MERCURY and CADMIUM

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: Mercury (Hg), atomic number: 80, atomic weight: 200.59, most stable oxidation state +2, lustrous silver-liquid heavy metal. Cadmium (Cd), atomic number: 48, atomic weight: 112.41, oxidation state +2, lustrous silver-white heavy metal.

B. Source in Nature: Hg and Cd are both naturally occurring in the environment in ores, rocks, and soils in limited quantities. Hg is introduced into the environment by natural and man-made processes, including: volcanic activity; incineration of coal, heating oil, and rubbish; mining and smelting; industrial use; and the manufacture of thermometers, batteries, and electrical equipment. Cd is introduced into the environment by corrosion of galvanized pipes; refining and electroplating; mining and smelting; manufacture of polyvinyl chloride products and nickel-cadmium batteries. Hg and Cd primarily enter surface waters through runoff or contaminated industrial disposal.

C. SDWA Limits: MCL for Hg is 0.002 mg/L, and 0.005 mg/L for Cd.

D. Health Effects of Contamination: Hg and Cd are poisonous and have no beneficial effect on humans. Chronic exposure over long periods to even low concentrations of Hg and Cd can have severe health effects. Both Hg and Cd accumulate in the food chain, are absorbed in the human body, and accumulate there. Hg poisoning includes kidney damage, brain and nerve damage, birth defects, and skin rash. Long-term effects from Cd poisoning includes kidney damage and changes to the constitution of the bone, liver, and blood. Short-term effects include nausea, vomiting, diarrhea, and cramps.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Coagulation and filtration, lime softening, and reverse osmosis are the BATs for Hg at concentrations <10 µg/L; and granular activated carbon is a BAT at any concentration. Coagulation and filtration, lime softening, ion exchange, and reverse osmosis are the BATs for Cd at any concentration.

! Coagulation and filtration for insoluble Hg and Cd 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; sludge disposal.

! Lime softening for soluble Hg and Cd uses $Ca(OH)_2$ in sufficient quantity to precipitate carbonate hardness and heavy metals. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Hg and Cd compounds may be formed at low carbonate levels requiring coagulation and flocculation.

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

! GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the media the dissolved contaminants are attracted and held (adsorbed) on the solid surface. Benefits: well established; suitable for home use. Limitations: effectiveness based on contaminant type, concentration, rate of water usage, and type of carbon used; requires careful monitoring. GAC cost curves will be included in a future revision.

! IX for soluble Cd uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Cd in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.

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 Hg and Cd remain in the boiler section. Activated alumina and powdered activated carbon are also alternative treatment methods for Cd.

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 for insoluble Hg and Cd uses the conventional chemical and physical treatment processes of chemical addition, rapid mix, coagulation with dry alum, 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). $Al_2(SO_4)_3$ has been proven to be the most effective coagulant for insoluble Hg and Cd 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.

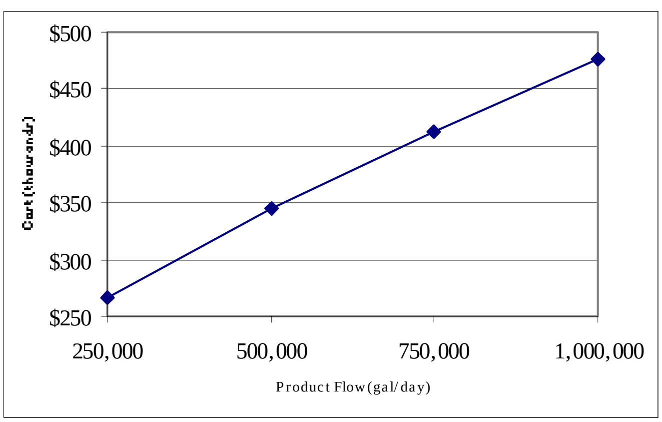
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.
! Suitable only for insoluble Hg and Cd.
! Produces high sludge volume.
! Waters high in sulfate may cause significant interference with removal efficiencies.

BAT Equipment Cost*



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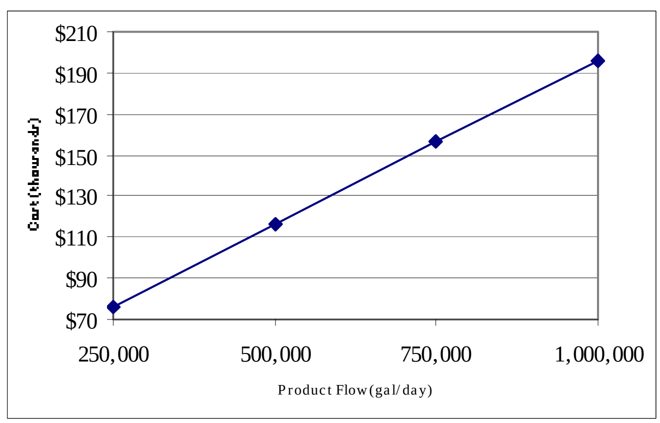


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal. Costs are presented for direct filtration (coagulation and flocculation plus filtration). Costs for coagulation and filtration would be less since flocculation is omitted.

3B. Lime Softening:

Process - Lime softening uses a chemical addition followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical addition includes adding $Ca(OH)_2$ in sufficient quantity to raise the pH while keeping the levels of alkalinity relatively low, to precipitate carbonate hardness. Heavy metals, like Hg and Cd, precipitate as $Hg(OH)_2$ and $Cd(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Hg and Cd, 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 and alkalinity for coagulation, and resulting pH and alkalinity adjustment, may be required. Optimum pH is about 10.

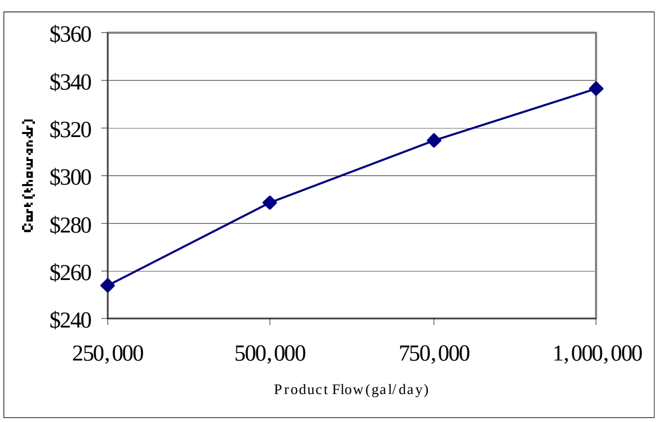
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 Hg and Cd sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Hg and Cd 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 -
! Excessive insoluble Hg and Cd may be formed requiring coagulation and filtration.
! Operator care required with chemical handling.
! Produces high sludge volume.

BAT Equipment Cost*



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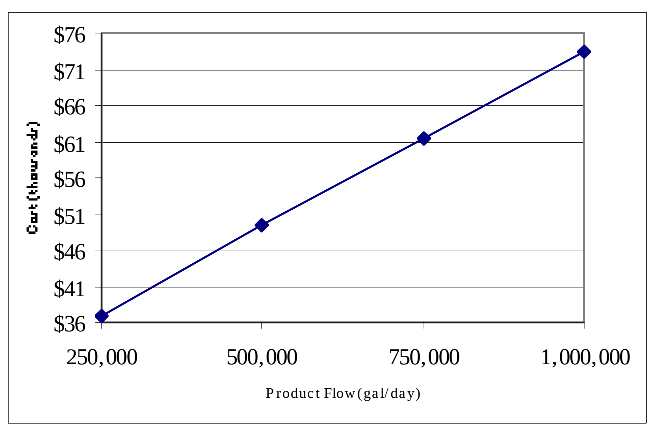

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3C. Reverse Osmosis:

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 Hg and Cd 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.

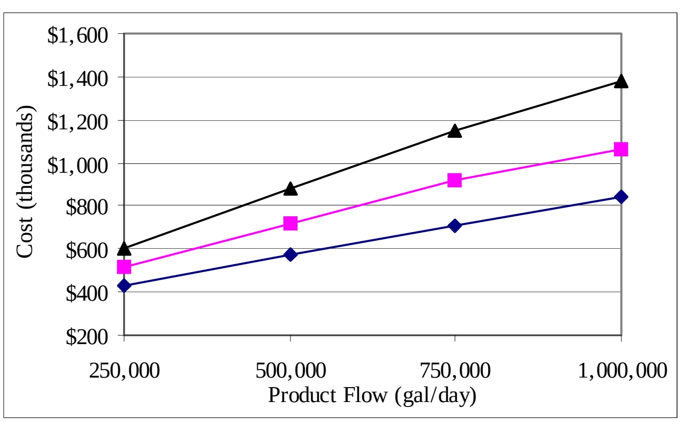
Disadvantages -

! Relatively expensive to install and operate.

! Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Hg and Cd removal.

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

BAT Equipment Cost*



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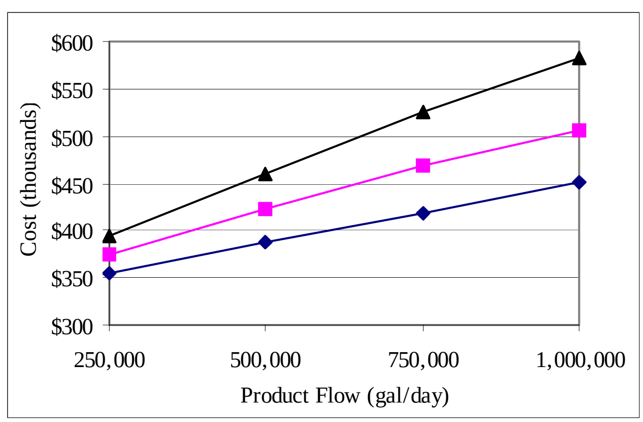

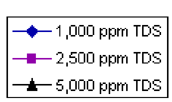

*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3D. Granular Activated Carbon:

Process - GAC uses extremely porous carbon media in a process known as adsorption. As water passes through the highly porous media which has an extremely high surface area for adsorption, the dissolved contaminants adsorb on the solid surface. GAC is made of tiny clusters of carbon atoms stacked upon one another. The carbon media is produced by heating the carbon source (generally activated charcoal) in the absence of air to produce a high carbon material. The carbon media is activated by passing oxidizing gases through the material at extremely high temperatures. The activation process produces the pores that result in such high adsorption properties. The adsorption process depends on the following factors: 1) physical properties of the GAC, such as type of raw carbon, method of activation, pore size distribution, and surface area; 2) the chemical/electrical nature of the carbon source or method of activation, and the amount of oxygen and hydrogen associated with them, such that as the carbon surfaces become filled the more actively adsorbed contaminants will displace the less actively adsorbed ones; 3) chemical composition and concentration of contaminants, such as size, similarity, and concentration, affect adsorption; 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 GAC, in that low contaminant concentration and flowrate with extended contact times increase the carbon's life. GAC devices include: pour-through for treating small volumes; faucet-mounted (with or without by-pass) for single point use; 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 type of carbon 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 carbon treatment may be required. With high TSS waters, prefiltration may be required.

Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used. The manufacturer's recommendations for media replacement should be consulted. Recharging by backwashing or flushing with hot water (145°F) may release the adsorbed organic chemicals, however this claim is inconclusive. 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 carbon 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 spend 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, rate of water usage, and type of carbon used.
- ! Bacteria may grow on carbon surface.
- ! Adequate water flow and pressure required for backwashing/flushing.
- ! Requires careful monitoring.

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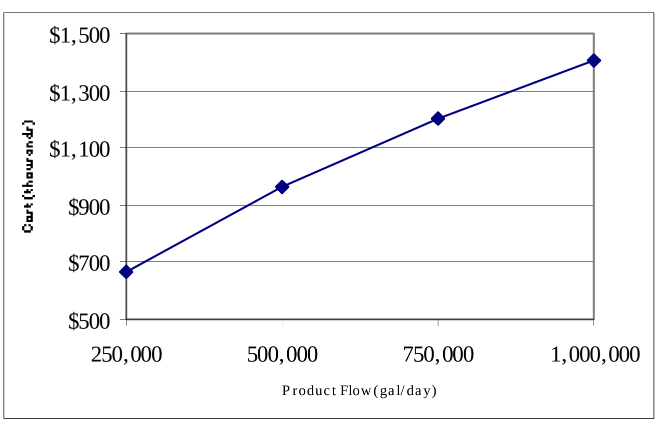

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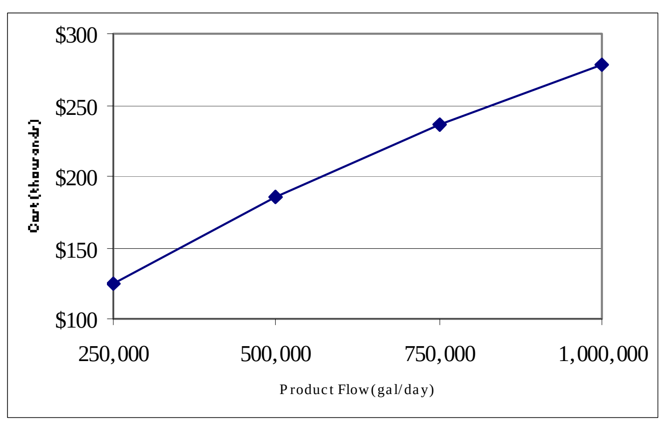

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3E. Ion Exchange:

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. Cation IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in ions is obtained. In the case of Cd, operation begins with a fully recharged resin bed, having enough positively charged ions to carry out the cation exchange. Usually a polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the positively charged ions are released into the water, being substituted or replaced with the soluble Cd in the water (ion exchange). When the resin becomes exhausted of positively charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the Cd^{+2} ions with $2Na^{+}$ ions. Typically, Cd ion exchange utilizes a strong acid cation resin bed.

Pretreatment - Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics. Pretreatment may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration.

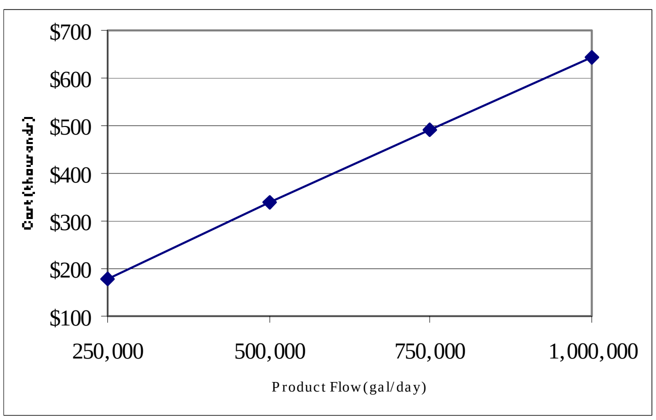
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Cd concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated Cd solution); occasional solid wastes (in the form of broken resin beads) which are backwashed during regeneration; and if utilized, spent filters and backwash waste water.

Advantages -
- ! Ease of operation; highly reliable.
- ! Lower initial cost; resins will not wear out with regular regeneration.
- ! Effective; widely used.
- ! Suitable for small and large installations.

Disadvantages -
- ! Requires salt storage.

BAT Equipment Cost*



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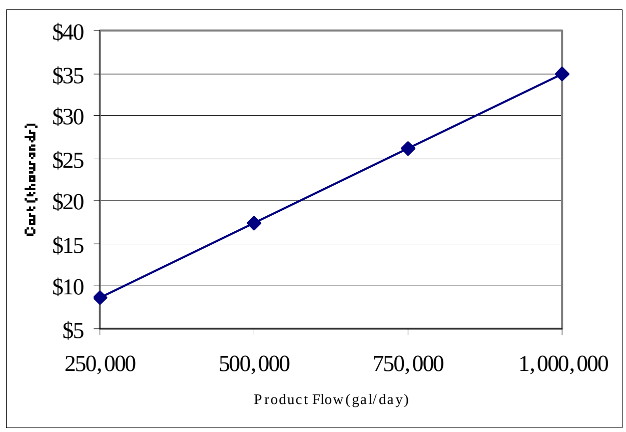

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