Welcome To:
Water Fluoridation Principles and Practices For Water Facility Operators
Presented by State Water Fluoridation Program

Water Fluoridation
Health Benefits
Regulatory Perspective
Fluoride Additives
Equipment/Facilities
Laboratory Analysis
Personnel Safety
Operations

Operator Knowledge Is Most Important Success Measure
• Good operator training essential
• Guidance on best practices
• Standard operating procedures (SOPs)
• Appropriate operator certification

Who, What, Where, Why, How
• Fluoridation is adjustment of water fluoride
• Used for optimum oral health benefits
• One of ten great public health achievements of the twentieth century (CDC)
• Water fluoridation has a 60-year history of success

Operator Training
Studies by EPA have found one-half of all operating problems are a result of inadequate operator training, or incorrect process understanding by an operator

Who?
• Dr. Frederick S. McKay initiated a study in 1908 of "Colorado Brown Stain" in Colorado Springs
• Important conclusions...
  - Affected teeth more resistant to dental decay
  - Life-long residents had stained teeth, more recent residents did not
  - High fluoride content of water identified in 1931
Who? (continued)

In 1930s, Dr. H. Trendley Dean conducted the “21 Cities Study”

- **Important conclusions:**
  - Optimum levels of fluoride for enhancing oral health (natural breakpoint at 1 mg/L)
  - 1.0 mg/L provided best combination of reduction in tooth decay (caries) and low risk of fluorosis
  - Established community fluorosis index (increased incidence at 2 mg/L)

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What?

Adjustment of fluoride in water to an optimum range of 0.7-1.2 mg/L

- Recommended CDC control range is 0.1 below to 0.5 mg/L above optimum
- Decreased benefits below optimum
- No additional benefit and more severe fluorosis above 2 mg/L

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Fluoridation Growth, by Population

United States, 1940–2002

- Total U.S. Population
- Public Water Supply Population
- Total Fluoridated Water Population
- Adjusted Fluoridation Population
- Naturally Fluoridated Water Population


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Halo Effect

- Processed products shipped to non-fluoridated communities
- Fluoride in toothpaste and food chain
- Difference in caries now only 20%-40%
Why?

- Fluoridated communities have 20%-40% fewer caries (dental decay)
- Cost-effective results: every dollar spent on water fluoridation avoids $38 in dental care, while increase in drinking water costs to consumers is less than 1%
- Benefits all consumers across socio-economic status
- Benefits all age groups, from children to senior citizens

Risk Factors for Caries

- Diet: sugars and carbohydrates
- Oral hygiene
- Xerostomia (Dry Mouth): saliva flow and composition
- Bacteria Levels: especially mutans streptococci

Progression of Caries

- First sign of a cavity is an increased microporosity of enamel
  - demineralization of apatite crystalites
  - A “chalky” appearance of the enamel
- Remineralization can regrow

How Fluoride Works

Source: Adapted from Featherstone, 1999

Fluoride Public Health Issues

- Fluoridation has resulted in a remarkable decline in the prevalence and severity of tooth decay
- Despite this reduction, dental caries is still the most common preventable chronic disease in the U.S.
  - 1 of 4 elementary school children
  - 2 of 3 adolescents
  - 9 of 10 adults
- Populations with increased risk:
  - Low SES
  - Low level of parental education
  - Little, if any, access to “dental care”
- Water fluoridation benefits all people young, old, rich, and poor
Fluoride Is Naturally Occurring

- Surface water typically low, less than 0.2 mg/L
- Groundwaters can have fluoride from less than 0.1 mg/L to over 5 mg/L
- Ocean water is typically 0.8 to 1.4 mg/L

Enamel Fluorosis

- Occurs when children with developing teeth consume excessive fluoride (pea-sized toothpaste sufficient)
- Ingestion of high-fluoride toothpaste by children a major cause of fluorosis
- Potential for enamel fluorosis increases as water content exceeds 2 mg/L
- Excessively high fluoride levels, generally greater than 10 mg/L, may result in skeletal fluorosis

Challenges

- Opponents of community water fluoridation have made claims that optimally fluoridated water can cause an array of health problems including:
  - Cancer
  - Increased bone fractures
  - Effects on the renal, gastrointestinal, and immune systems
  - Lower IQ in children
  - Down's syndrome
  - Allergies
  - AIDS
  - Alzheimer's disease
  - Reproductive problems

Alternatives to Fluoridated Water

- Fluoridated water most common vehicle (various estimates of 220-300 million people worldwide)
- Fluoridated salt second most common vehicle (various estimates of 40-300 million people worldwide)
- Dietary fluoride supplements -- drops, tablets, or vitamins (60 million people-WHO 2003)
- Fluoridated milk used in a few places

Credible Scientific Evidence

- Studies and Research
  - 60+ years - Extensive investigations demonstrate safety and effectiveness
  - Solid design
  - Can be replicated

Alarming allegations can drive public policy

"It's really terrifying the scientific illiteracy that supports these suspicions" - Dr. Marie McCormick, Institute of Medicine, 2004

Credible Scientific Evidence

- Expert Committees and Task Forces
  - Independent reviews
    - University of York, UK (2000)
    - CDC Fluoride Recommendations (2001)
  - National Research Council Review completed in 1993, Update currently in review
Safe and Effective

- Expert scientific panels, medical and professional organizations, and public health officials have concluded that water fluoridation is safe and effective.
- Water fluoridation has been endorsed by the past five Surgeons Generals of the United States including the current one, Dr. Richard Carmona.

Impact on Water Bill

- Average water and wastewater bill for a typical family is $41.95/month (source 2004 AWWA Raftelis survey).
- Average annual cost to fluoridate water supply for typical household of 2.4 people $4.25 (source Griffin; J. Public Health Dentistry, 1992 adjusted for inflation).
- Results in equivalent cost to fluoridate typically less than 1 percent of annual utility bill.

Public Policy on Fluoridation

- Recognized by the American Dental Association, U.S. Public Health Service, American Medical Association, World Health Organization, American Water Works Association, and virtually every scientific and professional organization in the health field.

Fluoridation Facts

- CDC web site at www.CDC.gov/OralHealth
- American Dental Association “Fluoridation Facts” available from www.ADA.org
- Your State Water Fluoridation Program and State Dental Director.

Water Fluoridation

Health Benefits

Regulatory Perspective

- Fluoride Additives
- Equipment/Facilities
- Laboratory Analysis
- Personnel Safety
- Operations

Safe Drinking Water Act (SDWA)

- Passed by Congress December 16, 1974
- Reauthorized in 1986 and 1996
- Assures that drinking water supplied to the public is safe
- Administered and enforced by individual states when they adopt criteria equal or exceeding the federal standards.
**National Primary Drinking Water Regulations**

- **Contaminant**
  - Any physical, chemical, biological, or radiological substance or matter in water
  - Some contaminants are nutrients that promote good health at low concentrations including fluoride, copper, iron, and others

**EPA and Water Fluoridation**

- EPA and the PHS were early partners in promoting water fluoridation
  - 1962 and 1972 Engineering Manual was predecessor to AWWA MOP #4
  - Regional Fluoridation Engineers
- 1974 SDWA defined water fluoridation as a state program, not an EPA program

**Water Additives Not Regulated by EPA**

- EPA focuses on safe water and contaminant levels that result in unfavorable health outcomes
- Other entities provide standards covering water additives (AWWA, NSF International)
- Water fluoridation is a state program, not a federal program

**National Primary Drinking Water Regulations**

- **MCL**
  - Maximum Contaminant Level
  - The maximum permissible level of a contaminant in water which is delivered to any user of a public water system.
  - Assure no short-term or long-term health risk
  - Economically and technologically feasible
  - States can set stricter standards

**National Primary Drinking Water Regulations**

- **MCLG**
  - Maximum Contaminant Level Goal
  - Maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and includes a margin of safety.
  - Non-enforceable health-based goal

**National Primary Drinking Water Regulations**

- **Maximum Fluoride Levels**
  - MCLG - 4.0 mg/L
  - MCL - 4.0 mg/L
National Secondary Drinking Water Regulations

- Aesthetic Qualities of Water
- Not Federally Enforceable
- Intended as Guidelines for the States

National Primary Drinking Water Regulations

- Public Notification – MCL
  - Tier 2 notification requirements
  - Within 30 days of violation
  - Applies to all CWS’s
  - Specific language
  - Description of CWS efforts to achieve compliance

National Secondary Drinking Water Regulations

- SMCL
  - Secondary Maximum Contaminant Level
  - EPA website indicates that this was promulgated for naturally high fluoride waters
  - 2.0 mg/L

National Primary Drinking Water Regulations

- Public Notification – SMCL
  - Any single exceedance of 2.0 mg/L SMCL triggers notification process
  - Tier 3 notification requirements
  - Within 12 months of exceedance
  - Applies to all CWS’s
  - Specific language

National Primary Drinking Water Regulations

- Sampling
  - Groundwater sources - 3 year
  - Surface water sources - Annual

State Water Fluoridation Program

- Managed at the state level
- 12 states have mandatory fluoridation requirements, other state programs promote implementation
- CDC provides technical assistance and support
**Water Fluoridation**

Health Benefits
Regulatory Perspective

**Fluoride Additives**

Equipment/Facilities
Laboratory Analysis
Personnel Safety
Operations

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**Fluoride Additives**

- **Three Common Additives in U.S.**
  - Sodium fluoride (NaF)
  - Sodium fluorosilicate (Na$_2$SiF$_6$ or NaFS) (sodium hexafluorosilicate, sodium silicofluoride, sodium sil)
  - Fluorosilicic acid (H$_2$SiF$_6$ or FSA) (FSA, hydrofluorosilicic acid, HFS, hexafluorosilicic acid)

What additive is used at your facility?

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**Apatite**

- Mixture of calcium compounds
  - Calcium phosphate
  - Calcium carbonates
  - Calcium fluorides (Contains 3 to 7% Fluoride)
- Primary source for fluoridation additives
- Raw material for phosphate fertilizer
- US largest world production; Florida principal location

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**Fluorosilicic Acid (FSA)**

- 22 to 26% FSA (as weight basis in water solution)
- Solution pH 1.2
- Density (25%) 10.1 pounds per gallon
- Avoid dilution range of 10:1 to 20:1 (precipitation of silica is a potential problem)

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**Fluorosilicic Acid (H$_2$SiF$_6$) FSA**

- Straw-colored, transparent
- Fuming corrosive acid
  - FSA is in equilibrium with volatile HF
- Derived from phosphate fertilizer manufacturing

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**Calcium fluoride Milled Apatite**

- Straw-colored, transparent
- Fuming corrosive acid
- Derived from phosphate fertilizer manufacturing

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**Fluorosilicic Acid (FSA)**

- 22 to 26% FSA (as weight basis in water solution)
- Solution pH 1.2
- Density (25%) 10.1 pounds per gallon
- Avoid dilution range of 10:1 to 20:1 (precipitation of silica is a potential problem)
Sodium Fluorosilicate (NaFS)
- Old name: “Sodium Silicofluoride”
- White odorless crystalline powder
- Produced by neutralizing fluorosilicic acid with sodium carbonate or sodium chloride
- Solubility varies with temperature
- Solution pH 3.0 to 4.0
- 14.0 pounds per million gallons to provide 1.1 mg/L F-

Sodium Fluoride (NaF)
- First to be used
- White odorless salt; powder or crystalline
- Produced by neutralizing fluorosilicic acid with caustic soda (NaOH)
- Relatively constant solubility of 4%
- Ideal for fluoride saturators
- Solution pH 7.6
- 1.8 pounds per million gallons to provide 1.1 mg/L F-

AWWA Verification Tests

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<thead>
<tr>
<th>FSA</th>
<th>NaFS</th>
<th>NaF</th>
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<td>- specific ion</td>
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</tr>
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<td>Insoluble matter</td>
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<tr>
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</table>

Fluoride Additives Standards
- American Water Works Association – specifies manufacturing and quality
  - AWWA B701-99 – Sodium Fluoride
  - AWWA B702-99 – Sodium Fluorosilicate
  - AWWA B703-00 – Fluorosilicic Acid
  - Key concept is additive must contribute less than 10 % of the MAL for any contaminant

Additive Availability
- Shortages occur mostly at the local level
- Problems with phosphate fertilizer production affect national supply
- Dry additives can be imported, FSA also from Mexico
- Plan to maintain 2 to 3 month inventory, coordinate with supplier

FSA Delivery
- Rail tank cars (20,000 gallons)
- Truck tank cars (4,000 – 6,000 gallons)
- Tote tanks (300 or 400 gallons)
- 55-gallon drums
- 13-gallon carboys
**FSA Delivery Issues**

- Most problems occur after shipment leaves manufacturing location or depot
- Typical problems:
  - Breakdown and release from transfer hoses
  - Delivery in damaged containers
  - Improperly or inadequately equipped delivery personnel
  - Attempted delivery to wrong storage area
  - Transport related trash including black particles attributed to breakdown of vehicle tank liners, plastic bags, other trash

**FSA Storage**

- Preferred storage location is inside building
- Keep sealed with air vent (HF) to outside
- Ensure storage area has adequate ventilation or air changes per hour
- Seal all electrical and other conduits
- Spill containment for 110 percent volume (double-wall tank or barrier)
- FSA is aggressive – use corrosion resistant materials
- Bulk storage container should never be used for additive feed supply...include day-tank

**Fluoridation Unrelated to Pipe Corrosion or Lead Levels**

- Some operators may think that since HF gas released from concentrated H₂SiF₆ storage results in corrosion, water fluoridation will corrode pipes
- EPA and University of Michigan (Ann Arbor) researchers have proven that at temperatures and concentrations for water fluoridation, FSA achieves complete dissociation to fluoride, hydrogen, and silica (sand) and cannot produce HF
- Silicates are actually used as a stabilizer for water corrosion

**FSA 55-Gallon Drum**

- Correct outside vent

**Up to 10,000 Gallon HDPE**

- Polyethylene tanks available from 10 to 10,000 gallons
- Gangs of multiple tanks can increase storage volume
- Depressed floor provides containment for spills

**Fiberglass Storage to 20,000 Gal**

- Fiberglass tanks have been used for storage, but may be susceptible to glass-fiber attack
- Verify that resins and coatings are suitable for hydrogen fluoride
- Concrete barrier provides containment for spills
Vent to Outside Structure

FSA Is Aggressive

Dry Additive Delivery Issues

- Most problems occurred after shipment leaves manufacturing location or depot
- Typical problems
  - Delivery in damaged packaging
  - Improperly or inadequately equipped delivery personnel
  - Attempted delivery to wrong storage area
  - Mixing with other chemicals
  - Degradation of product during transport

Dry Additive Storage

- Separate room – do not mix additives, secured access
- Good ventilation
- Elevated platform – keep dry additives on pallets
- Limit stacks to 6 bags
- Protected from elements: additives cake when compressed and exposed to moisture
- Convenient to feed location

Dry Additive Containers

Sizes
- 50-pound bags
- 100-pound bags
- 125 to 400-pound fiber drums
- 2,500-pound supersacks

Handling
- Use knife to slit bag
- Secured disposal to avoid personnel exposure

Dry Additive Delivery Issues

- FSA will damage concrete surfaces
- A dual application of epoxy undercoat with urethane topcoat provides corrosion resistance
- Consult with coating manufacturer for acceptable products

Fluoride Additives – Dry Spills

- Sweep and place in secure container
- Typically, supplier will agree to pick up for disposal

Check Codes and Regulations
- State hazardous waste agency
- Local Fire Marshall
Fluoride Additives – Liquid Spills

- Ensure that storage tank is in spill containment barrier or on containment pallets
- Use spill control pillows or dams that adsorb acid to contain liquid from spreading
- Neutralize and then consult with authorities on disposal requirements
- Avoid “flushing” to public sewer or on-site septage (septic tank) system

Neutralization – Lime

\[ \text{H}_2\text{SiF}_6 + \text{Ca(OH)}_2 \rightarrow \text{CaSiF}_6 + 2\text{H}_2\text{O} \]

\[ \text{CaSiF}_6 + 2\text{Ca(OH)}_2 \rightarrow 3\text{CaF}_2 + \text{SiO}_2 + 2\text{H}_2\text{O} \]

Calcium fluoride and silica (sand) are considered non-hazardous and accepted at most landfills.

0.39 pound of lime is required to neutralize one pound of acid for an acid strength of 25%.

Fluoride System Selection

- There is no one specific type of system or equipment that is best
- Historically
  - Large city - FSA
  - Medium system – FSA, dry feeder
  - Saturator or dry feeder

How Many Fluoridation Systems?

- Surface water system may have one treatment plant at intake with one fluoride addition location
- Groundwater system may have distributed feed with multiple wells each requiring separate feed system
Fluoride Additive Selection

- Fluoride Products Availability
- Existing Facilities
  - Compatibility with water system
  - Availability of space
  - Number of treatment sites (fluoride injection points)
- Characteristics of the Water
  - Natural fluoride level
  - Type of flow (variable or steady state)
  - Pressure (discharge)

Fluoride Additive Selection (continued)

- Estimated overall cost
  - Capital (initial)
  - Operation and Maintenance (O&M)
  - Chemicals
- State rules, regulations, and preferences

Objectives of Water Treatment

- Disinfection to protect against pathogenic organisms
- Reduction of contaminants for health effects
- Oxidation of undesirable reduced compounds
- Aesthetics – taste, odor, and color
- Not treatment, but a community benefit is fire fighting, which is the original reason for many community water systems

Context of Fluoridation to Water Treatment

- Must be compatible with other processes
- Must not contribute to water quality violations
- Different from other water treatment processes in being unrelated to safe drinking water standards
- Similar to fire fighting in that it promotes a community benefit
- EPA’s perspective is that fluoride is like copper: beneficial nutrient levels are close to levels that result in undesirable cosmetic results

Fluoridation Design Basics

- Basic design principles for fluoridation same as for other water treatment processes
- Equipment and process design same as for other standard water treatment processes
**Fluoride Additive Feed Equipment Requirements**

- Precise Delivery
- Small Quantities/Capacities
- Reliable
- Safety in Handling Hazardous Products
- Corrosion Resistance

**Metering Pump Classification**

- Mechanical Principles
  - Centrifugal: hydraulic vortex induces pressure delivery
  - Positive displacement: precise delivery of known volume, preferred for fluoride solution delivery

**Fluoride Feed Equipment**

- FSA Fed With Small Metering Pump
- Saturated Solutions of NaF
- Unsaturated solutions of NaF or NaFS

**Positive Displacement Pumps**

- Diaphragm
- Peristaltic or hose pump
- Piston
- Other (not used in fluoridation)
  - Progressive cavity
  - Screw
  - Rotary lobe or gear

**Dry Additive Feeders**

- Fluoride Saturators
  - Upflow: most common
  - Downflow: rarely used in United States
  - Venturi: rarely used except in large installations
- Dry Feeders
  - Volumetric
  - Gravimetric
Fluoride Saturators

- **Operating Procedure**
  - Generally uses sodium fluoride
  - Consistent fluoride additive bed maintained in tank
  - Water flows through bed
  - Water becomes saturated
  - Saturated solution injected

Dry Additive Feeders

- **Dry Volumetric Feeders**
  - Delivers a constant volume of fluoride additive
  - Generally sodium fluorosilicate, but also used with sodium fluoride

Typical Upflow Saturator

Water Softener with Saturator

- In areas with high hardness, a water softener is often needed to minimize the potential for calcium fluoride scale formation

Dry Additive Volumetric Feeders

- rotating disk
- oscillating pan
- vibratory pan
- roll
- rotating screw

Dry Feeder Solution Mixing

- Minimum 5 minutes to fully dissolve NaFS
- Hard water, colder temperatures (less than 60°F), and crystalline form of additive can increase the required time to fully dissolve NaFS
Dry Feeder Solution Mixing continued

- Failure to produce a clear, homogeneous solution indicates:
  - Dissolving chamber too small
  - Detention time inadequate
  - Dilution water insufficient
  - Agitation insufficient
  - Short-circuiting

Types of Auxiliary Equipment

- Water Meters
- Pacing Meters
- Vacuum Breakers
- Anti-Siphon Valves
- Day Tanks
- Mixers
- Scales
- Continuous analyzers

Volumetric Feeder Installation

- Water supply with backflow/vacuum breaker
- Top loading bin hopper
- Feeder
- Solution mixing tank with agitator
- Scales

Types of Auxiliary Equipment

- Unions
- Valves
- Strainers
- Timers
- Alarms
- Flow Switches
- Pressure Switches
- Hauling Equipment

Piping Considerations

- Use fluoride compatible materials such as PVC, HDPE
- Include numerous shut-off valves and unions at key locations to facilitate pipe repairs
- Identify the pipe
Backflow and Air-Relief Valves

- Include backflow prevention and air-relief valves in key locations so that tanks do not siphon or drain in the event of a line break

Storage of Fluoride Products

- Storage of additive—CDC recommends 3 months (annual average basis)
- Consult with vendors on product availability/reliability to determine appropriate storage requirements

Calibration Cylinders

- Calibration cylinders allow verification of pump discharge rates

Size/Capacity of Equipment

- Day tank sized for 1 to 3-day holding capacity of solution depending on regulations
- Saturator can be appropriately sized if also used as daytank
- Pumps provide maximum delivery equal to water capacity...do not provide excess fluoride solution delivery capability

Injector

- When solution is added to a pipe, an injector should be used to ensure good mixing with the water flow

Design Modifications

- Many states require review and approval of proposed modifications or additions prior to implementation. Know your state requirements.
Fluoride Testing Methods

- Three Principal Methods
  - Colorimetric
  - Specific Ion Electrode
  - Inductively Coupled Plasma Spectroscopy (ICP-MS)

Colorometric Analysis

- Source of Radiant Energy (lamp)
- Absorption Body
- Energy Detector

Color & Light Absorption

- Why is it Red?
- Absorption is a function of
  - Reflection
  - Transmission

Fluoride Testing Methods

- Colorimetric – Compares reduction of indicator solution color influenced by ions
- Specific Ion Electrode – Measures ionic activity as a relative indicator
- Inductively Coupled Plasma Spectroscopy (ICP-MS) – measures the number of ions in a fixed volume on basis of mass to charge ratio
**Visual Acuity**

![Graph showing visual acuity and wave length](image)

**Visual Determinations**

*“Do YOU See What I See?”*

**Color Perception**

- **Anomalous Trichromatism**
  - Difficulty in matching colors
- **Confuse Reds & Greens**

**Absorbance Measurement**

Two types of instruments

- Filter Photometer (Colorimeter)
- Spectrophotometer

**Filter Photometer**

![Diagram of filter photometer](image)

**Spectrophotometer**

![Diagram of spectrophotometer](image)

**SPADNS Method**

The colorimetric method relies on a reagent with color. For fluoride, this is **SPADNS**

*SODIUM 2-(PARASULFOPHENYLazo)-1,8-DIHYDROXY-3,6-NAPHTHCENEDISULFONATE*
**Colorimetric Analysis Sources of Error**

**Sample Collection**
- Is solution fully mixed?
- Is container used for collection clean?
- Is person introducing contamination?
- Is chlorine a contaminant?

**Sample Handling**
- Skill in using a pipette
- Bulb or pipette may be contaminated
- Parallax in measurement

**Testing Cell (cuvette)**
- Cell might be dirty or smeared
- Residuals could interfere
- Consistent optical clarity between cells
- Chips or scratches

**SPADNS Concentration Calculation**

Fluoride, mg/L = \( \frac{A_o - A_x}{A_o - A_t} \)

- **A₀** = Absorbance of Blank
- **Aₓ** = Absorbance of Sample
- **A₁** = Absorbance of 1 mg/L Fluoride Standard

**Zirconium SPANS Complex**

\( \text{Zr}^{+++} + \text{SPADNS} \rightleftharpoons \text{Color Lake}\)

- Colorless
- Observed Color

**Sources of Error**
- Sample collection
- Sample handling
- Testing cell
- Standards
- Electronic
- Calibration
- Interfering substances
Colorimetric Analysis
Sources of Error

Standards
• Use fresh standards
• Appropriate calibration of test
• Use true deionized water (zero fluoride)

Colorimetric Interfering Substances
Concentrations Causing 0.1 mg/L Error

<table>
<thead>
<tr>
<th>Substance</th>
<th>mg/L</th>
<th>Effect</th>
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<tbody>
<tr>
<td>Aluminum</td>
<td>0.1</td>
<td>↓</td>
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<tr>
<td>Iron</td>
<td>10.0</td>
<td>↓</td>
</tr>
<tr>
<td>Hexametaphosphate</td>
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</tr>
<tr>
<td>Phosphate</td>
<td>16.0</td>
<td>↑</td>
</tr>
<tr>
<td>Sulfate</td>
<td>200</td>
<td>↑</td>
</tr>
</tbody>
</table>

A down arrow means that the indicated value is lower than the actual Fluoride concentration, an up arrow means that the indicated value is higher than the actual.

Colorimetric Analysis
Sources of Error

Electronics
• Weak batteries
• Leaking batteries
• Deterioration of electronics

Specific Ion Electrode Analysis

Electrode Components
- Electrical Lead
- Electrode Body
- Ion Membrane
- Filling Solution

Measures Fluoride Ion Activity
LaF Crystal “Membrane”

Colorimetric Analysis
Sources of Error

Calibration
• Correct instrument calibration
• Background color or turbidity
• Temperature differences

Specific Ion Electrode Analysis

- Voltmeter
- Reference Electrode
- Sensing Electrode
- Stirred Sample
Specific Ion Electrode Analysis

Advantages
- Greater Range, 0.1 – 10.0 mg/L
- Fewer Interfering Substances
- Less Susceptible to Technique Errors

Disadvantages
- Expensive

Specific Ion Electrode Analysis

Total Ionic Strength Adjusting Buffer

<table>
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<tr>
<th>TISAB III</th>
<th>TISAB IV</th>
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<tr>
<td>CDTA</td>
<td>Tartrate</td>
</tr>
<tr>
<td>5.0 – 5.5 pH</td>
<td>8.5 pH</td>
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<td>Up to 5.0 mg/L Aluminum or Iron</td>
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<td>Lanthanum</td>
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Specific Ion Electrode Analysis

Total Ionic Strength Adjusting Buffer
- Adjusts pH 5 – 5.5 to Optimize Fluoride Ion Availability
- Adjusts Total Ionic Strength by Swamping Background
- Complexes Iron & Aluminum

Specific Ion Analysis

Sources of Error

- Sample collection
- Sample handling
- Standards
- Electronic
- Element
- Interfering substances

Specific Ion Electrode Analysis

Total Ionic Strength Adjusting Buffer

TISAB II
Equal parts TISAB & Sample
Complexes up to 5 mg/L Aluminum or Iron

Specific Ion Analysis

Sources of Error

Sample Collection
- Is solution fully mixed?
- Is container used for collection clean?
- Is person introducing contamination?
Specific Ion Analysis
Sources of Error
Sample Handling or Method Related
- Parallax in measurement
- Improper stirring
- Bubble
- Induced EMF
- Complexation (TISAB)
- Concentration out of range

Specific Ion Analysis
Sources of Error
Standards
- Use fresh standards
- Appropriate calibration of test
- Use true deionized water (zero fluoride)

Specific Ion Analysis
Sources of Error
Electronics
- Weak batteries
- Leaking batteries
- Deterioration of electronics
- Instrument drift
  - Batteries
  - Temperature

Specific Ion Analysis
Sources of Error
Fluoride Electrode Element
- Broken Lead
- Leaking
- Filling solution
  - Correct Type
  - Correct Amount
- Crystallized/plugged membrane
- Correct reference electrode

Specific Ion Interfering Substances
Concentrations Causing 0.1 mg/L Error

<table>
<thead>
<tr>
<th>Substance</th>
<th>mg/L</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>3.0</td>
<td>↓</td>
</tr>
<tr>
<td>Iron</td>
<td>200</td>
<td>↓</td>
</tr>
<tr>
<td>Hexametaphosphate</td>
<td>&gt;50,000</td>
<td></td>
</tr>
<tr>
<td>Phosphate</td>
<td>&gt;50,000</td>
<td></td>
</tr>
<tr>
<td>Sulfate</td>
<td>&gt;50,000</td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td>5,000</td>
<td></td>
</tr>
</tbody>
</table>

A negative effect means that the indicated value is lower than the actual Fluoride concentration, and vice versa.
Specific Ion Electrode Analysis

Storing the Electrodes

- Fluoride Single Junction: DRY!
- Fluoride Combination: Filling Solution
- Reference: Filling Solution

Principles of Occupational Safety

- All accidents are preventable
- All levels of management are responsible for safety
- All employees must be properly trained to safely perform their work
- All employees are responsible for their own safety and the safety of their co-workers

Source: Handbook of OSHA Construction Safety, 1999

Water Fluoridation

Health Benefits
Regulatory Perspective
Fluoride Additives
Equipment/Facilities
Laboratory Analysis
Personnel Safety
Operations

Safe Practices

- A safe practice comprises:
  - Knowledge
  - Action
  - Attitude

Safe Practices - Knowledge

- Understand the risk
  - Identify unsafe conditions
  - Anticipate situations
  - MSDS sheets

- Learn the rules
  - OSHA (in the USA)
  - State specific rules
  - Union or labor requirements

Why Is Safety a Consideration in a Water Fluoridation Program?

- People are our most important resource
- All people have the right to work in safe conditions, and regulations mandate safe conditions
Safe Practices - Action


Understand the Risk

- OSHA hazard communication standard establishes minimum requirements to ensure employees know chemical hazards and protective measures
- Employers have a requirement to provide all relevant information
- Employees should expect and obtain information on how to protect themselves against hazards

Safe Practices - Attitude

- All Employees must value safety for themselves and others
- Safety should be integrated into all activities and actions

Understand the Risk

- Material Safety Data Sheets (MSDS): must be provided by chemical suppliers for their product
- Manufacturers commonly provide for their product rather than an “industry generic standard”
- Check for annual updates and revisions

Water Fluoridation Safety

- Hazards are the same as water facility operators experience in other aspects of facility operation
- Specific hazards are related to material handling considerations

Learn the Rules

- Obtain, train, and use correct personnel respirators
- Obtain, train, and use correct personnel protective gear
- Learn additives and associated material handling hazards
- Develop SOPs and best practices
- Formulate response plans for spills and excessive employee exposure
Toxic Exposure

- Toxic = something harmful to the body
- As with anything, dose/exposure is key
- Acute vs. chronic
  - Chronic (uncommon in U.S.)
    - Long term, happens over years
    - Impairment of function
  - Acute (rare)
    - Emergency situation, take rapid action
    - Serious immediate consequences, even death
- Exposures avoided by good safety habits

Toxic Doses

- Inhalation & dermal
  - Little information on toxic doses in humans (difficult to quantify)
  - No deaths reported for dermal exposure
  - Animal studies show varied responses

Toxic Exposure

- Route, dose, and frequency affect exposure
  - Route
    - Inhalation - air (hydrogen fluoride gas, hydrofluoric acid, fluoride dust)
    - Dermal - skin contact (hydrofluoric acid, FSA)
    - Ingestion - eating (NaF or Na₂SiF₆)
  - Dose (safety gear avoids exposure)
    - Large dose – acute
    - Smaller doses – chronic

Acute Toxic Exposure

- Single MASSIVE dose
- Symptoms (may or may not be present)
  - Nonspecific - headache, sweating, excessive salivation, tearing, mucous discharges from nose and mouth, diarrhea, generalized weakness
  - Potentially fatal – spasms, tetany and convulsions, weak pulse, low blood pressure, irregular heartbeats, pulmonary edema

Chronic Toxic Exposure

- Unlikely to experience in the U.S.
- Most commonly associated with excessive natural fluoride in water
- High level: (greater than 10 mg/L)
  - Lack of appetite
  - Slight nausea
  - Anemia
  - Constipation
  - Pain in liver region
  - Shortness of breath

Emergency & First Aid Procedures

- Call 911
- Inhalation – remove person from exposure to fresh air.
- Eye contact – flush eyes with large amounts of water
- Skin contact – wash the contaminated skin with soap or mild detergent and water. Remove contaminated clothing. For FSA, shower a minimum of 15 to 20 minutes.
- Ingestion – if conscious, give person large quantities of water immediately. Do NOT induce vomiting. Milk may be given for soothing effect.
Toxic Doses

- Ingestion
  - Toxic dose = 5-10 mg/kg F body weight (11-22 mg/kg NaF; 8-16 mg/kg Na₂SiF₆)
  - Not possible with optimally fluoridated water
  - Ingestion of 386 liters (102 gallons) for 170 lb person
  - Lethal dose = 5-10 g
    - Potentially lethal dose (32-64 mg/kg) F in adults (70-141 mg/kg NaF; 51-102 mg/kg Na₂SiF₆) and 500 mg F (1100 mg NaF and 800 mg Na₂SiF₆) in small children

Protective Gear

- Air purifying respirator
- Long rubber or neoprene gloves with sleeve gauntlet
- Rubber or neoprene apron
- Rubber boots
- Long-sleeve overalls
- Eye protection if not included with respirator

Respirators

- Two major types of respirators
  - Air Purifying Respirators
    - Removes or reduces specific particulate, vapor and gas contaminants
    - Not suitable for situations with less than 19.5 percent oxygen content in atmosphere
  - Air Supplying Respirators
    - Provides protection independent of conditions in the room
    - Can be either stationary gas source or Self Contained Breathing Unit (SCBU)

- OSHA requires use of respirator when the PEL (Permissible Exposure Limit) is exceeded for the time period to conduct the work task
- Although exposure is inherently low, best practice is to mandate the use of respirators for protection in the event an unexpected exposure

Respirators

- Consensus of additive supplier MSDS guidance and MSA recommendations: Air Purifying Respirator with a hydrogen fluoride rating is appropriate for standard exposure for both dry additives and FSA
- Exception: SCBU necessary in the event of fire

Respirators

- NIOSH approved air purifying respirator with fluoride rated replaceable canisters
Respirators

Correct procurement, training, and maintenance

- Ensure mask is correctly sized for the individual and provides the appropriate protection: integral eye protection preferred
- Verify that canister is particulate and hydrogen fluoride rated
- Training and practice on correct use
- Replacement schedule for canister
- Periodically inspect seals for wear

FSA Safety Equipment

- Face shield
- Safety goggles
- Heavy apron
- Gloves
- Rubber boots
- Safety shower
- Eye wash
- Coveralls

FSA Safety Equipment

- Heavy apron/coveralls
- Long-sleeve gauntlet gloves
- Durable rubber boots
  - Turn back the cuff
- Latex gloves do not provide protection

Storage of Gear

- Keep gear in a designated location convenient to the point of use
- Avoid contamination with other gear or clothes

FSA Safety Equipment

- Full face shield
- Safety goggles
  - Safety shower/eye wash
    - Test regularly!

Standard Operating Procedures

- Promote “best practices”
- Provide guidance to less experienced staff
- Remind all staff members of correct procedures
- Can promote “best practices”
- Preserve institutional memory
Examples of Best Practices

• Always use personnel protective gear
• Never eat or smoke in additive storage area
• Always clean up additive storage area promptly after spill
• Always wash clothes and body after excessive exposure
• Always wash hands after entering fluoride storage area
• Always have a backup buddy when entering additive storage area.
• Use a checklist and document its use

Optimal Fluoride Levels

• Based on maximum daily air temperature (presumed water consumption) from 0.7 to 1.2 mg/L
• Benefits to oral health decline as fluoride levels drops below optimum
• Little incremental benefit gained as fluoride levels increase over optimum
• CDC recommends control range 0.1 mg/L below to 0.5 mg/L above optimum level

Proper Signage and Markings

• Ensure appropriate warning signs are installed
• Install barriers to minimize unauthorized entry to controlled spaces – doors, fences, etc.
• Use floor markings to manage use of space – lines to demarcate limits of storage locations or perimeter of special safety precautions

Goal Is To Maintain Optimal Level

• For benefits of fluoridation to be realized, fluoride must be maintained at or near optimal level
• Principal reason for low or erratic fluoride levels is poor operation and maintenance

Water Fluoridation

Health Benefits
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Proper Operator Understanding of Job Is Most Important Success Measure

• Good operator training essential
• Guidance on best practices
• SOPs
Standard Operating Procedures

- SOPs prepared for all job elements
- SOPs written presuming high employee turnover could jeopardize operational continuity
- SOPs should include operational considerations, safety, performance measures, best practices, reporting, and documentation

Process Calculations

- Desired dosage
  - Amount of fluoride chemical needed to obtain optimal level
- Optimal level
- Natural level

\[
\text{Dosage} = \text{Optimal level} - \text{Natural level} \quad (\text{mg/l}) \quad (\text{mg/l}) \quad (\text{mg/l})
\]

Simplified Process Control Scheme

1. Measure raw and treated water fluoride content
2. Determine fluoride additive required
3. Calculate proper feed rate
4. System operation
5. Adjust feed to deliver desired dosage

Process Calculations - Units

- Capacity
  - MGD, gpm, m³/day
- Fluoride dosage
  - mg/L = ppm
- Fluoride additive feed rate
  - lb/day, lb/hr, mL/min, gpd, gph

Process Calculations

- Treatment facility capacity
  - Maximum hour capacity (2.0)
  - Maximum day capacity (1.4)
  - Maximum month capacity (1.0)
  - Annual average capacity (0.8)
  - Actual capacity (could be any of the rates)
  - Actual operating rate (measured)
  - Minimum capacity (0.2)

- Groundwater well delivers constant volume, often to a storage tank

Process Calculations

- Chemical purity and available fluoride ion (AFI)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Formula</th>
<th>Purity</th>
<th>Available Fluoride Ion (AFI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Fluoride</td>
<td>NaF</td>
<td>98%</td>
<td>0.452</td>
</tr>
<tr>
<td>Sodium Fluorosilicate</td>
<td>Na₂SiF₆</td>
<td>98.5%</td>
<td>0.807</td>
</tr>
<tr>
<td>Fluorosilicic Acid</td>
<td>H₂SiF₆</td>
<td>23%</td>
<td>0.792</td>
</tr>
</tbody>
</table>
Process Calculations

- Fluoride feed rate

\[
\text{Fluoride feed rate (lb/day)} = \frac{\text{Dosage (mg/L) \times Capacity (MGD)} \times 8.34}{\text{AFI} \times \text{chemical purity}}
\]

Calculation Problem 1

- Plant 1 has an average daily flow of 1.4 MGD and the source water has a natural fluoride level of 0.15 mg/L. The optimal level for oral health is 0.9 mg/L. If the FSA has a concentration of 25%, what is the dosage required and how many gallons will be necessary?

Calculation Problem 1 (step 1)

- Average daily flow is 1.4 MGD
- Optimal fluoride level is 0.9 mg/l
- Natural fluoride level is 0.15 mg/l
- Optimal minus natural is the dosage
  \[0.9 - 0.15 = 0.75 \text{ mg/L}\]

Calculation Problem 1 (step 2)

- Average daily flow of 1.4 MGD
- Optimal minus natural is
  \[0.9 - 0.15 = 0.75 \text{ mg/L}\]
  \[\text{Fluoride feed rate (lb/day)} = \frac{\text{Dosage (mg/L) \times Capacity (MGD)} \times 8.34}{\text{AFI} \times \text{chemical purity}}\]
  \[44 \text{ (lb/day)} = \frac{0.75 \text{ (mg/L) \times 1.4 \text{ (MGD)} \times 8.34}}{0.792 \times 0.25}\]
### Calculation Problem 1 (step 3)

**Average daily flow of 1.4 MGD**

**Optimal minus natural is**

\[ 0.9 - 0.15 = 0.75 \text{ mg/L} \]

**44 (lb/day) =**

\[
\frac{0.75 \text{ mg/L} \times 1.4 \text{ MGD} \times 8.34}{0.792 \times 0.25}
\]

44 lbs/day divided by 24 hours is 1.8 lbs per hour

FSA at 25 percent purity weighs 10.1 pounds per gallon to give 0.18 pounds per hour

The total feed rate is

- 4.4 gallons per day (44 lbs divided by 10.1 pounds per gallon)
- 0.18 gallons per hour (4.4 gal per day divided by 24 hours)
- 690 mL per hour (4.4 gal multiplied by 3.78 liters per gallon)

---

### Calculation Problem 2 (step 2)

**Average daily flow of 5.8 MGD**

**Optimal minus natural is**

\[ 0.8 - 0.2 = 0.6 \text{ mg/L} \]

**Fluoride feed rate**

\[
\frac{\text{Dosage} \times \text{Capacity} \times 8.34}{\text{AFI} \times \text{chemical purity}}
\]

\[ 0.607 \times 0.98 \]

The feed rate is 49 pounds per day, or

- 2.0 pounds per hour (dividing by 24 hours)
- 0.92 kilograms per hour (divide pounds by 2.2 to get Kg)
- 15 mg per minute (1000 mg in a Kg, and 60 minutes in an hour)

---

### Calculation Problem 2 (step 3)

**Average daily flow of 5.8 MGD**

**Optimal minus natural is**

\[ 0.8 - 0.2 = 0.6 \text{ mg/L} \]

**49 (lb/day) =**

\[
\frac{0.6 \text{ mg/L} \times 5.8 \text{ MGD} \times 8.34}{0.607 \times 0.98}
\]

The feed rate is 49 pounds per day, or

- 2.0 pounds per hour (dividing by 24 hours)
- 0.92 kilograms per hour (divide pounds by 2.2 to get Kg)
- 15 mg per minute (1000 mg in a Kg, and 60 minutes in an hour)

---

### Calculation Problem 3

**Plant 3 has an average daily flow of 0.45 MGD and the ground water has a natural fluoride level of 0.4 mg/L.**

**The optimal level for oral health is 1.1 mg/L. The fluoride product is sodium fluoride with 96% purity.**

What is the dosage required and how many pounds will be necessary?
Calculation Problem 3 (step 1)
Average daily flow is 0.45 MGD
Optimal fluoride level is 1.1 mg/L
Natural fluoride level is 0.4 mg/L
Optimal minus natural is
\[ 1.1 - 0.4 = 0.7 \text{ mg/L} \]

Calculation Problem 3 (step 2)
Average daily flow of 0.45 MGD
Optimal minus natural is
\[ 1.1 - 0.4 = 0.7 \text{ mg/L} \]

Fluoride feed rate
\[ \text{lb/day} = \frac{\text{Dosage} \times \text{Capacity} \times 8.34}{\text{AFI} \times \text{chemical purity}} \]

\[ \text{Feed Rate} = \frac{0.7 \text{ (mg/L)} \times 0.45 \text{ (MGD)} \times 8.34}{0.452 \times 0.96} = 6.1 \text{ (lb/day)} \]

Calculation Problem 3 (step 3)
Average daily flow of 0.45 MGD
Optimal minus natural is
\[ 1.1 - 0.4 = 0.7 \text{ mg/L} \]

\[ 6.1 \text{ (lb/day)} = \frac{0.7 \text{ (mg/L)} \times 0.45 \text{ (MGD)} \times 8.34}{0.452 \times 0.96} \]

The saturator would need an additional 6.1 pounds per day.

A saturated solution of sodium fluoride is 40,000 mg/L, which is 18,000 mg/L of fluoride ion.

6.1 pounds per day is 2,770 grams per day, or 2,770,000 mg.
2,700,000 mg divided by 40,000 mg/L is 69 liters per day.
69 liters per day is 2.9 liter per hour or 18 gallons per day.
18 gallons per day is 0.76 gallons per hour.

Operation
- Understand how it works
  - Read the manual
  - Understand the operating cycle
    - When the equipment operates automatically
    - When the equipment shuts down automatically
  - Know what it sounds like

Sampling
- Minimum EPA sampling may only require annual testing
- AWWA and CDC both recommend daily sampling of product water
- Hourly testing of product water is often practiced by larger facilities that are well operated
- Occasional spot-sampling at random locations in the distribution system can identify other problems with system such as storage tanks
- Verify sampling location is representative of flow
Records

- Verify state records and reporting requirements
- Operational records
- Laboratory records
- Maintenance records
- Customer comments

Laboratory Records

- Dates, times, technician, location, methodology, etc. for sampling events
- Results of split-sampling with state proficiency laboratory
- Verification of analytical procedure against standards
- Maintenance of laboratory equipment

Operational Records

- Source/product water fluoride level (daily)
- When and where sampling occurred
- Amount of fluoride additive used (daily)
- Pump or feeder calibration curves and pump or feeder operational settings (quarterly)
- Make-up water for saturators and feeders
- Assay on chemical purity (with each delivery)
- Check with state on other record or documentation requirements

Maintenance Records

- Dates of maintenance activities
- Documentation when pump hoses or heads are replaced
- Electrical records related to possible fluoride system operation
- Vendor for parts, supplies, and equipment manuals
- Preventative maintenance not repairs: continuous, dependable operation

Operational Records

- Reporting of operating results important for public health
- Results are compiled and help public health officials, medical doctors, dentists, and other health care providers make good decisions for communities and patients
- Submit results monthly

Suggested Maintenance

- Daily
  - Watch for trouble
    - Inspect system, listen to sounds
    - Look for leaks or differences
  - Liquid systems
    - Check solution levels, check level switch
    - Check hoses for air locks
    - Check pump for prime
    - Refill day tank
  - Dry feeders
    - Check for compaction
    - Refill additive hopper
### Suggested Maintenance

**Every 3 months-FSA feed system**
- Check all piping for leaks, and gas venting for integrity
- Check pipes/hoses for encrustations
- Inspect tank level measurement (floats, gauges, etc)
- Calibrate pump delivery rate

**Every 3 months-dry feeder**
- Thoroughly clean, remove cinders/encrustations
- Check belts; adjust if necessary
- Lubricate bearings
- Calibrate feeder dispensing rate
- Rotate your additive inventory

**Every 3 months-saturator**
- Thoroughly clean, remove cinders/encrustations in saturator, pipes and hoses
- Verify uniform flow through additive bed: no short circuiting or piping
- Verify water softener in working order
- Clean water strainer
- Check all piping for leaks
- Inspect tank level measurement (floats, gauges, etc)
- Calibrate pump delivery rate
- Rotate your additive inventory

### Suggested Maintenance

**Every 6 months**
- Motor driven pumps
  - Check lubrication, adjustments
- Foot valves, lines, hoses, injector
  - Check for crystalline deposits
  - Disassemble and clean
- Vacuum breaker, Anti siphon valve
  - Test operation
  - Disassemble, replace worn parts
- Saturator
  - Drain, disassemble and clean

### Suggested Maintenance

**Annually**
- Metering pump
  - Disassemble and replace worn parts
  - Replace hoses, diaphragms, seats, etc
- Clean valves
  - Foot valve
  - Suction, discharge valves
  - Anti siphon valves; vacuum breaker
  - Injection check valves
- Dry feeder
  - Check for worn gears, replace worn parts
  - Lubricate, change gear oil

### Troubleshooting

**Change in the equipment**
**Deviations in sound or smell**
**Change in amount of chemical fed**
**Change in fluoride concentration**
**Trouble Shooting – continued**

- **Pump won’t pump**
  - Check hoses & fittings
  - Test check valves, foot valve
  - Check back pressure
  - Verify float/level controller operation

- **Pump won’t pump like it used to**
  - Clogged foot valve or strainer
  - Ruptured diaphragm
  - Worn seals
  - Change of pump stroke or speed
  - Pumps or pipes clogged with impurities

- **Softener**
  - Verify water hardness before/after softener
  - Check backwashing/regeneration

**Low Fluoride Readings**

- **In a saturator**
  - Inadequate chemical depth
  - Incomplete mixing—verify no short circuiting or piping in bed
  - Inconsistent chemical addition
  - Accumulation of cinders, encrustations
  - Verify no slimes or grease layers in gravel or additive bed
  - Verify softener working properly
  - Test the solution strength to verify that the solution is saturated

**High Fluoride Readings**

- **Phosphates**
  - When using SPADNS method
  - Verify with ISE meter

- **Sample chlorine residual**

- **Check natural level**
  - Fluctuations due to
    - Run off
    - Low river flows
    - Seasonal variations

**Variable Fluoride Readings**

- **Check feeder or pump for variable output—recalibrate settings**

- **Air binding in metering pumps**

- **Low chemical levels in saturator or insufficient material in bin hopper**

- **Intermittent operations**

- **Are calculations being conducted correctly? Do they compare to records of actual additive being consumed?**

**Trouble Shooting – Dry Feeders**

- **Feed helix not turning but power ON**
  - Check for obstructions

- **Chemical will not feed**
  - Increase frequency of hopper agitator
  - Check moisture content (fish eyes)
  - Is material bridging or packing in bin

- **Erratic feed**
  - Binding of drive shaft or helix
  - Low speeds
Variable Fluoride Readings
• Verify additive purity, water content or silica content
• Verify chemical not bridging or packing in bin
• Verify additive does not have excessive moisture or fish eyes
• Incomplete mixing, verify that mixing tank has adequate volume for hydration/saturation
• Is tank experiencing stratification of concentrations? (different batches, complete dissolution, storage tanks?)

Variable Fluoride Readings
• Maintenance can result in unintended changes to controls and wiring
• Are controls and process working as intended?
• Is wiring correct?
• Does solution pump activates with one service pump but not the other?

Low Fluoride Readings
• Interferences with lab tests
• Poor glassware
• Improperly cleaned glassware
• Phosphate detergent
• Rinse with distilled water
• Sample temperatures
• Improper laboratory methodology
• Instrument errors, damage

Calibration for Pumps
• Close valve to pump, open valve to calibration column and fill
• Close valve from storage tank, open valve to pump
• Measure time to pump measured volume for various pump settings

Calibration for Dry Feeders
• Conduct pan test
  − Fill hopper to normal depth
  − Set machine to low feed rate, allow discharge rate to achieve a stable and consistent rate, then collect discharge over a measured time in first pan
  − Repeat for several higher feed rates collecting discharge over measured time in sequential pans
  − Measure weight of pans with material and subtract pan weight to obtain material feed rate for each discrete machine setting

Calibration Curve

<table>
<thead>
<tr>
<th>Pump rate (GPH) or discharge (pounds/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00</td>
</tr>
<tr>
<td>Feed rate or pump setting</td>
</tr>
<tr>
<td>0 10 20 30 40 50 60 70 80 90 100</td>
</tr>
</tbody>
</table>
Calibration of Feed Delivery

- Calibration curve must be prepared for each pump or feeder
- Verify curve accuracy monthly, more frequently if additive character changes or maintenance is performed on equipment
- Curve should be based on 4 to 5 settings over the full range
- Always include the date of the calibration test

Overfeed

- CDC provides overfeed recommendations, verify state specific requirements
- Water treatment facilities should have overfeed instructions with operator instruction on procedures
- For overfeeds less than MCL, continue operation while problem is identified
- For overfeeds exceeding MCL
  - Temporarily stop operations while problem is identified
  - Notification of state personnel
  - Flush lines
  - Notify the public