac{\text{(1.2 - 0.2) mg/L x 1.0 MGD x 8.34 lbs/gal}}{\text{0,79 x 0.23}}$$

Fluoride Feed Rate = 45.9 1b/day

Thus, it takes 45.9 pounds of 23 percent fluorosilicic acid to treat l.0 MG of water to a concentration of 1 .0 mg/La of fluoride.

C. Sodium Fluoride

EXAMPLE 1. 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? [Notes, CDC recommends against using sodium fluoride in a dry feeder.] Assume 0.l mg/L natural fluoride and 1.0 mg/L is desired in the drinking water.

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

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

Fluoride Feed Rate = 0.003 lb/min or 0.18 1b/hr

Thus, sodium fluoride can be fed at a rate of 0.1 8 lbs/hr to obtain l .0 mg/L of fluoride in the water.

5.4.8 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 I 8,000 milligrams of fluoride ion (40,000 mg/L times the percent available fluoride (45 percent) equals 1 8,000 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.

$$\text{Fluoride Feed Rate (gpm)} = \frac{\text{capacity (gpm) x dosage (mg/L)}}{\text{1 8,000 mg/L}}$$

The fluoride feed rate will have the same units as the capacity. lf the capacity is in gallons per minute (gpm), the feed rate will be in gpm also. lf the capacity is in gallons per day (gpd) the feed rate will be in gpd.
For the purist the following derivation is given.

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

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 4% x 8.34 lb/gal,)

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

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

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

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

5.4.9 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?

$$\text{Fluoride Feed Rate (gpd)} = \frac{\text{capacity (gpd) x dosage (mg/L)}}{\text{18 000 mg/L.}}$$

$$\text{Fluoride Feed Rate (gpd)} = \frac{\text{l ,000,000 gpd x l .0 mg/L}}{\text{18,000 mg/L}}$$

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 l .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?

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

Fluoride Feed Rate (gpm) = $\frac{180 \text{ gpm x (1.0-0.1)}}{\text{l 8,000 mg/L}}$

Fluoride Feed Rate = 0.009 gpm

To convert to mil/min, multiply by 3785 ml/gal
Fluoride Feed Rate = 0.009 gpm x 3785 ml/gal
Fluoride Feed Rate = 34. ml/min

So, 34.l ml/min of sodium fluoride solution must be fed into the water to obtain l .0 mg/lo of fluoride. It should be noted that this problem is the same as problem No.C. 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 1 8.5 lbs of sodium fluoride in 55.6 gallons of saturated sodium fluoride solution.

Fluoride Feed Rate (Ib/hr) = $\frac{\text{0.009 gal/min x 60 min/hr x l 8.5 lb}}{\text{55.6 gal}}$

Fluoride Feed Rate = 0.18 lb/hr

This is the same amount as shown in Example 1 in Problem C,

5.4.10 Calculated Dosage

Some states require that records be kept regarding the amount of chemical used, 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:

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

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). Note, the amount of fluoride fed (1bs) will be determined over a time period (day, week, etc.) and the Actual Production will be determined over the same time period.

$$\text{Calculated Dosage (lmg/L)} = \frac{\text{fluoride fed (lbs) x AFI x chemical purity}}{\text{actual production (MG) x 8.34 lbs/gal}}$$

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:

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

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 x 8.34 lbs/gal = 375 lbs. of water

$$\frac{\text{6.5 lbs NaF}}{\text{375 lbs } H_2O} = \text{l .7\% NaF solution}$$

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:

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

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).

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

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

Solution concentration = 7,650 mg/L

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

$$\text{Calculated Dosage (mg/L)} = \frac{\text{Solution fed (ga1) x solution concentration (mg/L)}}{\text{actual production (ga1)}}$$

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

5.4.11 Calculated Dosage Problems

A. Sodium Fluorosilicate

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

$$\text{Calculated Dosage (mg/L)} = \frac{\text{Fluoride fed (1bs) x AFI x purity}}{\text{actual production (MG) x 8.34 lbs/gal}}$$

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

Calculated Dosage = 0.84 mg/L

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

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

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

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 fluorosilicate was fed in one day, what was the calculated dosage?

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

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

Calculated Dosage = 0.9 mg/L

B. Fluorosilicic Acid

EXAMPLE 1. A plant uses 43 lbs. of fluorosilicic acid in treating 1,226.000 gallons of water, Assume the acid is 23 percent purity. What is the calculated dosage?

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

$$\text{Calculated Dosage (mg/L)} = \frac{\text{43 lbs x 0.792 x 0.23}}{\text{1 .226 MG x 8.34 lbs/gal}}$$

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 fluorosilicic acid in treating 17,058,000 gallons of water. What is the calculated dosage?

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

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

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 fluorosilicic 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

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

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

Calculated Dosage = 1.43 mg/L

Thus, the calculated fluoride level is l .4 mg/L, plus the natural fluoride level. 0.2mg/L or 1.6mg/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?

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

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

Calculated Dosage = 1.2 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?

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

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

Calculated Dosage = 0.9 mg/L

EXAMPLE 2. A plant uses 1 9 gallons of solution from its saturator in treating 360,000 gallons of water. What is the calculated dosage?

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

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

Calculated Dosage = 0.95 *mg/L*

EXAMPLE 3. A small water plant uses sodium fluoride from a saturater at a rate of 1,0 gallon per day, and the plant treats 4,500 gallons per day. What is the calculated dosage?

$$\text{Calculated Dosage (mg/L)} = \frac{\text{solution fed (ga1) x 18,000 mg/L}}{\text{capacity (gal)}}$$

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

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?

$$\text{Solution concentration (mg/L)} = \frac{\text{18.000 mg/L x solution strength (\%)}}{\text{4\%}}$$

$$\text{Solution concentration (mg/to)} = \frac{\text{18,000 mg/L x 0.02}}{\text{0.04}}$$

Solution concentration = 9,000 mg/L

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

$$\text{Calculated Dosage (mg/f-,)} = \frac{\text{93 gal x 9,000 mg/L}}{\text{800,000 gal}}$$

Calculated Dosage = 1.05 mg/L

5.5 Chemistry of Fluoride Analysis

5.5.1 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 arc generally not applicable.

Years ago, only the calorimetric 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 calorimetric fluoride test (SPADNS). Either method has the required sensitivity--the electrode method, however, has far fewer interferences.

Under the Safe Drinking Water Act, rigorous analytical requirements must be met for fluoride analysis. These tests are for measuring 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 calorimetric analyses must be distilled prior to color development. Daily operational tests need not be distilled.

5.5.2 Interferences with Fluoride Analysis

The substances that interfere with the analysis of the fluoride ion are shown in Table 5-1. As can be seen, some of the interferences for the calorimetric (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.

5.5.3 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 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.

5.5.4 SPADNS Method for Fluoride Analysis

The calorimetric 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.

TABLE 5-1
INTERFERING SUBSTANCES*

Concentration of substance, in mg/lo, required to cause error of plus or minus 0.1 mg at 1.0 mg/L fluoride

Interfering Substances	SPADNS	Electrode
Alkalinity (CaCOa)	5,000 (-)	7,000 (+)
Aluminum (AI)	0.1 (-)**	3.0 (-)
Chloride (C1)	7,000 (+)	20,000 (-)
Iron (Fe)	1 0 (-)	200 (-)
Hexametaphosphate ([NaPO3])	1.0 (+)	50,000
Phosphate (PO4)	16 (+)	50,000
Sulfate (SO4	200 (+)	50,000 (-)
Chlorine	Must be completely removed with arsenite	5,000
Color & Turbidity	Must be removed or compensated for	-

*American Public Hea1th Association, American Water Works Association Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater 18th Ed. 1992 pp 4-59 to 4-64
**Above figure is for immediate reading

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 analyses 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 corvette, 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 desired, for these reasoned 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 safes preferably approximately 20 degrees (221 degree) C (680 F). 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 and free from scratches and chips. In the fluoride test, the concentration of fluoride being determined is extremely small. Any fluoride test is very sensitive to small residues 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 (use pipette for SPADNS).
- If chlorine is present, it should be eliminated, using arsenate solution.
- 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 l .5ppm fluoride. it is recommended that a 1.5ppm standard fluoride solution be bought and used rather than the l.0ppm solution.
- Perhaps the most important source of error is the presence of interfering ions in the water sample. None of the calorimetric 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.l to 2.0ppm. Beyond this range, dilutions must be made using deionized water to obtain accurate measure of the fluoride concentration. Dilutions must be carefully made.

5.5.5 Electrode Method for Fluoride Analysis

The electrode method is capable of measuring fluoride concentrations from 0. l to 10 ppm. 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 19ppm result in positive voltage readings. Some electrodes contain no internal solution, but the principle of operation is similar.

5.5.6 Continuous Monitors

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