# FLUORIDE

## FACT SHEET

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cost Assumptions; Raw Water Composition; Total Plant Costs; and WaTER Program.

## 1. CONTAMINANT DATA

**A. Chemical Data:** Fluoride ($F^-$) monotomic, inorganic anion. $F^-$ are ions or compounds containing the element Fluorine (F), atomic number: 9, atomic weight 19.0. Common compounds include: sodium fluoride (NaF), sodium silicofluoride ($Na_2SiF_6$), and calcium fluoride ($CaF_2$). F is the most reactive nonmetallic element and forms salts when combined with metals.

**B. Source in Nature:** The most common source of $F^-$ in the environment is the natural mineral fluorapatite, which is a fluorinated calcium phosphate rock. Fluorapatite is mined as the primary source of phosphate fertilizer. $F^-$ is used in the manufacture of glass and steel and may be a contaminant in industrial discharges. $F^-$ may be added to drinking water supplies or toothpastes for prevention of tooth decay. This may result in high concentrations in discharges from sewage treatment plants. Seawater naturally contains about 1.3 mg/L of $F^-$. $F^-$ in ground or surface waters is a result of natural deposits or from industrial/mining contamination. Organic F is present in vegetables, fruits, and nuts. Inorganic F, or NaF, is a waste product of aluminum and is used in some rat poisons.

**C. SDWA Limits:** MCL for $F^-$ is 4.0 mg/L and the SMCL is 2.0 mg/L (may be less if regulated by an individual state).

**D. Health Effects of Contamination:** Municipal water treatment plants commonly add $F^-$ compounds to water to achieve a desired concentration of about 1.0 mg/L for prevention of tooth decay; however, tooth discoloration or dental fluorosis can develop from concentrations in excess of 2.0 mg/L. Prolonged consumption of water containing $F^-$ at 4.0 mg/L or greater causes skeletal fluorosis, a serious bone crippling disorder resembling osteoporosis, as well as dental malformation, decalcification, mineralization of tendons, and digestive and nervous disorders. These conditions occur in different people at very different levels of $F^-$ content.

## 2. REMOVAL TECHNIQUES

**A. USEPA BAT:** Not yet specified in regulation; however, technologies with the highest removal efficiencies are reverse osmosis and activated alumina.

! RO for soluble $F^-$ uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble $F^-$), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.

! AA uses extremely porous and highly adsorptive aluminum ore media to adsorb $F^-$. Benefits: suitable for small or large systems; containment of $F^-$ in adsorption bed. Limitations: careful selection/design required. AA cost curves will be included in a future revision.

**B. Alternative Methods of Treatment:** Distillation heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The $F^-$ remains in the boiler section. Generally, distillation for $F^-$ removal is considered a POU process. IX for soluble $F^-$ uses charged anion resin to exchange acceptable ions from the resin for undesirable forms of $F^-$ in the water. Lime softening for $F^-$ treatment can be used provided the water has a sufficient Mg content, since it is the Mg that adsorbs the F. The water may be enriched with $MgSO_4$ or dolomitic lime. Lime softening uses two types of chemical additions. First, $Ca(OH)_2$ is added in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness. Next, $Na_2CO_3$ is added to precipitate noncarbonate hardness. Benefits: proven and reliable. Limitations: operator care required with chemical usage; sludge disposal.

**C. Safety and Health Requirements for Treatment Processes:** Personnel involved with demineralization treatment processes should be aware of the chemicals being used (MSDS information), the electrical shock hazards, and the hydraulic pressures required to operate the equipment. General industry safety, health, and self protection practices should be followed, including proper use of tools.

## 3. BAT PROCESS DESCRIPTION AND COST DATA

**General Assumptions:** Refer to: Raw Water Composition Fact Sheet for ionic concentrations; and Cost Assumptions Fact Sheet for cost index data and process assumptions. All costs are based on *ENR*, PPI, and BLS cost indices for March 2001. General sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal are not included.

**3A. Reverse Osmosis:**

Process - RO is a physical process in which contaminants are removed by applying pressure on the feed water to direct it through a semipermeable membrane. The process is the "reverse" of natural osmosis (water diffusion from dilute to concentrated through a semipermeable membrane to equalize ion concentration) as a result of the applied pressure to the concentrated side of the membrane, which overcomes the natural osmotic pressure. RO membranes reject ions based on size and electrical charge. The raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Common RO membrane materials include asymmetric cellulose acetate or polyamide thin film composite. Common membrane construction includes spiral wound or hollow fine fiber. Each material and construction method has specific benefits and limitations depending upon the raw water characteristics and pretreatment. A typical large RO installation includes a high pressure feed pump, parallel 1st and 2nd stage membrane elements (in pressure vessels); valving; and feed, permeate, and concentrate piping. All materials and construction methods require regular maintenance. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Factors influencing performance are raw water characteristics, pressure, temperature, and regular monitoring and maintenance.

Pretreatment - RO requires a careful review of raw water characteristics and pretreatment needs to prevent membranes from fouling, scaling, or other membrane degradation. Removal of suspended solids is necessary to prevent colloidal and bio-fouling, and removal of dissolved solids is necessary to prevent scaling and chemical attack. Large installation pretreatment can include media filters to remove suspended particles; ion exchange softening or antiscalant to remove hardness; temperature and pH adjustment to maintain efficiency; acid to prevent scaling and membrane damage; activated carbon or bisulfite to remove chlorine (postdisinfection may be required); and cartridge (micro) filters to remove some dissolved particles and any remaining suspended particles.

Maintenance - Monitor rejection percentage to ensure $F^-$ removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly flushed through the system at high volume/low pressure with a cleaning agent to remove fouling and scaling. The system is flushed and returned to service. $NaHSO_3$ is a typical caustic cleaner. RO stages are cleaned sequentially. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

Waste Disposal - Pretreatment waste streams, concentrate flows, and spent filters and membrane elements all require approved disposal.

Advantages -

! Produces highest water quality.

! Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.

! Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

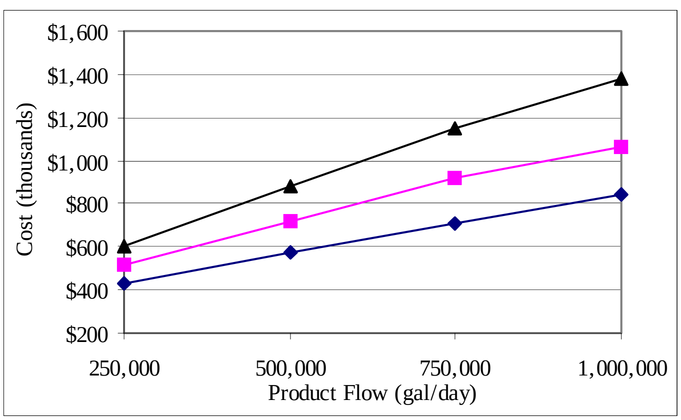
Disadvantages -

! Relatively expensive to install and operate.

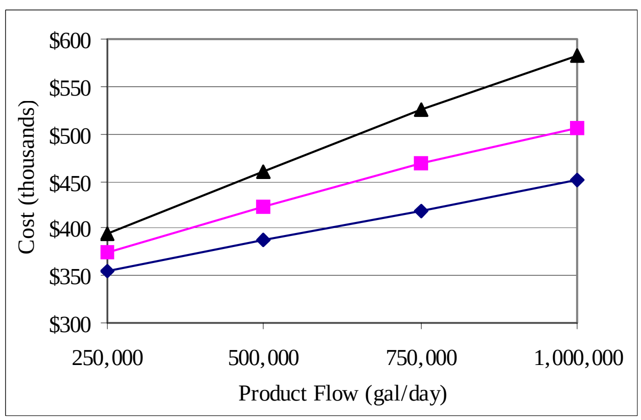
! Frequent membrane monitoring and maintenance; monitoring of rejection percentage for $F^-$ removal.

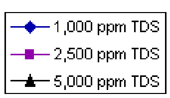
! Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

**BAT Equipment Cost***




**BAT Annual O&M Cost***




*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

**3B. Activated Alumina:**

Process - AA uses an extremely porous media in a physical/chemical separation process known as adsorption, where molecules adhere to a surface with which they come into contact, due to forces of attraction at the surface. AA is a media made by treating aluminum ore so that it becomes porous and highly adsorptive, and is available in powder, pellet, or granule form. The media is activated by passing oxidizing gases through the material at extremely high temperatures. This activation process produces the pores that result in such high adsorption properties.

Contaminated water is passed through a cartridge or canister of AA. The media adsorbs the contaminants. The adsorption process depends on the following factors: 1) physical properties of the AA, such as method of activation, pore size distribution, and surface area; 2) the chemical/electrical nature of the alumina source or method of activation and the amount of oxygen and hydrogen associated with them, such that as the alumina surfaces become filled the more actively adsorbed contaminants will displace the less actively adsorbed ones; 3) chemical composition and concentration of contaminants effect adsorption, such as size, similarity, and concentration; 4) the temperature and pH of the water, in that adsorption usually increases as temperature and pH decreases; and 5) the flowrate and exposure time to the AA, in that low contaminant concentration and flowrate with extended contact times increase the media life. AA devices include: pour-through for treating small volumes; faucet-mounted (with or without by-pass) for POU; in-line (with or without by-pass) for treating large volumes at several faucets; and high-volume commercial units for treating community water supply systems. Careful selection of alumina to be used is based on the contaminants in the water and manufacturer's recommendations.

Pretreatment - With bacterially unstable waters, filtration and disinfection prior to AA treatment may be required. With high TSS waters, prefiltration may be required. If treatment is based on flowrate, a water meter may be required to register and total flowrates.

Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of media may be required and is based on contaminant type, concentration, and rate of water usage. The manufacturer's recommendations for media replacement should be consulted. Recharging by backwashing or flushing with hot water (145$^{o}$F) may release the adsorbed chemicals, however this claim is inconclusive. Periodic cleaning with an appropriate regenerant such as $Al_2(SO_4)_3$, acid, and/or caustic will extend media life. With bacterially unstable waters, monitoring for bacterial growth is required because the adsorbed organic chemicals are a food source for some bacteria. Flushing is required if the AA filter is not used for several days, and regular backwashing may be required to prevent bacterial growth. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

Waste Disposal - Backwash/flush water disposal is required if incorporated. Disposal of spent media may be the responsibility of a contractor providing media replacement services.

Advantages -
- Suitable for some organic chemicals, some pesticides, and THMs.
- Suitable for home use, typically inexpensive, with simple filter replacement requirements.
- Improves taste and smell; removes chlorine.

Disadvantages -
- Careful selection/design required.
- Effectiveness is based on contaminant type, concentration, and rate of water usage.
- Bacteria may grow on alumina surface.
- Adequate water flow and pressure required for backwashing/flushing.
- Requires careful monitoring.

Costs - The BAT costs curves for AA equipment and annual operation and maintenance are being developed and will be included in a future revision.