

SELENIUM

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: Selenium (Se), inorganic element, solid nonmetal, stable and sparingly soluble, atomic number 34, atomic weight 78.96. Oxidation states (in water): +4 (Selenite), +6 (Selenate), and -2 (Selenide); +7 (Perselenate) is less common.

B. Source in Nature: Se is a naturally occurring element found in soils, surface water, and groundwater. The weathering of rocks and soils is the major naturally occurring source of Se in the environment. For industry and manufacturing, Se is not mined, but rather produced as a by-product of copper refinery slimes. Se in various forms is used in dyes, insecticides, pigments, electronic devices, photocopying, glass manufacturing, veterinary medicine, anti-dandruff shampoos, feed additives, and by pharmaceuticals; and is a by-product of mining, smelting, and coal/oil combustion processes. NPDES permits regulate the effluent discharges from industry and manufacturing. Consequently, elevated concentrations of Se of a non-natural source in surface and groundwaters are typically a result of the irrigation of infertile land in arid areas where the parent soil materials are sedimentary rocks of marine origin. Se concentrations in agricultural runoff are a result of the leaching of the naturally occurring alluvial deposits in combination with the evaporation of the irrigation water.

C. SDWA Limits: MCL for Se is 0.05 mg/L

D. Health Effects of Contamination: Received in minute quantities as part of a normal nutritional diet, Se is an important antioxidant, key in maintaining the body's immune system. Exposure to toxic levels can result in liver and nervous system damage; growth inhibition; psychological disorders; digestive problems; irritation to mucous membranes; and dermatitis or skin discoloration.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Coagulation and filtration; lime softening; reverse osmosis; electrodialysis; or activated alumina.

! Coagulation and filtration uses the conventional treatments processes of chemical addition, coagulation, and dual media filtration. Benefits: low capital costs for proven, reliable process. Limitations: operator care required with chemical usage; not suitable for Se⁺⁶; sludge disposal.

! Lime softening for Se treatment 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, Na₂CO₃ is added to precipitate noncarbonate hardness. Benefits: proven and reliable. Limitations: operator care required with chemical usage; sludge disposal.

! RO uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids, to pass through the membrane. Benefits: produces highest Se removal, along with high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.

! EDR uses semipermeable membranes in which ions migrate through the membrane from a less concentrated to a more concentrated solution as a result of the ions' representative attractions to direct electric current. Benefits: contaminant specific removal. Limitations: electrical requirements; concentrate disposal.

! AA uses extremely porous and highly adsorptive aluminum ore media to adsorb Se. Benefits: containment of Se in adsorption bed. Limitations: when used with Se⁺⁴ results in creation of hazardous waste requiring disposal. 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 contaminants remain in the boiler section. Distillation will remove all inorganic chemicals. It works very slowly and is expensive to operate due to the amount of energy it uses. For purposes of protecting waters from agricultural runoff or drainage effluent, new studies are attempting to test the ability of certain types of algae and bacteria to take up Se well enough to form the basis for an efficient drainage treatment method.

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. Coagulation and Filtration:

Process - Coagulation and filtration uses the conventional chemical and physical treatment processes of chemical addition, rapid mix, coagulation, flocculation, and dual media filtration. Chemical coagulation and flocculation consists of adding a chemical coagulant combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). $\text{Fe}_2(\text{SO}_4)_3$ has been proven to be the most effective coagulant for Se^{+4} removal; while $\text{Al}_2(\text{SO}_4)_3$ proved most effective for Se^{+6} removal. Filtration provides final removal by dual media filtering of all floc and suspended solids.

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required.

Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Routine checks of contaminant buildup in the filter is required, as well as filter backwash. Recharging or clean installation of media is periodically required.

Waste Disposal - Filter backwash and spent material require approved disposal.

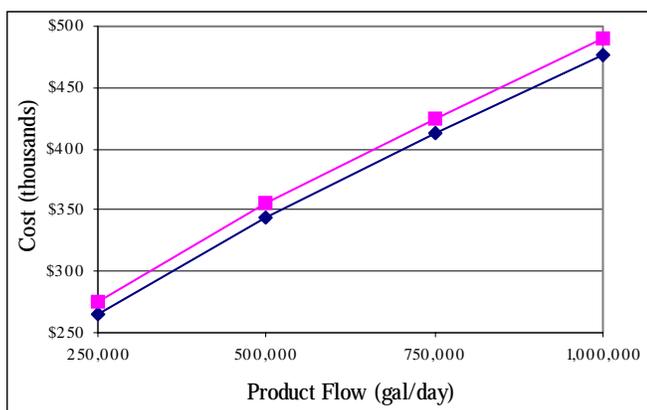
Advantages -

- ! Lowest capital costs.
- ! Lowest overall operating costs.
- ! Proven and reliable.
- ! Low pretreatment requirements.

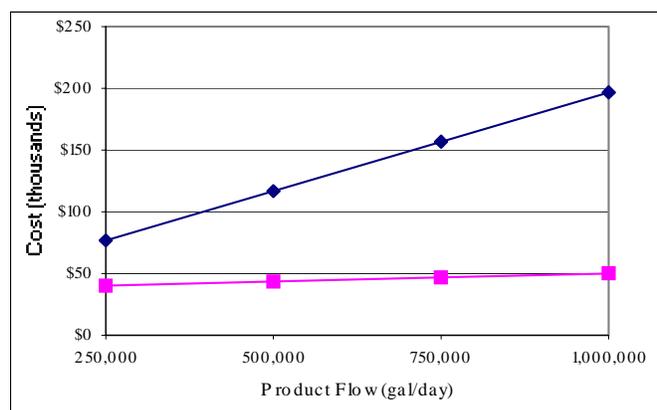
Disadvantages -

- ! Operator care required with chemical handling.
- ! Not suitable for Se^{+6} removal.
- ! Produces high sludge volume.
- ! Waters high in sulfate may cause significant interference with removal efficiencies.

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. Costs are presented for direct filtration (coagulation and flocculation plus filtration). Costs for coagulation and filtration would be less since flocculation is omitted.

3B. Lime Softening:

Process - Lime softening uses chemical additions followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical additions include $\text{Ca}(\text{OH})_2$ to precipitate carbonate and Na_2CO_3 to precipitate noncarbonate hardness. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Se, into larger particles), and final clarification occur. In the upflow SCC, the clarified water flows up and over the weirs, while the settled particles are removed by pumping or other collection mechanisms (i.e. filtration).

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required. Optimum pH is about 10.

Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Similar procedures also apply to the sludge disposal return system, which takes the settled sludge from the bottom of the clarifier and conveys it to the dewatering and disposal processes.

Waste Disposal - There are three disposal options for Se sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Se and other economically important materials is also a viable option, however, costs of the isolation and recovery must be compared to the value of the recovered materials.

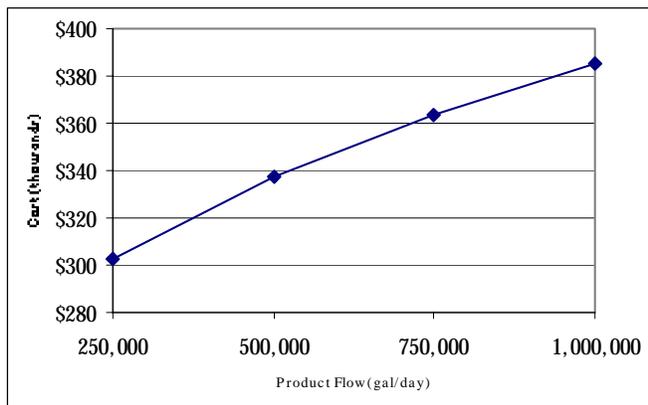
Advantages -

- ! Other heavy metals are also precipitated; reduces corrosion of pipes.
- ! Proven and reliable.
- ! Low pretreatment requirements.

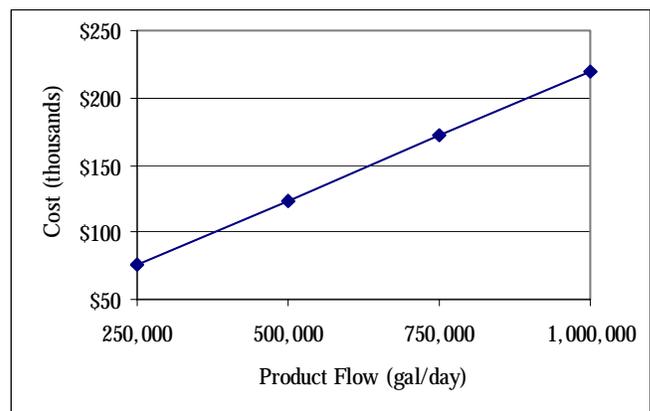
Disadvantages -

- ! Operator care required with chemical handling.
- ! Produces high sludge volume
- ! Waters high in sulfate may cause significant interference with removal efficiencies.

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.

3C. 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 Se 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. NaHSO₃ 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.

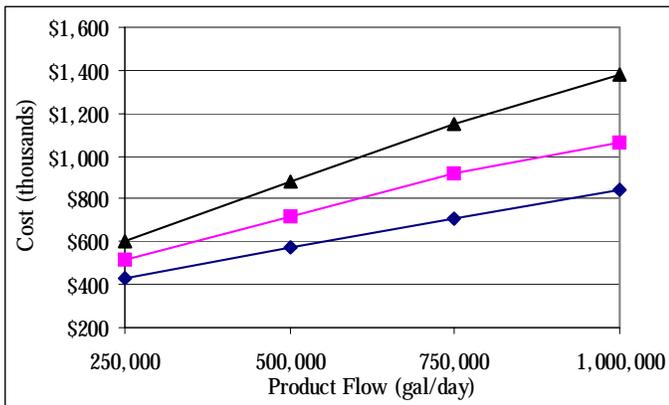
Advantages -

- ! Produces highest Se removal; produces highest quality water.
- ! 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.

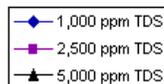
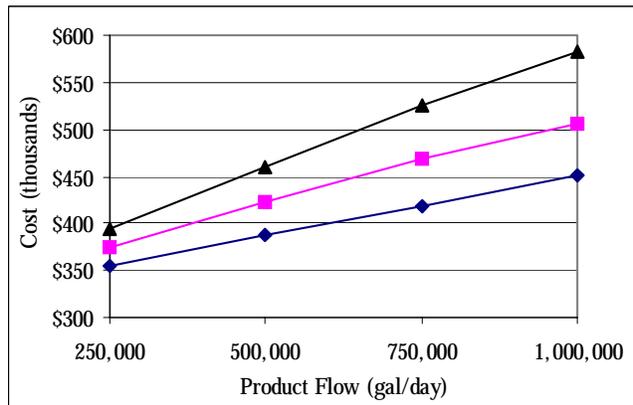
Disadvantages -

- ! Relatively expensive to install and operate.
- ! Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Se 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.

3D. Electrodialysis Reversal:

Process - EDR is an electrochemical process in which ions migrate through ion-selective semipermeable membranes as a result of their attraction to two electrically charged electrodes. A typical EDR system includes a membrane stack with a number of cell pairs, each consisting of a cation transfer membrane, a demineralized flow spacer, an anion transfer membrane, and a concentrate flow spacer. Electrode compartments are at opposite ends of the stack. The influent feed water (chemically treated to prevent precipitation) and concentrated reject flow in parallel across the membranes and through the demineralized and concentrate flow spacers, respectively. The electrodes are continually flushed to reduce fouling or scaling. Careful consideration of flush feed water is required. Typically, the membranes are cation- or anion-exchange resins cast in sheet form; the spacers are HDPE; and the electrodes are inert metal. EDR stacks are tank contained and often staged. Membrane selection is based on careful review of raw water characteristics. A single-stage EDR system usually removes 50 percent of the TDS; therefore, for water with more than 1000 mg/L TDS, blending with higher quality water or a second stage is required to meet 500 mg/L TDS.

Electrodialysis Reversal (EDR) uses the technique of regularly reversing the polarity of the electrodes, thereby freeing accumulated ions on the membrane surface. This process requires additional plumbing and electrical controls, but increases membrane life, does not require added chemicals, and eases cleaning.

Pretreatment - Guidelines are available on accepted limits on pH, organics, turbidity, and other raw water characteristics. Typically requires chemical feed to prevent scaling, acid addition for pH adjustment, and a cartridge filter for prefiltration.

Maintenance - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode reaction. The byproducts are hydrogen, formed in the cathode space, and oxygen and chlorine gas, formed in the anode spacer. If the chlorine is not removed, toxic chlorine gas may form. Depending on raw water characteristics and Se concentration, the membranes will require regular maintenance or replacement. EDR requires system flushes at high volume/low pressure; EDR requires reversing the polarity. Flushing is continuously required to clean electrodes. If utilized, pretreatment filter replacement and backwashing will be required. The EDR stack must be disassembled, mechanically cleaned, and reassembled at regular intervals.

Waste Disposal - Highly concentrated reject flows, electrode cleaning flows, and spent membranes require approved disposal. Pretreatment processes and spent materials also require approved disposal.

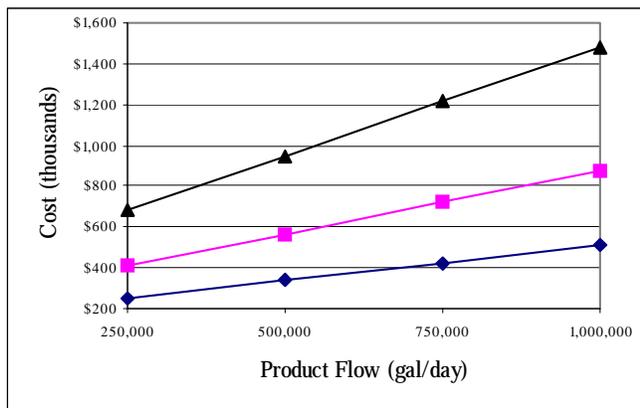
Advantages -

- ! EDR can operate with minimal fouling or scaling, or chemical addition; suitable for higher TDS sources.
- ! Low pressure requirements; typically quieter than RO.
- ! Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

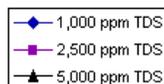
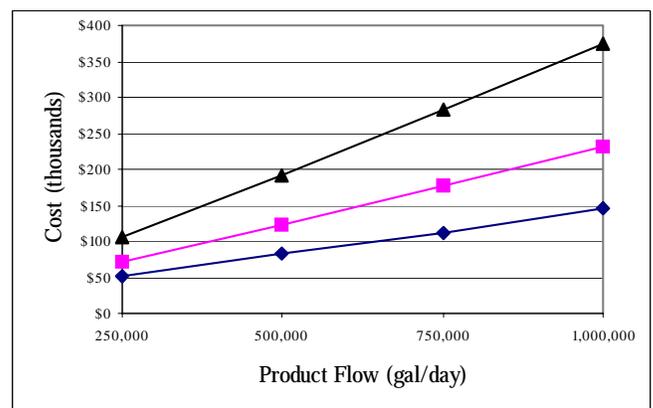
Disadvantages -

- ! Not suitable for high levels of Fe and Mn, H₂S, chlorine, or hardness.
- ! Limited current density; current leakage; back diffusion.
- ! At 50% rejection of TDS per pass, process is limited to water with 3000 mg/L TDS or less.

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.

3E. 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°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 is the responsibility of the contractor providing the media replacement services.

Advantages -

- ! Well established.
- ! 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 -

- ! 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.