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“Water Treatment Primer for Communities In Need”

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WATER TREATMENT PRIMER

FOR COMMUNITIES IN NEED

Advanced Water Treatment Research Program Report No. 68

September 2001

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Technical Service Center
Water Treatment Engineering and Research Group

Mission Statements

U.S. Department of the Interior

The mission of the Department of the Interior is to protect and provide access to our Nation’s natural and cultural heritage and honor our trust responsibilities to tribes.

Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

PRIMER CONTENTS

INTRODUCTION

Contained in this primer are various water quality contaminant fact sheets and related fact sheets containing supporting information. These primer and fact sheets are resources offered by the Bureau of Reclamation (Reclamation) as a means of sharing technical information. The purpose of the contaminant fact sheets is to provide timely and accurate summations of water treatment principles and techniques for various water quality contaminants of concern. The fact sheets are intended as a first source of information for small communities or communities of low economic status which typically do not have the resources to hire water treatment consultants. Cooperation with other federal, state, and local agencies and water treatment entities in solving the water treatment issue of concern is recommended and encouraged. As research reveals new water treatment techniques, the fact sheets will be revised and updated to reflect state of the art methods for water treatment. In 2001, a total plant cost ($/1000 gal) fact sheet was prepared for 9 of the more common best available technology (BAT) treatment techniques.

Each of the contaminant fact sheets contains the following information:

1. CONTAMINANT DATA.
   A. Chemical data including name, symbol, molecular weight, cation/anion, metal/nonmetal, reactivity, etc.
   B. Source in nature including sources of contamination in surface and groundwater.
   C. SDWA limits including MCL, MCLG, and SMCL limits.
   D. Health effects of contamination.
2. REMOVAL TECHNIQUES.
   A. USEPA BAT including brief description.
   B. Alternative methods of treatment including historically common, low cost alternatives.
   C. Related WTTP/DWPR publications (this section may be expanded to include publications from other sources).
   D. Safety and health requirements for treatment processes.
3. BAT PROCESS DESCRIPTION AND COST DATA.
   A. Individual process description including pretreatment, maintenance, waste disposal, advantages, and disadvantages; and equipment and O&M cost curves for flows of 0.25, 0.50, 0.75, and 1.0 MGD.

RECLAMATION'S DESALTING RESEARCH PROGRAMS

Funding for this primer has come from a number of Reclamation desalting research programs: Water Treatment Technology Program (WTTP - www.usbr.gov/water/wttp.html), Desalination & Water Purification Research & Development Program (DWPR - www.usbr.gov/water/desal.html), and Advanced Water Treatment Research Program (AWTR - www.usbr.gov/water/awtr.html). Year 2001 revisions were prepared under the AWTR program. These programs are funded through Reclamation's office of Research and Natural Resources, Shannon Cunniff, Director.

DIRECT INQUIRIES TO:

1. Mail to: Bureau of Reclamation, Technical Service Center, PO Box 25007, Denver, CO 80225,
   Attention: Water Treatment Engineering and Research Group, D-8230.

2. Contact: Kevin Price, Group Manager, telephone at (303) 445-2260 or FAX at (303) 445-6329.

3. Internet: www.usbr.gov/water/water.html.

Funding for most Reclamation projects and programs is provided through US Congressional appropriations. Occasionally, grants and general investigation funds are available for specific areas of research. Cost-shared funding for use of the Reclamation's Mobile Treatment Plant is provided through the AWTR program, Task E. Contracts under the DWPR program are awarded yearly, contingent upon Congressional appropriations, through Broad Agency Announcements. Work not funded through the AWTR or DWPR programs or covered by Congressional appropriations generally requires full cost reimbursement.

ACRONYMS and ABBREVIATIONS

FOR CONTAMINANT FACT SHEETS

ACRONYM/ABBREVIATION	DEFINITION
α	alpha (radionuclides)
AA	activated alumina
AC	activated carbon
A&E	architectural and engineering
$Al_2(SO_4)_3$	aluminum sulfate (alum)
AS	air stripper
AWTR	Advanced Water Treatment Research Program
Ba	barium
BAT	best available technology
Be	beryllium
BLS	Bureau of Labor Statistics
β	beta (radionuclides)
^oC	degrees Celsius
Ca	calcium
$CaCO_3$	calcium carbonate
$Ca(OH)_2$	calcium hydroxide (lime)
Cd	cadmium
CFU	colony forming units
Cl^-	chloride ion
Cl_2	chlorine
CO_2	carbon dioxide
Cr	chromium
CSI	Construction Specification Institute
cu	color unit
Cu	copper
DBPR	Disinfection Byproducts Rule
DE	diatomaceous earth
DesalR&D	Water Desalination Research and Development Program
DF	direct filtration
DT	detention time
DWPR	Desalination and Water Purification Research and Development Program
F	fluorine
F^-	fluoride
^oF	degrees Fahrenheit
ED	electrodialysis
EDR	electrodialysis reversal
ENR	Engineering News Record
FDA	Federal Drug Administration
Fe	iron
$Fe_2(SO_4)_3$	ferric sulfate
FLR	filter loading rate
ft/sec	feet per second
ft^2	square foot
ft^3	cubic foot
g	gram
G	velocity gradient - feet per second per foot
GAC	granular activated carbon
gal	gallon
$gal/min/ft^2$	gallon per minute per square foot

HCO_3^-	bicarbonate
HDPE	high density polyethylene
Hg	mercury
HOCl	hypochlorous acid
hr	hour
hr/day	hours per day
H_2S	hydrogen sulfide
IX	ion exchange
K	potassium
KCl	potassium chloride
$KMnO_4$	potassium permanganate
kPa	kilopascal
Kw	kilowatt
Kw-hr	kilowatt hour
lbs	pounds
L	liter
m	meter
m^2	square meters
m^3	cubic meters
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF/L	million fibers per liter
Mg	magnesium
$MgCO_3$	magnesium carbonate
$MgSO_4$	magnesium sulfate
MGD	million gallons per day
mg/L	milligrams per liter (ppm)
min	minute
mL	milliliter
Mn	manganese
MSDS	material safety data sheets
MTP	mobile treatment plant
MW	molecular weight
Na	sodium
NaCl	sodium chloride
Na_2CO_3	sodium carbonate (soda ash)
NaF	sodium fluoride
$NaHSO_3$	sodium bisulfite
NF	nanofiltration
Ni	nickel
NO_3^-	nitrate ion
NO_2^-	nitrite ion
NOM	natural organic matter
NPDES	National Pollutant Discharge Elimination System
NSF	National Sanitation Foundation
NTU	nephelometric turbidity unit
OCl^-	hypochlorite ion
OH^-	hydroxide
O&M	operation and maintenance
PAC	powdered activated carbon
Pb	lead
pCi/L	pico Curie per liter
PCBs	polychlorinated byphenols
PFU	plate forming units
pH	acidic or basic value, hydrogen ion concentration
POE	point-of-entry
POU	point-of-use
ppb	parts per billion (µg/L)
PPE	personal protective equipment
PPI	producer price index
ppm	parts per million (mg/L)
psi	pounds per square inch

Ra	radium
RO	reverse osmosis
Rn	radon
RT	retention time
Sb	antimony
SCC	solids contact clarifier
SDWA	Safe Drinking Water Act
Se	selenium
Se^{+4}	selenite (in water)
Se^{+6}	selenate (in water)
sec	second
SLR	surface loading rate
SMCL	secondary maximum contaminant level
SO_4^{-2}	sulfate ion
SOC	synthetic organic chemicals
TDH	total dynamic head
TDS	total dissolved solids
THM	trihalomethane
Tl	thallium
TTHMs	total trihalomethanes
ton	threshold odor number
TPC	total plant cost
TSS	total suspended solids
TT	treatment technique
μg/L	microgram per liter (ppb)
μm	micrometer
U	uranium
USEPA	United States Environmental Protection Agency
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic chemical
w	watt
WaTER	water treatment estimation routine
WTTP	Water Treatment Technology Program
Zn	zinc

GLOSSARY OF TERMS

FOR CONTAMINANT FACT SHEETS

Advanced Water Treatment Research Program - A Reclamation research program which specifically supports engineering and research that has a direct impact on Reclamation's mission. The primary goal of the program is to provide engineering assistance and research support for Reclamation's Regional and Area Offices.

Agglomeration - The coming together or clumping of small scattered particles into larger particles which settle.

Alkalinity - The capacity of water to neutralize acids. A measure of how much acid can be added to a liquid without causing a great change in pH.

Anion - A negatively charged ion resulting from the dissociation of salts, minerals, or acids in water.

Antiscalant - A chemical agent added to water that raises the solubility limit and inhibits chemical precipitation.

Bacteria - Microscopic living organisms usually consisting of a single cell which live either by absorbing food from the environment (photosynthesizing) or by using some chemical reactions to provide energy and multiply by simple division.

Best Available Technology - A USEPA term for the water treatment process(es) that provide optimum treatment for a specified contaminant.

Biofouling - Blockage or obstruction on a membrane surface due to living or dead animal or plant matter.

Blending - Mixing desalted water with undesalted water to obtain the following advantages: the addition of hardness and alkalinity from undesalted water reduces the corrosivity of the product water; and the amount of posttreatment chemical and the water treatment plant size are reduced, thereby lowering capital and operating costs.

Cation - A positively charged ion resulting from the dissociation of salts, minerals, or acids in water.

Cellulose Acetate - A acetic acid ester of cellulose which when compounded with suitable plasticizer forms a tough thermoplastic material which may be manufactured as semipermeable membrane.

Coagulation - The clumping together of very small particles into larger particles caused by the use of chemicals (coagulants).

Concentrate - The waste stream (concentrated ions) produced as a byproduct of membrane treatment. Also called brine or reject.

Contaminant - Any undesirable physical, chemical, or microbiological substance or matter in a given water source or supply. Anything in water which is not chemically water may be considered a contaminant.

Demineralization - Any process that removes mineral substances from water. Usually synonymous with deionization.

Desalination and Water Purification Research and Development Program - A Reclamation research program funded from October 1997 to September 2002, with the primary goal of developing more cost-effective, technologically efficient, and implementable means to desalinate water.

Direct Filtration - A method of filtration where the feed stream is fed directly to the filtration media. In conventional terms, the conventional treatment train less sedimentation or clarification.

Distillation - The process of heating water to evaporation and its subsequent condensation to purify the water.

Electrodialysis - A process in which ions are transferred through membranes from a less concentrated to a more concentrated solution as a result of the passage of direct current electrical potential.

Electrodialysis Reversal - An automatic operating feature of some ED units that reverses the electrical potential applied to the two electrodes about every 15 minutes to promote cleaning of the unit.

Feed Water - The input solution to any water treatment process.

Flocculation -The gathering together of small particles in water by gentle mixing after the addition of coagulant chemicals to form larger particles.

Fouling - The act of depositing suspended solids on a membrane surface or in the feed channel which impedes the proper operation of the membrane unit.

Greensand - A naturally occurring mineral that consists largely of dark greenish grains of glauconite, and is a natural ion exchange mineral capable of softening water and removing iron and manganese.

Inorganic - Substances which are of mineral origin, such as sand, salt, iron, and calcium salts.

Ion - An electrically charged atom, radical, or molecule formed by the loss or gain of one or more electrons.

Ion Exchange - A chemical process where certain unwanted ions of a given electrical charge are absorbed on to resin, removed from solution, and replaced by wanted ions of a like charge.

Maximum Contaminant Level - The maximum concentration of a contaminant allowed under the USEPA National Primary Drinking Water Standards. Primary contaminants threaten human health.

Maximum Contaminant Level Goal - The recommended maximum concentration of a contaminant allowed under the USEPA National Primary Drinking Water Standards. MCLGs are not enforceable, and are health goals based entirely on health effects.

Membrane - A thin sheet of natural or synthetic material that is permeable to substances in solution.

Microfiltration - The low pressure membrane filtration through a coherent medium with a nominal pore size range from slightly below 0.1 µm to slightly above 1.5 µm.

Microorganisms - A plant or animal of microscopic size.

Mobile Treatment Plant - Reclamation's MTP was constrcuted to provide technical assistance to small and Native American communities which lack financial resources to remove the health risks from their water supply and meet increasingly stringent water quality regulations. The MTP is used to determine the optimum water treatment process which achieves the desired product water quality. For qualified communities, the MTP and supporting staff of engineers, chemists, scientists, and technicians will address water treatment problems and recommend solutions on a 50-50 cost share basis.

Nanofiltration - A membrane process capable of filtering down to 0.001 micron. NF has a lower rejection rate for monovalent ions than multivalent ions and can operate at significantly lower operating pressures than RO membranes.

Organic - Substances that come from animal or plant sources, and always contain carbon.

Oxidation - The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound.

Pathogens - Disease causing organisms.

Permeate - The product water from a desalting process. Also called product.

pH - Measurement of acidity (<7) or alkalinity (>7). The logarithm of the reciprocal of hydrogen ion concentration in an aqueous solution.

Phytoplankton - Small, usually microscopic plants (such as algae) found in lakes, reservoirs, or other bodies of water.

Pretreatment - Treatment units located upstream of the main treatment process which are necessary to remove compounds that are detrimental to the main treatment process.

Product - See permeate.

Protozoa - Single-celled, parasitic animals.

Raw Water - Water in its natural state, prior to any treatment. Usually the water entering the first treatment process of a treatment plant.

Recovery - The amount of permeate water attainable, expressed as a percent of the feed flow.

Rejection - The process where certain ions are not allowed to pass through a semipermeable membrane.

Reject - See concentrate.

Resins - A class of chemicals, many of which have ionic replacing properties to absorb specific ions (and releasing others) such as ammonia, nitrate, metals, etc. An anion resin adsorbs anions in the water while a cation resin removes cations in the water. Both require careful selection of a regenerant type and concentration (i.e. caustic or acid base).

Reverse Osmosis - The reverse of the natural osmosis process. The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane.
Secondary Maximum Contaminant Level - The maximum concentration of a contaminant allowed under the USEPA National Secondary Drinking Water Standards. Secondary contaminants do not threaten human health, but cause aesthetic problems.

Sedimentation - A process in which solid particles settle out of the water being treated in a clarifier or sedimentation basin.

Sediments - A general description of any number of materials or large waterborne particles that settle.

Scaling - A process where precipitation or crystallation of salt compounds or solids form a coating on working surfaces of a system.

Semipermeable - The ability to allow some molecules from a mixture to pass through but not all.

Sodium Bisulfite - An acid salt ($NaHSO_3$) usually prepared by passing sulfur dioxide through a solution of sodium carbonate.

Total Dissolved Solids - All of the dissolved solids in the water. The residue after filtering of suspended solids and evaporation.

Total Plant Cost - The cost of treated water expressed in $/1000 gal. TPC includes the annualized capital equipment costs for all the unit processes, annual O&M costs, and various project related special costs.

Total Suspended Solids - The quantity of material removed by filtering, usually with either a Gooch crucible or a 0.45 µm filter

Toxicant - A substance which is poisonous to an organism.

Treatment Technique - A USEPA term for a procedure that a water system must follow, in lieu of meeting an MCL, that assures the water delivered to the system's customers prevents known or anticipated adverse health effects. The procedures include such things as installation of a treatment technology to achieve specified goals, self-certification of adhering to certain standard operating procedures, public education, replacement of pipe, etc.

Turbidity - The cloudy appearance of water caused by the presence of suspended particles and colloidal matter, which interferes with the passage of light through the water.

Viruses - Obligate microorganisms capable of causing disease.

Water Treatment Estimation Routine - WaTER is an Excel spreadsheet application developed for use with Reclamation's MTP. The program is a result of a cooperative effort between Reclamation and the National Institute of Standards and Technology. Unlike other cost estimation programs that require the user to have information about the size of equipment and chemical dosage rates, the only inputs required for the WaTER program are the production capacity and raw water quality composition.

Water Treatment Technology Program - A Reclamation research program that formed partnerships with private industry, universities, and local communities to address a broad range of desalting and water treatment needs. The overall objective of the program was to reduce the cost of desalting and water treatment technologies. Funding for the program concluded in September 1997.

COST ASSUMPTIONS

FOR CONTAMINANT FACT SHEETS

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

1. COST INDEX DATA

Construction and annual O&M costs were derived from: the WaTER Program; *Estimating Water Treatment Costs*, volumes 1 and 2 of EPA-600/2-79-162a, August 1979; or from manufacturer's product data information. Cost estimates are as of March 2001, are considered accurate within +30% to -15%, and are primarily intended as a guide for comparing alternative water treatment options. More accurate cost estimates can be determined given site specific data and verification of assumptions.

EPA cost index updates as follows:
October 1978 ENR construction cost index = 2581; February 1999 = 5992; March 2001 = 6273.
October 1978 PPI O&M materials index = 71.6; February 1999 = 130.8; March 2001 = 137.8.
October 1978 PPI O&M energy cost = \$0.03/kW-hr; February 1999 & March 2001 = \$0.07/kW-hr.
October 1978 PPI O&M labor cost = \$10/hr; February 1999 = \$30/hr; March 2001 = \$32.5/hr.
Total annual O&M cost = sum of materials, energy, and labor costs.

The following WaTER Program cost components are based on those used by *ENR* at www.enr.com or 212-512-2000:

Category	2001 Value	Used For
Construction cost index	6,279.45	Manufactured & electrical equipment
Building cost index	3,541.01	Housing
Skilled labor index	5,874.20	Excavation, site work, & labor
Materials index	2,115.65	Piping & valves
Steel cost (\$/cwt)	28.01	Steel
Cement cost (\$/ton)	80.35	Concrete
Materials index	2,115.65	Maintenance materials
Electricity cost (\$/kWhr)	0.07	Power
Labor rate (\$/hr)	32.5	Labor

2. PROCESS ASSUMPTIONS

A. Raw Water Pumps: Costs derived from WaTER program. No. of pumps: 2 centrifugal single stage. Pump efficiency: 75%, motor efficiency 90%. Horsepower based on flowrate.

B. Screening/Straining: Costs derived from manufacturer's product data information. Velocity: 2.5 ft/sec, "Water Supply and Pollution Control;" second edition; J.W. Clark, W. Viessman Jr., and M.J. Hammer. Screen size opening: 1/4-inch. 3-, 4-, 5-, and 6-inch diameter screens for flows 0.25, 0.50, 0.75, and 1.0 MGD, respectively. Estimated annual O&M for all flows: \$1,000.

C. Rapid Mix: Costs derived from "Estimating Water Treatment Costs." DT: 30 sec, "Recommended Standards for Water Works;" 1982. G value = 900.

D. Polymer Addition: Costs derived from WaTER program. General settling aid: \$1.50/lb. Dosage: 3.0 mg/L.

E. Antiscalant: Costs derived from WaTER program. RO and EDR membrane aid: \$1.50/lb. Dosage: 0.5 mg/L.

F. Dry Alum Coagulation: Costs derived from WaTER program. $Al_2(SO_4)_3$ cost: \$22/100 lbs. Dosage: 230 mg/L.

G. Ferric Sulfate Coagulation: Costs derived from WaTER program. $Fe_2(SO_4)_3$ cost: \$260/short ton. Dosage: 3.0 mg/L.

H1. Lime Softening with Upflow Solids Contact Clarifier: Costs derived from WaTER program. $Ca(OH)_2$ cost: \$340/ton. Dosage: 84.3 mg/L. Two SCC units, each sized for ½ total flow. SCC DT: 120 min. SCC O&M G value = 150.
H2. Lime/Soda Ash Softening with Upflow Solids Contact Clarifier: Costs derived from WaTER program. $Ca(OH)_2$ cost: \$340/ton. Na_2CO_3 cost: \$340/ton. $Ca(OH)_2$ dosage: 84.3 mg/L; Na_2CO_3 dosage: 278 mg/L. Two SCC units, each sized for ½ total flow. SCC DT: 120 min. SCC O&M G value = 150.

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Water Treatment Engineering and Research Group, D-8230
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Revision Date: 9/21/01

I. Horizontal Paddle Flocculator: Costs derived from "Estimating Water Treatment Costs." DT: 30 min, "Recommended Standards for Water Works;" 1982. G value = 80.

J1. Circular Clarifier: Costs derived from "Estimating Water Treatment Costs." SLR: 1.0 gal/min/ft^2, "Recommended Standards for Water Works;" 1982. DT @ 12' sidewall depth: 90 min. Structure is concrete.
J2. Tube Settler: Costs derived from "Estimating Water Treatment Costs." SLR: 2.5 gal/min/ft^2, "Estimating Water Treatment Costs;" volumes 1 and 2; EPA-600/2-79-162a; August 1979.

K. Dual Media Gravity Filter: Costs derived from WaTER program are based on two concrete basins. Dual media cost: \$938/m^3@0.25 MGD; \$815/m^3@0.50 MGD; \$701/m^3@0.75 MGD; & \$582/m^3@1.0 MGD. Dual media FLR: 5.0 gal/min/ft^2, "Estimating Water Treatment Costs;" volumes 1 and 2; EPA-600/2-79-162a; August 1979. 2 units, each sized for plant capacity. 24 hr wash cycle. Media depth: 1 m. Media volume: 3.2 m^3@0.25 MGD; 6.5 m^3@0.50 MGD; 9.7 m^3@0.75 MGD; 12.9 m^3@1.0 MGD. TSS density: 35 g/L. Costs include backwash pump, filter structure, and pipe gallery housing. Backwash piping: 7 ft/sec. Backwash pump: 50' TDH. Maximum backwash rate: 18 gal/min/ft^2.

L. Chlorine Disinfection: Costs derived from WaTER program. Gaseous Cl_2 cost: \$500/short ton, tank. Dosage (2.5 mg/L) = demand (2 mg/L) + residual (0.5 mg/L). Free chlorine residual of 0.2 - 0.5 mg/L and DT of 30 min for groundwater or 2 hrs for surface water, "Recommended Standards for Water Works;" 1982. Free chlorine residual = chlorine available as HOCl and OCl^-.

M1. Ion Exchange (Anion): Costs derived from WaTER program. Regeneration cycle: 14 days. Resin cost: \$5,227/m^3; 1.0 nominal equivalent/liter of resin for NO_3^-. NaCl regeneration at 10% strength. Regenerant storage tank included.
M2. Ion Exchange (Cation): Costs derived from WaTER program. Regeneration cycle: 14 days. Resin cost: \$1,819/m^3; 1.9 nominal equivalent/liter of resin. NaCl regeneration at 10% strength.
M3. Ion Exchange (Mixed Bed): Costs derived from WaTER program. Regeneration cycle: 14 days. Nuclear grade resin mixture (cation:anion) generally 1:1. Resin cost: \$4,662/m^3; 1.9 nominal equivalent/liter (cation) resin; and 1.4 nominal equivalent/liter (anion) resin. NaCl regeneration at 10% strength.

N. Oxidation with $KMnO_4$ followed by Greensand Filtration: Costs derived from WaTER program, adjusting gravity filtration for greensand filtration. $KMnO_4$ cost: \$2.10/lb (hopper truck). $KMnO_4$ dosage: 1.1 mg/L. Total gravel, greensand, and anthracite costs: \$1,750m^3@0.25 MGD; \$1,539/m^3@0.50 MGD; \$1,361/m^3@0.75 MGD; & \$1,202/m^3@1.0 MGD. Greensand loading rate: 5.0 gal/min/ft^2. 2 units, each sized for plant capacity. 24 hr wash cycle. Media depth: 1 m. Media volume: 3.2 m^3@0.25 MGD; 6.5 m^3@0.50 MGD; 9.7 m^3@0.75 MGD; 12.9 m^3@1.0 MGD. TSS density: 35 g/L. Costs include backwash pump and filter structure.

O. Granular Activated Carbon: Costs derived from WaTER program. 6 month bed life.

P. Reverse Osmosis: Total direct capital costs derived from WaTER program and include cleaning system and some pretreatment (antiscalant) filters/chemicals. Operating pressure: 1380 kPa (200 psi). Membrane cost: \$525 per 8" module. Membrane life: 3 years. Product quality: 500 mg/L TDS. Two stage unit operating at 80% recovery with blending. Pretreatment not included.

Q. Microfiltration: Total direct capital costs derived from WaTER program and include cleaning system and some pretreatment filters/chemicals. Design feed pressure: 207 kPa (30 psi). Membrane cost: \$650. Membrane life: 5 years.

R. Electrodialysis Reversal: Costs derived from WaTER program and Ionics, Inc. Unit operates at 80% recovery. Product quality: 500 mg/L TDS. Pretreatment not included.

S. Clearwell: Costs derived from WaTER program. Below ground concrete tank sized based on water source (30 min DT for groundwater or 2 hr DT for surface water) and flowrate.

3. RAW WATER VARIABLES

An assumed raw water composition is shown on the Raw Water Composition Fact Sheet. Following are the only raw water variables used to determine the cost curves:

A. Flow: Costs for each BAT were prepared for flows of 0.25, 0.50, 0.75, and 1.0 MGD.

B. TDS: A TDS of 2,500 mg/L was assumed for all processes; except for RO and EDR where three TDS ranges were estimated at 1,000, 2,500, and 5,000 mg/L.

C. TSS: For dual media gravity and greensand filtration a TSS of 13.0 mg/L was estimated.

RAW WATER COMPOSITION

FOR CONTAMINANT FACT SHEETS

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

The following raw water composition was used in determining cost curves for various treatment processes:

	Component	Valence	MW	MCL/SMCL (mg/L)	Units	Concentration
METALS	Aluminum	3	26.97	0.05-0.2	mg/L	0.005
	Antimony	3	121.75	0.006	mg/L	--
	Arsenic	3	74.92	0.05	mg/L	0.002
	Barium	2	137.33	2	mg/L	0.11
	Beryllium	2	9.01	0.004	mg/L	--
	Cadmium	2	112.41	0.005	mg/L	0.001
	Calcium	2	40.08	--	mg/L	99
	Chromium	2	52	0.1	mg/L	0.002
	Copper	2	63.55	1	mg/L	0.001
	Iron	2	55.85	0.3	mg/L	0.005
	Lead	2	207.2	0.015	mg/L	--
	Magnesium	2	24.3	--	mg/L	19
	Manganese	2	54.94	0.05	mg/L	0.003
	Mercury	2	200.59	0.002	mg/L	--
	Nickel	2	58.71	0.1	mg/L	0.002
	Potassium	1	39.1	--	mg/L	12
	Selenium	4	78.96	0.05	mg/L	--
	Silver	1	197.87	0.1	mg/L	0.001
	Sodium	1	22.99	--	mg/L	31
	Strontium	2	87.6	--	mg/L	0.61
	Thallium	1	204.37	0.002	mg/L	--
	Zinc	2	65.38	5	mg/L	0.02
OTHER INORGANICS	Alkalinity-HCO_3^-	-1	61	--	--	100
	Alkalinity-CO_3^{-2}	-2	60	--	--	--
	Carbon Dioxide (aq)	0	44	--	--	--
	Asbestos	--	--	7	MF/L	--
	Chloride	-1	35.45	250	mg/L	--
	Residual disinfectant	--	71	detectable	mg/L	--
	Color	--	--	15	cu	--
	Conductivity	--	--	--	--	920
	Corrosivity	--	--	non-corrosive	mg/L	--
	Cyanide	--	--	0.2	mg/L	--
	Fluoride	-1	19	4	mg/L	0.2
	Foaming agents	--	--	0.5	mg/L	--
	Nitrate (as N)	-1	14	10	mg/L	12
	Nitrite (as N)	-1	14	1	mg/L	--
	Ammonium	1	--	10	mg/L	--
	Odor	--	--	3	ton	--
	pH	--	--	6.5-8.5	pH	7.2
	o-Phosphate	-3	95	--	--	--
	Silica	--	--	--	--	--
	Silicon	--	--	--	--	28
	Solids (TDS)	--	--	500	mg/L	2500
	Sulfate	-2	96	250	mg/L	130
	Temperature	--	--	--	--	13
	Solids (TSS)	--	--	--	mg/L	--

Bureau of Reclamation, Technical Service Center
Water Treatment Engineering and Research Group, D-8230
PO Box 25007, Denver CO 80225 (303) 445-2260

Revision Date: 9/21/01

Following are the only raw water variables applied to the above:

A. TDS: For RO and EDR, three TDS ranges were estimated at 1,000, 2,500, and 5,000 mg/L.

B. TSS: For dual media gravity and greensand filtration, a TSS of 13.0 mg/L was estimated.

C. Metals for Cl_2: The following concentrations were adjusted for use with Cryptosporidium/Giardia and Total Coliform/E-Coli:

Iron	550 mg/L
Manganese	550 mg/L
Chromium	200 mg/L
Nickel	200 mg/L
Nitrite	200 mg/L

TOTAL PLANT COSTS

FOR CONTAMINANT FACT SHEETS

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

1. CONTAMINANTS AND TREATMENT PROCESSES

Total plant costs (TPC) are provided for the following groundwater (0 mg/L TSS) treatment processes: direct filtration (DF); reverse osmosis (RO); electrodialysis reversal (EDR); microfiltration (MF); cation and anion ion exchange (IX); softening with lime; and softening with lime and soda ash. TPCs are also provided for the following surface water (13 mg/L TSS) treatment processes: conventional treatment technique (TT); greensand with $KMnO_4$; coagulation and filtration with alum; and coagulation and filtration with ferric sulfate.

● DF is a BAT for asbestos.

● RO is a BAT for: alpha & beta particles (radionuclide); antimony; arsenic; barium; beryllium; copper; cyanide; fluoride; lead; mercury & cadmium; nickel; nitrites & nitrates; radium (radionuclide); selenium; total dissolved solids; trihalomethanes; uranium (radionuclide); and zinc.

● EDR is a BAT for: barium; nitrites & nitrates; selenium; total dissolved solids; and trihalomethanes.

● Cation IX is a BAT for: alkalinity; barium; beryllium; copper; lead; mercury & cadmium; nickel; radium; thallium; and zinc.

● Anion IX is a BAT for: alkalinity; chromium; cyanide; nitrites & nitrates; and uranium.

● Lime softening is a BAT for: alkalinity; barium; beryllium; chromium; copper; lead; mercury & cadmium; nickel; and zinc.

● Lime & soda ash softening is a BAT for: arsenic; radium; selenium; and uranium.

● Conventional TT is a BAT for *Cryptosporidium* & *Giardia*.

● Greensand and $KMnO_4$ is a BAT for iron & manganese.

● Coagulation and filtration with alum is a BAT for: antimony; asbestos; beryllium; chromium; copper; lead; mercury & cadmium; selenium; and uranium.

● Coagulation and filtration with ferric sulfate is a BAT for: arsenic; selenium; and trihalomethanes.

Although MF is not currently a recommended BAT, its versatility and usage is rapidly gaining acceptance in the water treatment industry. Therefore, MF TPCs are included for reference and comparison purposes with other treatment processes.

See the appropriate contaminant fact sheet for specific information on the contaminant and the EPA recommended BAT treatment processes.

2. TOTAL PLANT COSTS

There is a need to be able to compare various treatment processes costs - not only on an individual unit process basis (as done in each contaminant fact sheet), but on a total plant costs basis by amortizing capital equipment and annual O&M costs over time. To help address that need, this total plant costs fact sheet was prepared.

S. R. Qasim, *et al.*, "Estimating Costs for Treatment Plant Construction," *Journal AWWA*, August 1992, state, "Preliminary cost estimates can be used to compare the economics of various treatment processes or the costs of major project components. Such estimates do not, however, represent the actual construction and operation and maintenance costs of the project. Actual project costs are site-specific, cannot be generalized, and must be developed for individual circumstances. Many factors influence the construction costs - plant capacity, design criteria, treatment processes, site conditions and land cost, climate, permit costs, competition among bidders and suppliers, and general local and nationwide economic conditions."

These statements also apply to the individual contaminant fact sheet's BAT capital equipment and annual O&M cost curves, as well as the TPC cost curves presented herein. All TPCs should be considered preliminary cost estimates for comparison purposes only. Secondary cost estimates must be developed during the design process and final cost estimates must be developed prior to construction.

The TPCs were developed using the following information and the assumptions presented on the Cost Assumptions, Raw Water Composition, and WaTER Program related fact sheets. The TPCs include the annualized capital equipment costs for all the unit processes in the BAT treatment train (see the following treatment train schematic diagrams). TPCs also include annual O&M costs, and various project related special costs including special site work, general contractor's overhead & profit, engineering fees, land costs, legal fees, fiscal costs, administrative costs, and interest during construction. The project related special costs are those listed by USEPA in the *Estimating Water Treatment Costs* manual - and are considered more directly related to the total cost of the project than to the cost of the individual unit processes. For this reason, the project related special costs included in the TPCs must be considered even more preliminary than the equipment and O&M costs. Project related special costs can only be developed once a specific site is identified. However, for comparison purposes only, several assumptions and estimates were developed and as many references and sources that could be reasonably be obtained were consulted prior to developing the following project related special costs. These include:

- Special site work is considered site work specific to a particular site rather than a project (i.e., river crossings; earthquake, high wind, or snow loadings, etc.). Because these are so site specific, very few references were found. Therefore, an estimate of 2% of the capital equipment costs was included.

- General contractor's overhead & profit can include project and business overhead, profit, and bonds. Historical data from several Reclamation projects indicate a range from 14.5 - 32.5% of the capital equipment costs. The Construction Specification Institute (CSI) suggests 10 - 15% of the direct costs. Two A&E firms in the Denver area suggest 25 - 33%. Therefore, an estimate of 20% of the capital equipment costs was included.

- Engineering fees include those charged by A&E firms. The Means 2001 Cost Data estimates 2.5 - 6%. CSI suggests 19.5 - 23.9% of the direct costs. Two A&E firms in the Denver area suggest 10%. Irving Moch, Jr., Moch & Associates, Inc., suggests 10%. Therefore, an estimate of 10% of the capital equipment costs was included.

- Land costs are very site specific. Historical data from several Reclamation projects indicate a range from $500 - $10,000/acre. Therefore, an estimate of $2,500/acre for 5 acres was included.

- No references were found for legal fees and fiscal costs. Therefore, an estimate of 1% of the capital equipment costs was included.

- Administrative costs can include construction and administrative management/oversight. Means 2001 Cost Data estimates 4.5 - 7.5% for job values to $1,000,000 and 2.5 - 4% for job values to $5,000,000. Therefore, an estimate of 5% of the capital equipment costs was included.

- Interest during construction is very project specific. Irving Moch suggests 2 - 5%. Information from Reclamation's economics group suggests 3 - 4% for a 1 year loan when payments are equally spaced. Therefore, an estimate of 3% of the capital equipment costs was included.

All project related special costs totaled 41% plus $12,500 for land ($2,500/acre at 5 acres).

Following are the equations used to develop the TPCs:

- Annualized capital cost = [(total capital equipment costs for all treatment train unit processes) + (project related special costs)] x capital recovery factor for 30 years at 3.89% real annual interest based on no lagged impact on interest = 0.057.

- Total annual cost = (annualized capital costs) + (total annual O&M costs for all treatment train unit processes).

- TPC in $/1000 gal of water produced = (total annual cost) / annual flow.

3. RO TPC

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. The conventional RO treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an antiscalant, slow mix flocculator, sedimentation basin or clarifier, gravity filters, RO membranes, chlorine disinfection, and clearwell storage. MF could be used in place of flocculation, sedimentation, and filtration.

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 contaminant 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.

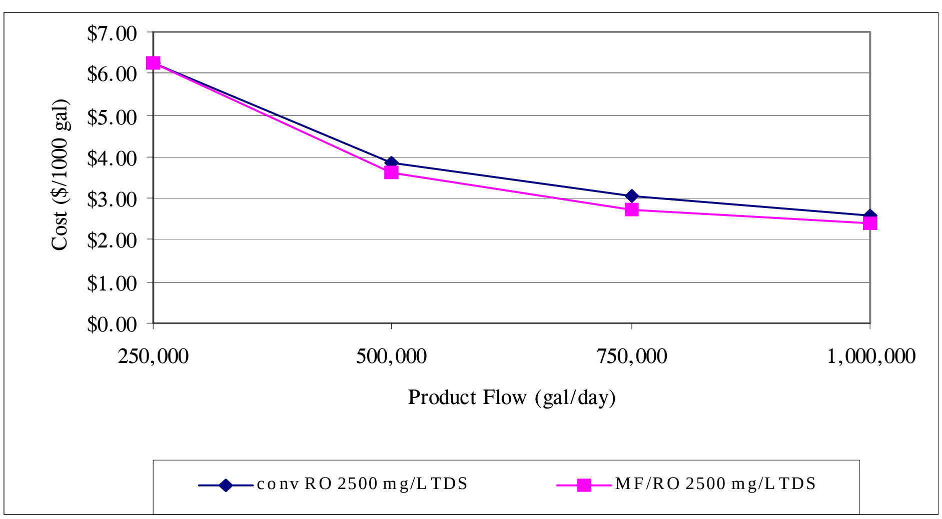
Advantages -

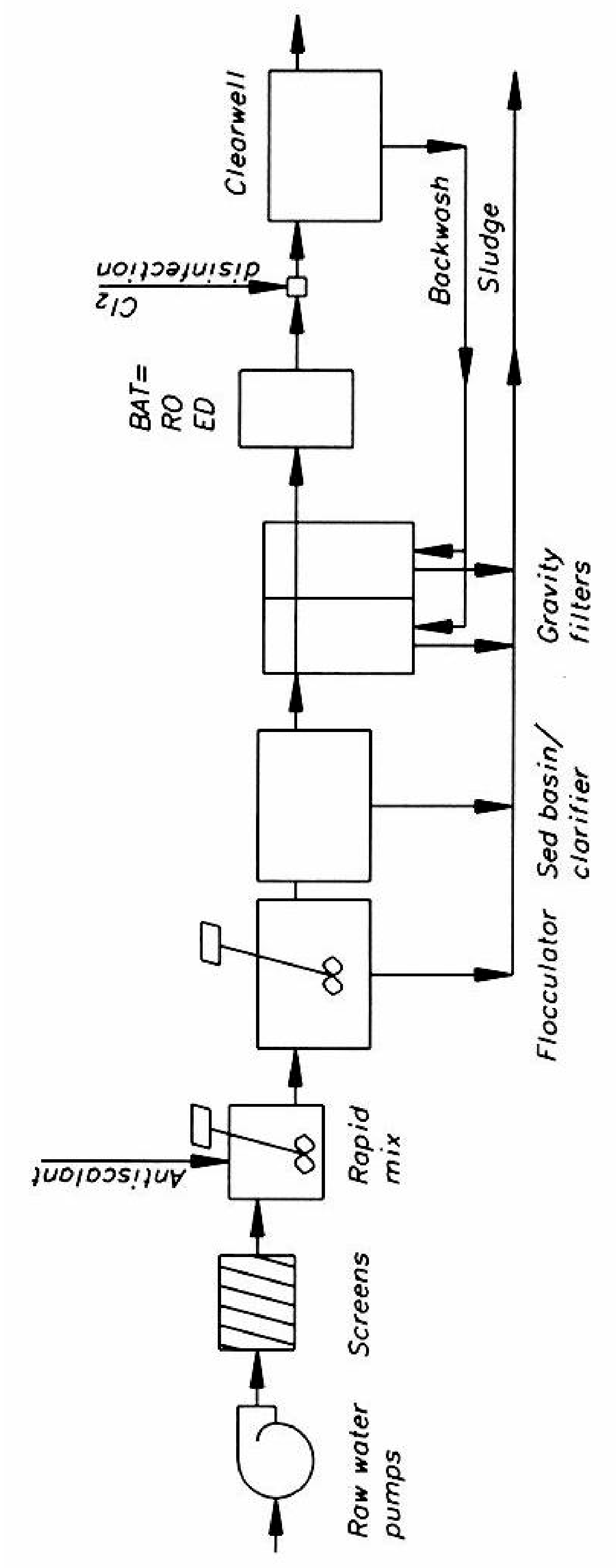
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

Disadvantages -

- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Sb removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

TPC - $/1000 gal




Row water pumps
Screens
Antiscalant
Rapid mix
Flocculator
Sed basin/ clarifier
Gravity filters
BAT= RO ED
Cl_2 disinfection
Clearwell
Backwash
Sludge

4. EDR TPC

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. 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. The conventional EDR treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an antiscalant, slow mix flocculator, sedimentation basin or clarifier, gravity filters, EDR membranes, chlorine disinfection, and clearwell storage. MF could be used in place of flocculation, sedimentation, and filtration.

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 Ba concentration, the membranes will require regular maintenance or replacement. EDR requires reversing the polarity. Flushing at high volume/low pressure 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.

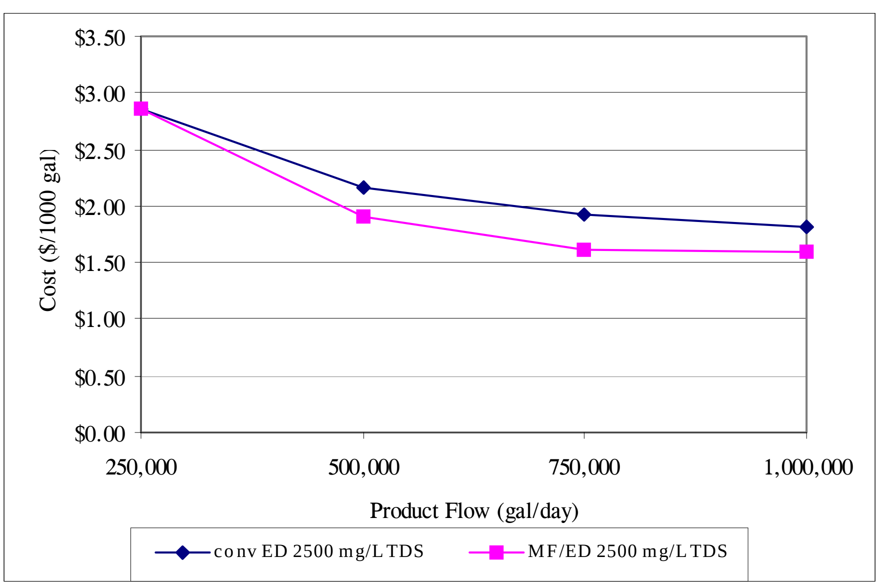
Advantages -

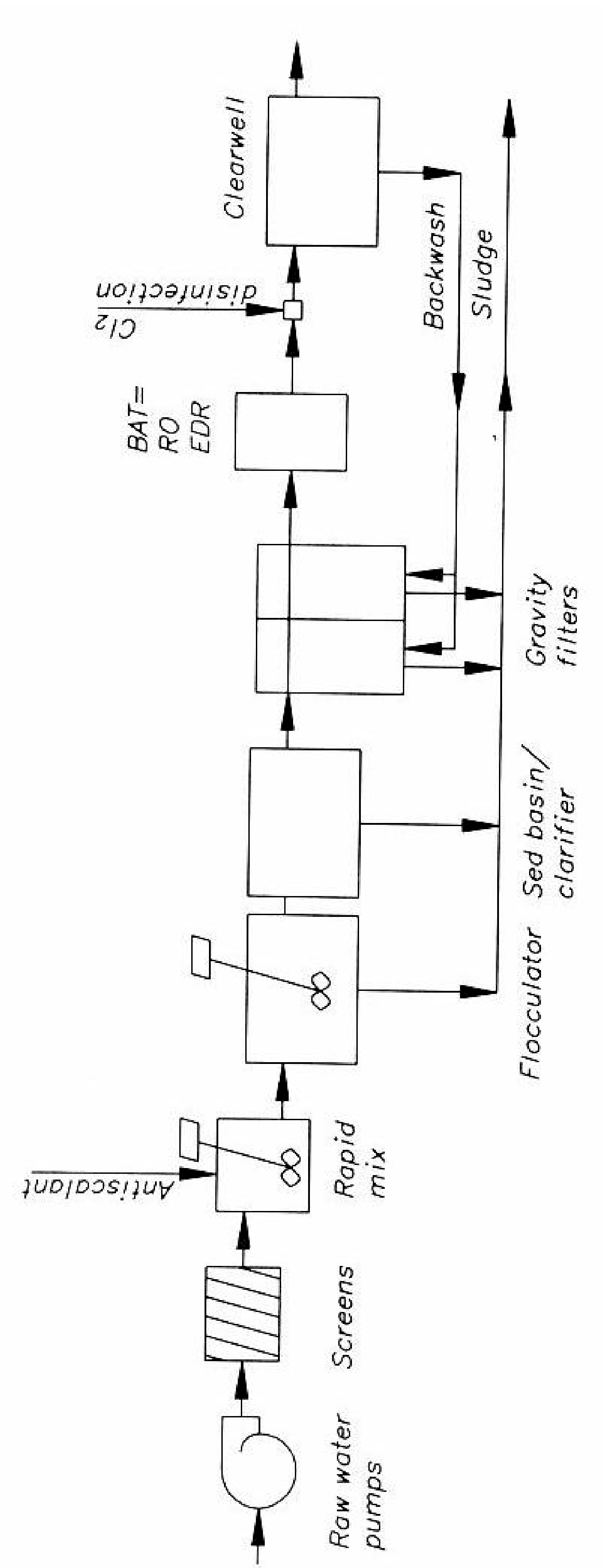
- EDR can operate with minimal fouling or scaling, or chemical addition.
- Low pressure requirements; typically quieter than RO.
- Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

Disadvantages -

- Not suitable for high levels of Fe and Mn, H_2S, chlorine, or hardness.
- Limited current density; current leakage; back diffusion.
- At 50% rejection of TDS per pass, process favors low TDS water.

TPC - $/1000 gal




Raw water pumps
Screens
Antiscalant
Rapid mix
Flocculator
Sed basin/ clarifier
Gravity filters
BAT= RO EDR
Cl_2 disinfection
Clearwell
Backwash
Sludge

5. IX TPC

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. 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. Operation begins with a fully recharged cation or anion resin bed, having enough positively or negatively charged ions to carry out the cation or anion 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 or negatively charged ions are released into the water, being substituted or replaced with the contaminant ions in the water (ion exchange). When the resin becomes exhausted of positively or negatively charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the contaminant ions with Na or K ions. Many different types ofresins can be used to reduce dissolved contaminant concentrations. Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-contaminant is greater than 1. The IX treatment train typically includes raw water pumps, debris screens, gravity filters, cation or anion resin beds, chlorine disinfection, and clearwell storage.

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.

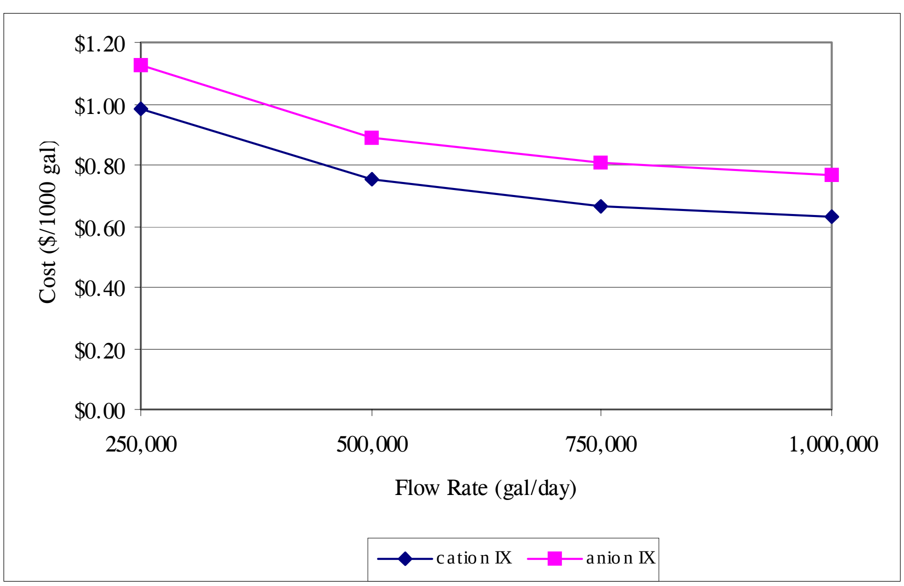
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the contaminant concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

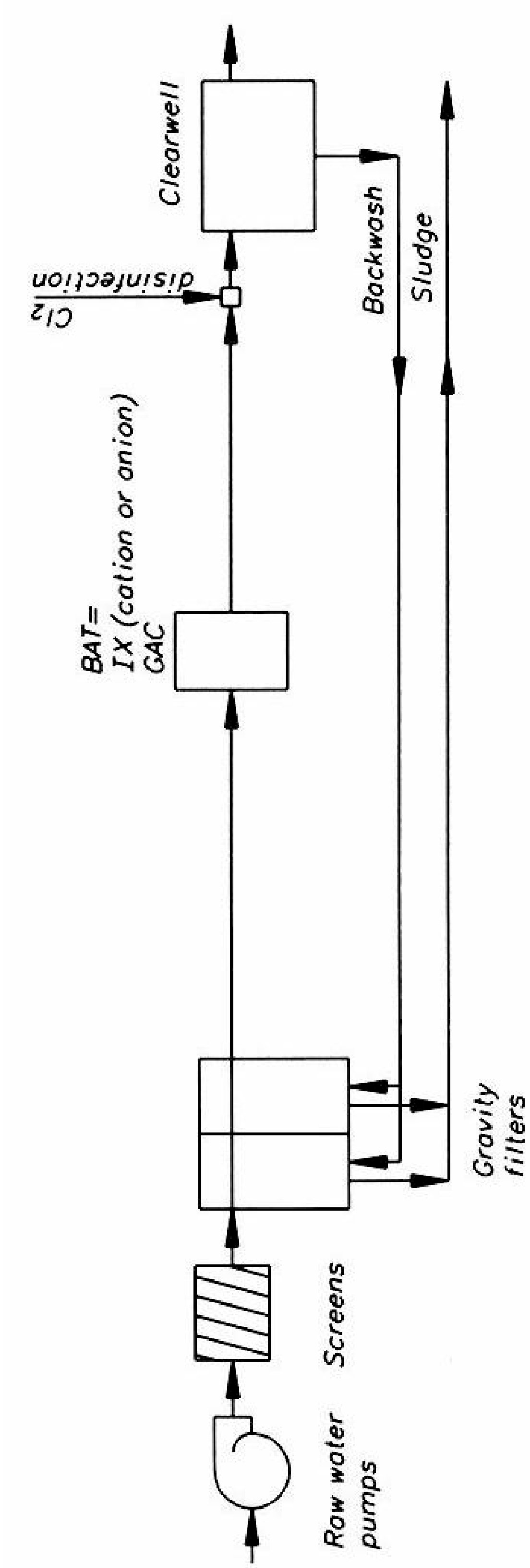
Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline solution); occasional solid wastes (in the form of broken resin beads) which are backwashed during regeneration; and if utilized, spent filters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

Advantages -
- Acid addition, degasification, and repressurization is not required.
- 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.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

TPC - $/1000 gal




Raw water pumps
Screens
Gravity filters
BAT=
IX (cation or anion)
GAC
Cl2 disinfection
Clearwell
Backwash
Sludge

6. SOFTENING TPC

Process - Lime softening uses a chemical addition followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical additions include adding (1) $Ca(OH)_2$ in sufficient quantity to raise the pH while keeping the levels relatively low to precipitate CO_3^{-2} hardness or (2) $Ca(OH)_2$ to precipitate carbonate and Na_2CO_3 to precipitate noncarbonate hardness. The contaminant precipitates as sludge. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material into larger particles) and final clarification occur. The clarified water flows up and over the weirs, while the settled particles are removed by pumping or other collection mechanisms (i.e. filtration). The softening treatment train typically includes raw water pumps, debris screens, addition of $Ca(OH)_2$ or $Ca(OH)_2$ & Na_2CO_3 at an upflow SCC, gravity filters, chlorine disinfection, and clearwell storage.

Pretreatment - Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required. Optimum pH is about 10 for $Ca(OH)_2$ and about 10.5 or higher for $Ca(OH)_2$ and Na_2CO_3.

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 softening sludges: incineration, landfill, and ocean disposal.

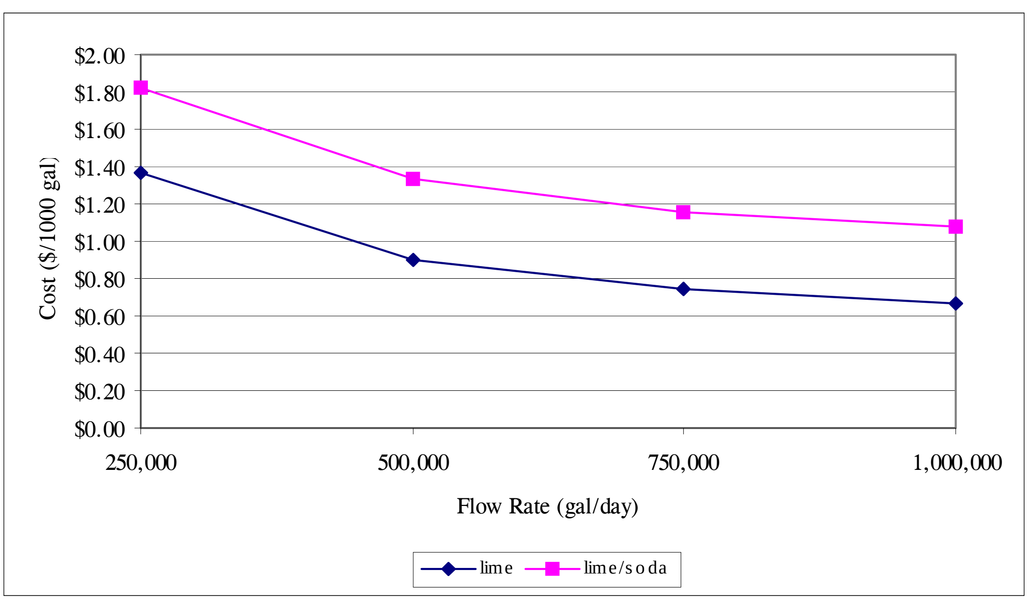
Advantages -

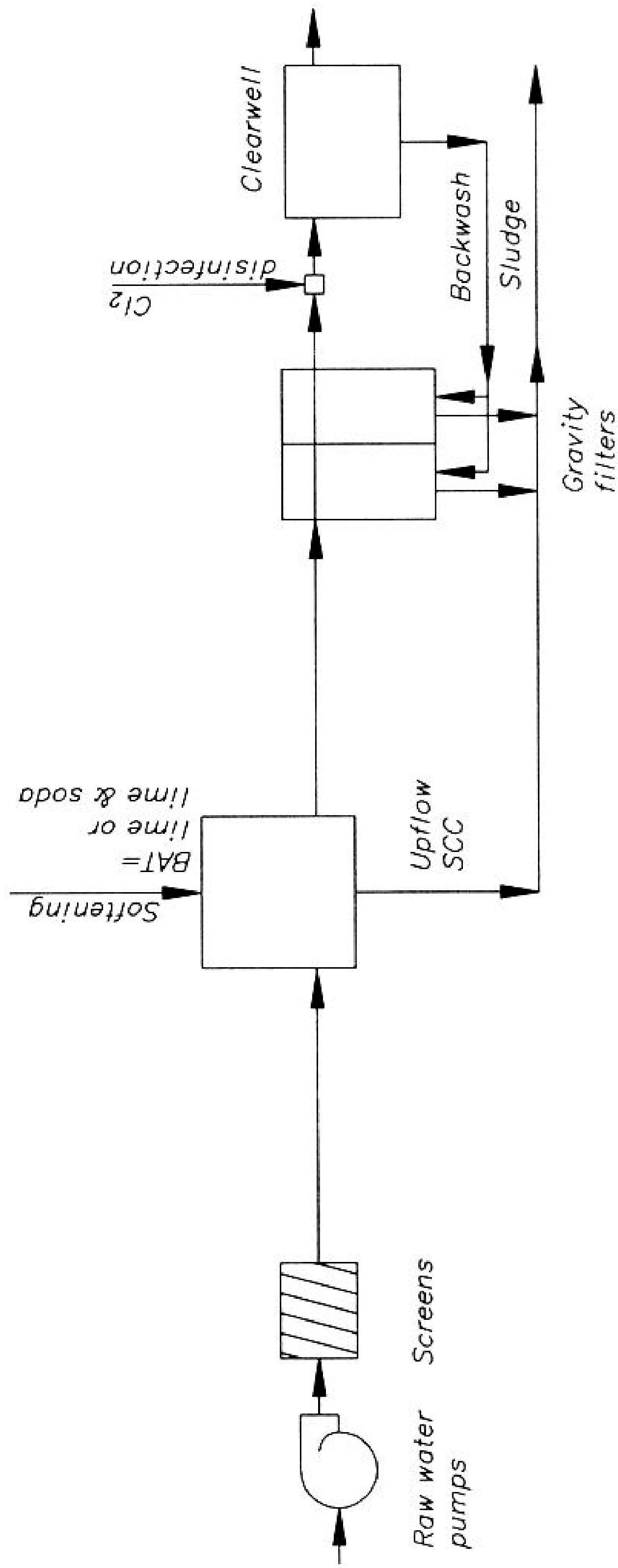
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -

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

TPC - $/1000 gal




Raw water pumps
Screens
Softening
BAT= lime or lime & soda
Upflow SCC
Gravity filters
Backwash
Sludge
Cl_2 disinfection
Clearwell

7. CONVENTIONAL TT TPC

Process - For community surface and groundwater (under the direct influence of surface water) systems, conventional treatment techniques, including presedimentation or screening, chemical coagulation and flocculation, final settling or clarification, filtration, and disinfection ensure protection of both surface and groundwaters prior to entering distribution systems. These TTs work to remove and inactivate pathogens before they enter the distribution system. Not all processes are required in every case, so actual process selection depends on careful review of overall raw water quality and characteristics. Presedimentation or screening consists of removing the largest/heaviest suspended solids from the raw water. Chemical coagulation and flocculation consists of adding a chemical coagulant ($Al_2(SO_4)_3$ and polymer) combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). Costs presented below include alum (230 ppm) as the coagulant, rapid mix for 30 seconds, and flocculation for 30 minutes. Final settling or clarification consists of settling of the floc matter. Filtration consists of final removal by dual media filtering (or membrane) of all floc; suspended; and, based on filtration method/size, most dissolved solids, including pathogens. These TTs result in lowering overall TSS/TDS and turbidity, which in turn allows greater disinfection contact time on remaining pathogens. Disinfection consists of chemical inactivation (killing) of pathogens, bacteria, and viruses, usually by chlorination. As a result of crypto/giardia occurrences, investigations into the effectiveness of various water treatment processes for oocyst/cyst removal/inactivation are continuing. In addition to the unit processes mentioned, the conventional TT treatment train typically includes raw water pumps, debris screens, and clearwell storage.

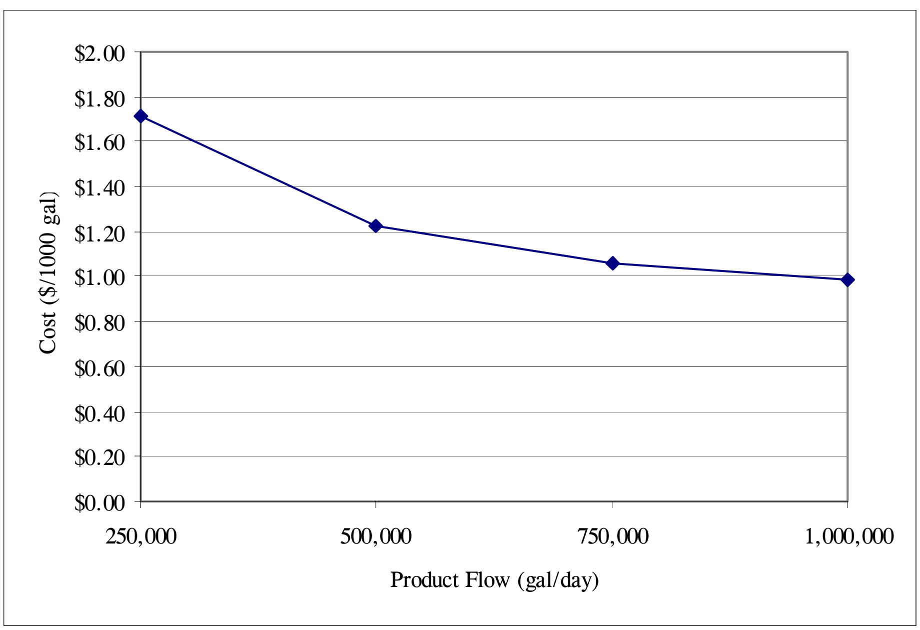
Maintenance - Proper monitoring, operation, and maintenance procedures, especially of the final filter, are essential to ensure the reliability of these TT processes. Recycled filter backwash or membrane cleaning methods may concentrate oocyst/cysts and result in a significant source of increased turbidity and crypto/giardia infestation. As a result, a period of filter-to-waste flow may be required after post-backwash/membrane cleaning periods. Because turbidity removal can parallel oocyst/cyst removal, finished water turbidity monitoring (<0.5 NTU) may be a useful tool for indicating the degree of pathogen removal. Depending on filtration process, recharging or clean installation of media is required.

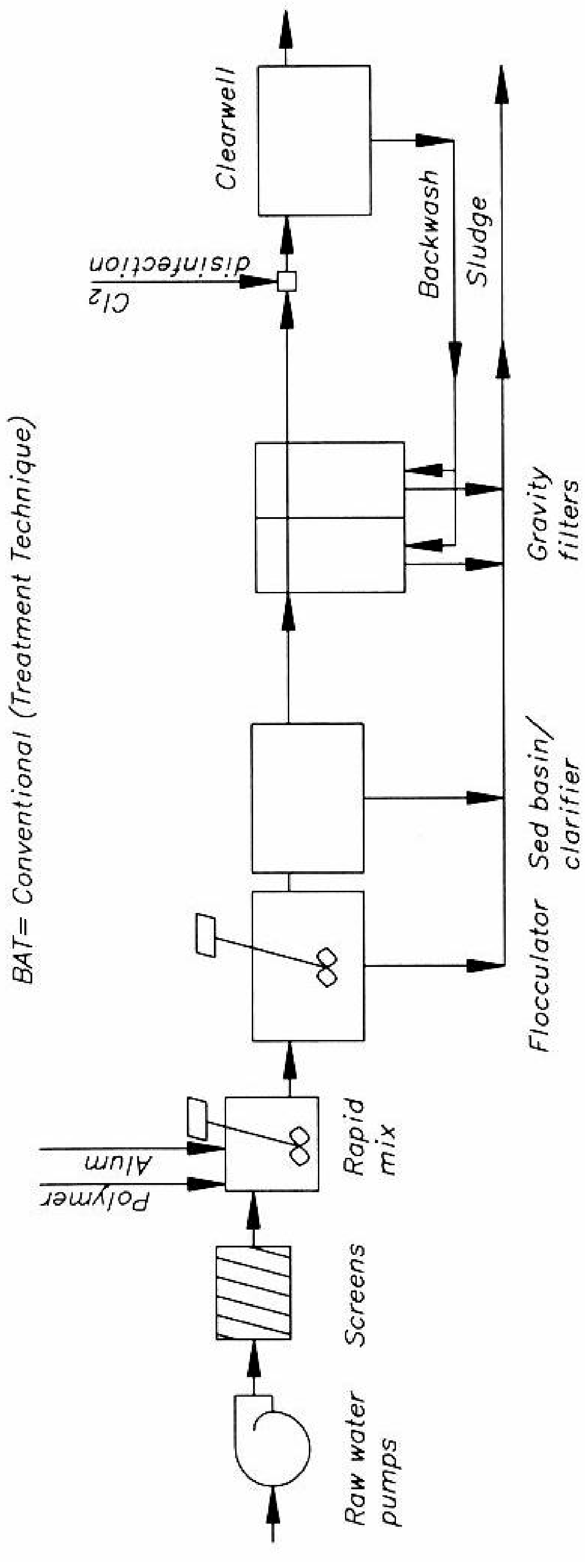
Waste Disposal - Pretreatment waste streams and spent filters or filter material require approved disposal.

Advantages -
- Well established and reliable.
- Low operator requirements.

Disadvantages -
- Costly initial investment and land intensive.
- Lack of accepted testing and monitoring techniques may cause confusion.

TPC - $/1000 gal




BAT= Conventional (Treatment Technique)
Raw water pumps
Screens
Polymer
Alum
Rapid mix
Flocculator
Sed basin/ clarifier
Gravity filters
Cl_2
disinfection
Clearwell
Backwash
Sludge

8. GREENSAND & $KMnO_4$ TPC

Process - Oxidation is a chemical process and filtration is a physical process. $KMnO_4$ is added to the raw water which oxidizes the soluble Fe and Mn into insoluble ferric and manganic oxides which will settle and are filterable. $KMnO_4$ (without prechlorination) is usually used according to the following stoichiometry:

0.94 mg/L $KMnO_4$ per mg/L of Fe^{+2} removed and
1.92 mg/L $KMnO_4$ per mg/L of Mn^{+2} removed.

After the oxidation process is complete, the greensand filter removes the insoluble material. Greensand is a green clay material whose active mineral is glauconite, a natural zeolite with ion exchange properties. Greensand is layered loosely to form the media bed. As water passes through the filter, any remaining soluble Fe and Mn are pulled from the solution by the ion exchange properties of the greensand, and the insoluble Fe and Mn are filtered by the greensand media. Periodically, the greensand media is regenerated by continually feeding $KMnO_4$ just before the filter to recharge the glauconite, regenerating the ion exchange properties. Additionally, periodic backwashing of the filter media to remove the Fe and Mn is required. The greensand and $KMnO_4$ treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an polymer, slow mix flocculator, sedimentation basin or clarifier, greensand filters with $KMnO_4$ addition, chlorine disinfection, and clearwell storage.

Pretreatment - Feeding chlorine ahead of the $KMnO_4$ can make the process more economical. $Ca(OH)_2$ addition may be necessary to achieve the desired pH level or to remove CO_2.

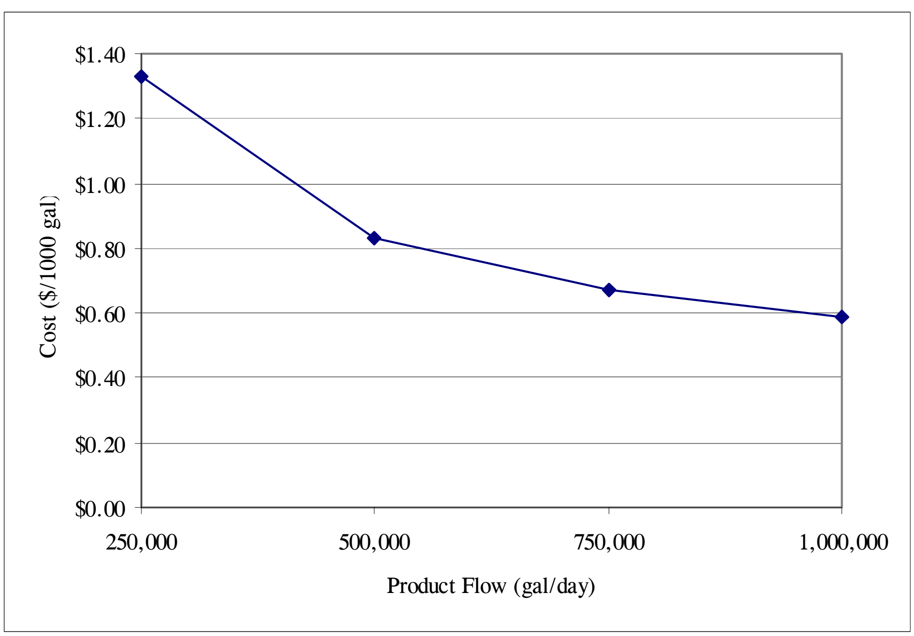
Maintenance - Tests should be conducted at least monthly on samples of the water entering the filter to ensure the contaminants are in their insoluble oxidized states and to verify $KMnO_4$ dosages. Regeneration and backwashing should be done in accordance with the greensand media manufacturer's recommendations. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

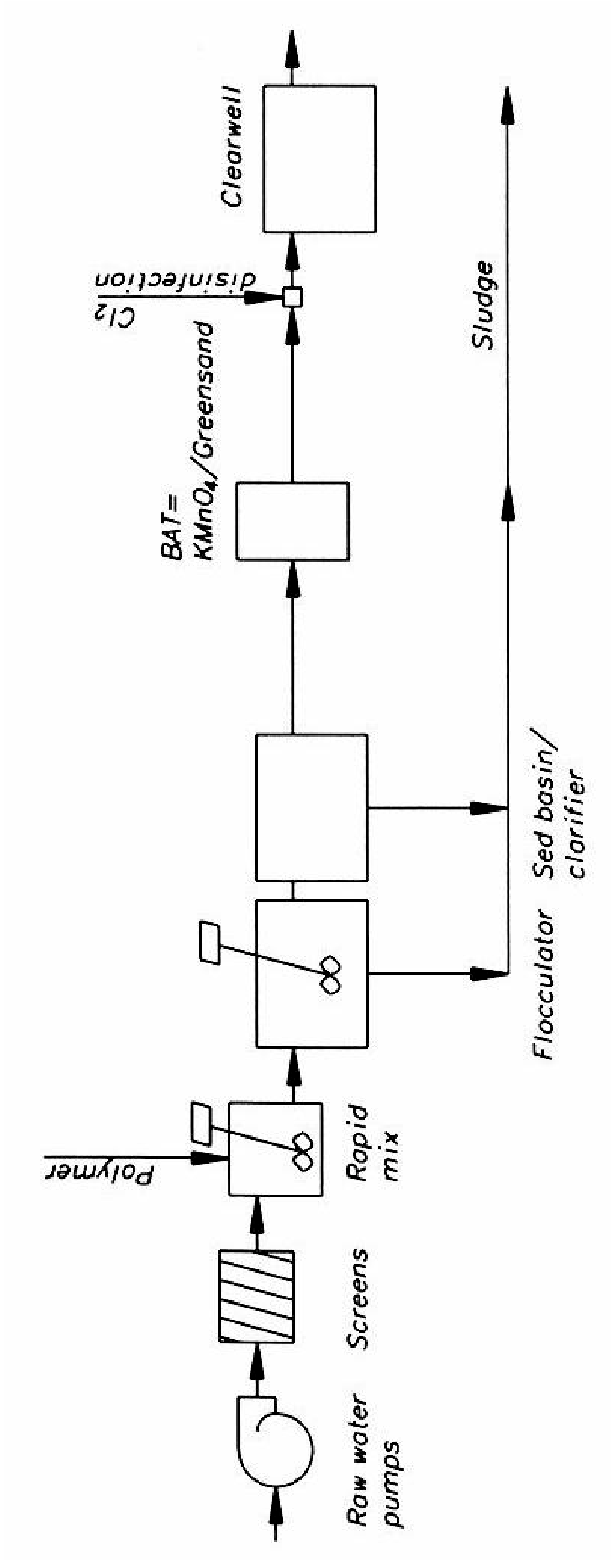
Waste Disposal - Filter regeneration and backwash waters, and spent media require approved disposal.

Advantages -
- Low cost.
- Efficient; proven; reliable.

Disadvantages -
- $KMnO_4$ dosage must be exact; bench scale tests are required to determine exact dosage; monitoring of performance to ensure proper dosage.
- Sufficient pressure and flowrate required for backwashing; backwash disposal required.
- Regeneration required; regeneration disposal required.

TPC - $/1000 gal




Raw water pumps
Screens
Polymer
Rapid mix
Flocculator
Sed basin/ clarifier
BAT= $KMnO_4$/Greensand
Cl_2 disinfection
Clearwell
Sludge

9. COAGULATION & FILTRATION TPC

Process - Coagulation and filtration 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). Depending on the contaminant, either $Al_2(SO_4)_3$ or $Fe_2(SO_4)_3$ can be the most effective coagulant. Filtration provides final removal by dual media filtering of all floc and suspended solids. In addition to the unit processes mentioned, the coagulation and filtration treatment train typically includes raw water pumps, debris screens, sedimentation, chlorine disinfection, and clearwell storage.

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

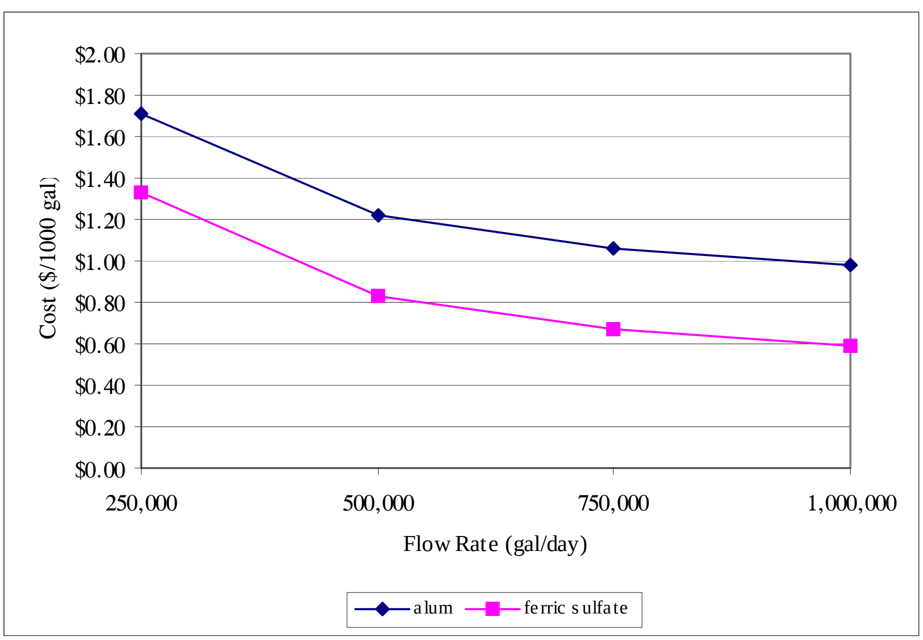
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

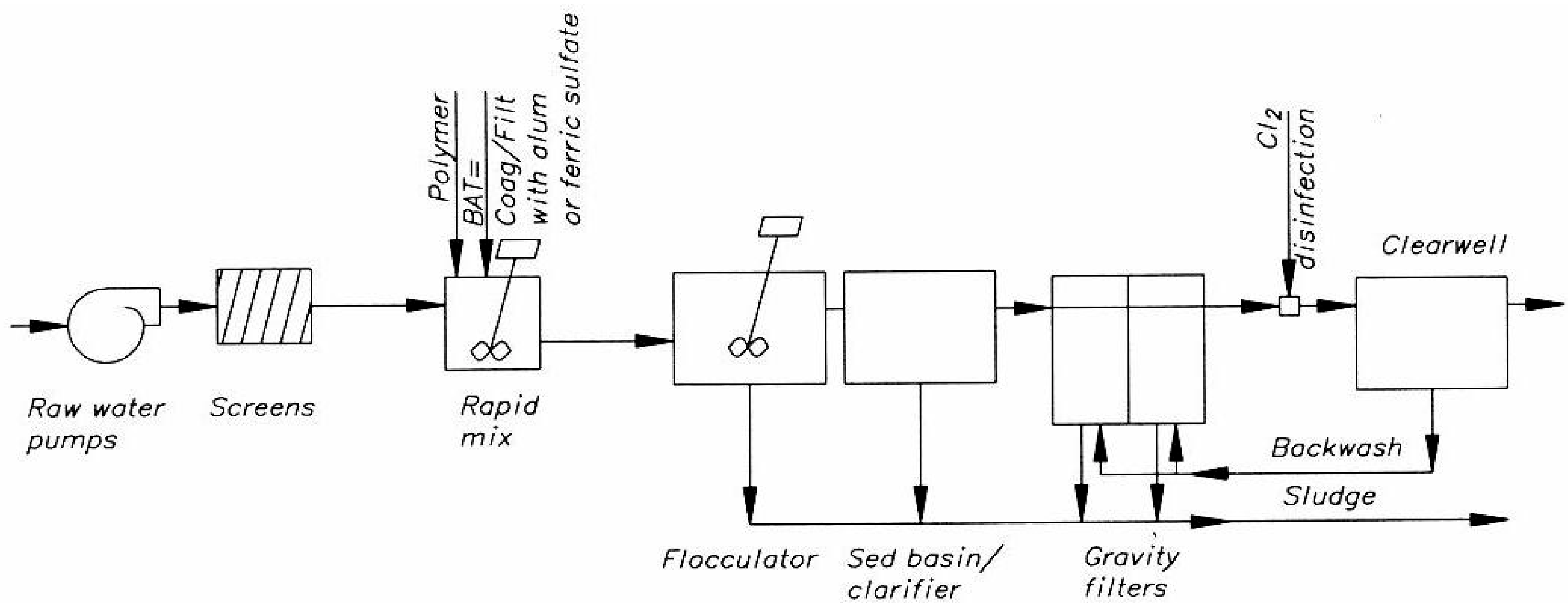
Waste Disposal - Filter backwash and spent material require approved disposal.

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

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

TPC - $/1000 gal




Polymer
BAT=
Coag/Filt
with alum
or ferric sulfate
Cl_2
disinfection
Clearwell
Raw water
pumps
Screens
Rapid
mix
Backwash
Sludge
Flocculator
Sed basin/
clarifier
Gravity
filters

10. GAC TPC

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. The GAC treatment train typically includes raw water pumps, debris screens, gravity filters, GAC units, chlorine disinfection, and clearwell storage.

Pretreatment - With bacterially unstable waters, filtration and disinfection prior to carbon treatment may be required. With high TSS waters, prefiltration may be required.

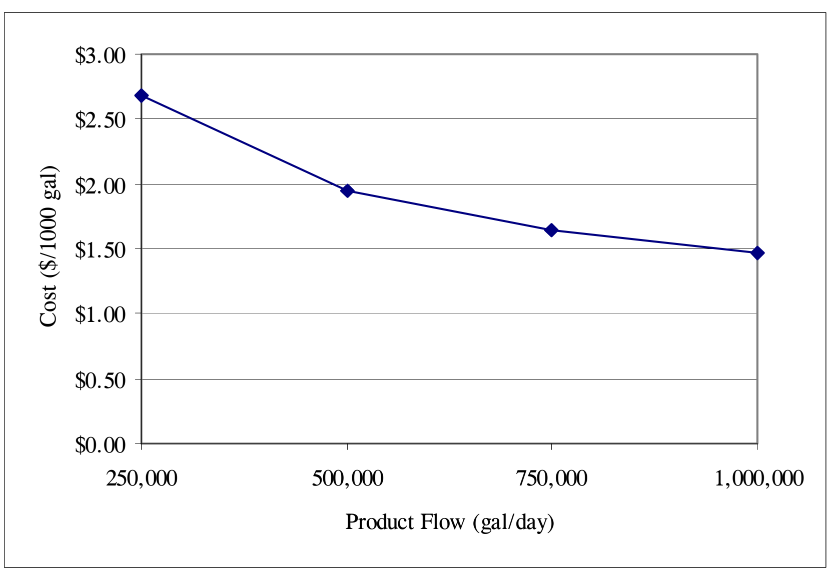
Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used. The manufacturer's recommendations for media replacement should be consulted. Recharging by backwashing or flushing with hot water (145°F) may release the adsorbed 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.

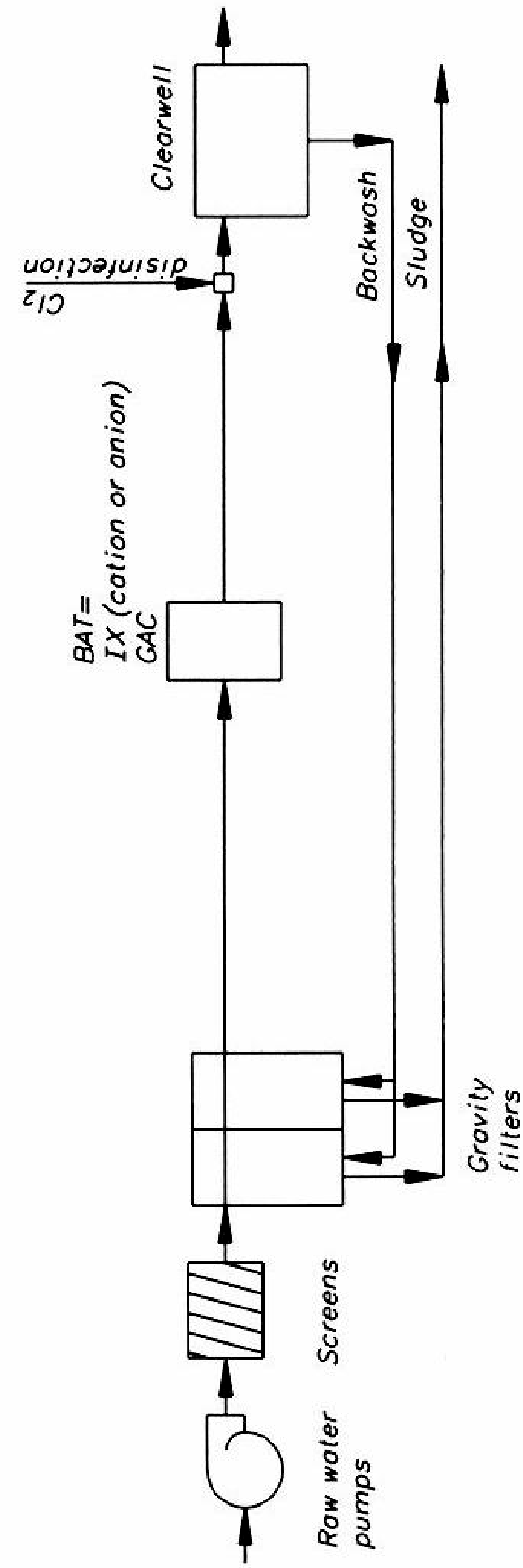
Waste Disposal - Backwash/flush water disposal is required if incorporated. Disposal of spend media is the responsibility of the contractor providing the media replacement services.

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.

TPC - $/1000 gal




Raw water pumps
Screens
Gravity filters
BAT=
IX (cation or anion)
GAC
Cl2 disinfection
Clearwell
Backwash
Sludge

11. DF TPC

Process - Direct filtration 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 asbestos removal. Filtration provides final removal by dual media filtering of all floc and suspended solids. In addition to the unit processes mentioned, the DF treatment train typically includes raw water pumps, debris screens, and clearwell storage.

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

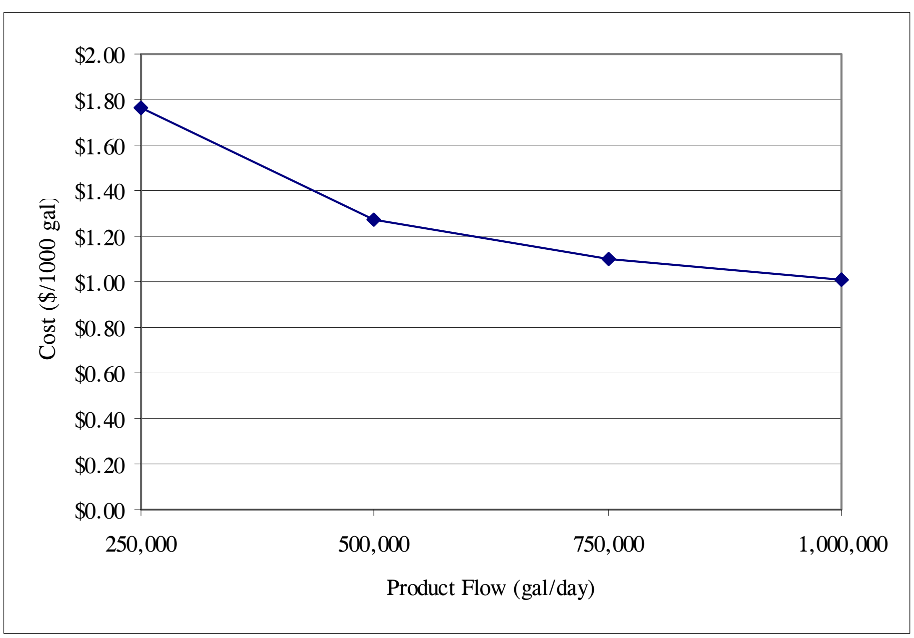
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

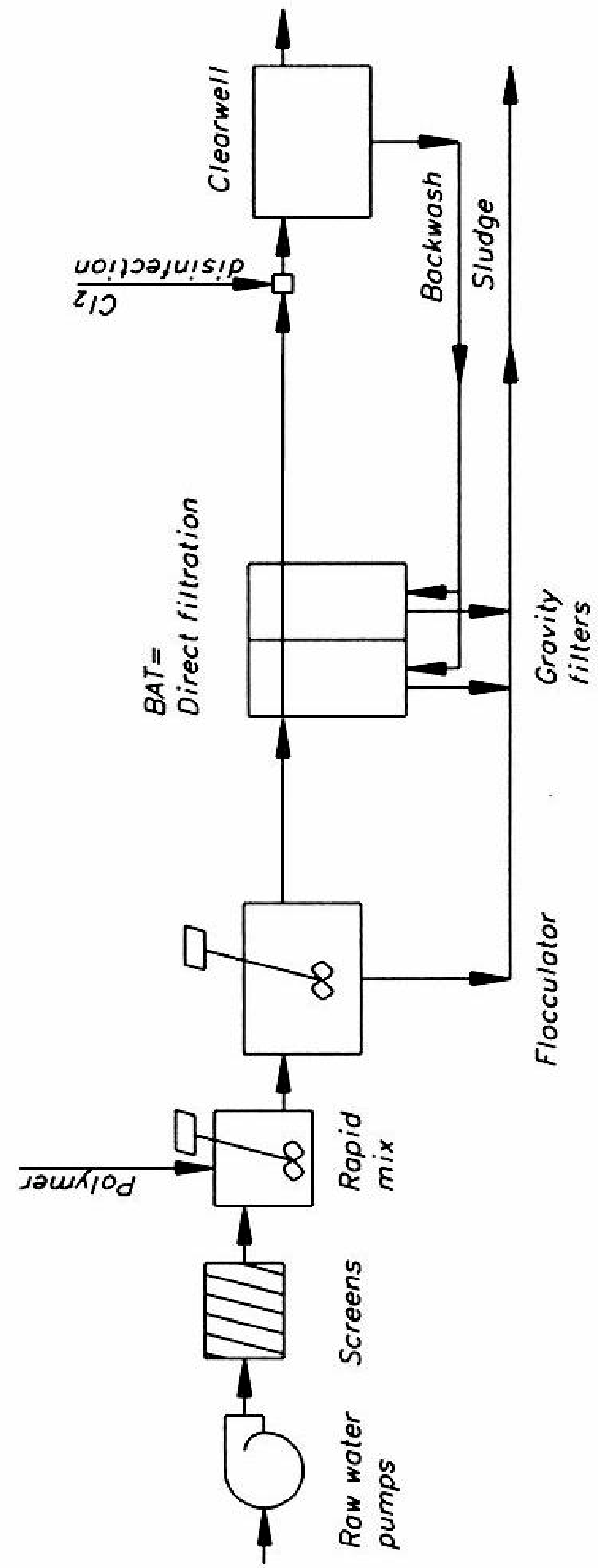
Waste Disposal - Filter backwash and spent media require approved disposal.

Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- 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.

TPC - $/1000 gal





Raw water pumps
Screens
Polymer
Rapid mix
Flocculator
BAT=
Direct filtration
Gravity filters
Cl_2 disinfection
Clearwell
Backwash
Sludge

12. MF TPC

Process - Microfiltration is a physical process and refers to filtration through a coherent medium with a nominal pore size range from slightly below 0.1 µm to slightly above 1.5 µm. This size range refers to the pore size of the medium itself. Thus, in terms of pore size, MF fills in the gap between ultrafiltration and granular media filtration. In terms of characteristic particle size, this range covers the lower portion of the conventional clays and the upper half of the range for humic acids. This is smaller than the size range for bacteria, algae and cysts, and larger than that of viruses. Similar to RO, the raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Unlike RO, lower hydraulic pressures are required. MF membranes includes both crossflow separation and dead-end filtration. 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. The DF treatment train typically includes raw water pumps, debris screens, rapid mix with addition of an polymer, slow mix flocculator, MF membranes, chlorine disinfection, and clearwell storage.

Pretreatment - Jar tests to determine optimum polymer addition may be required.

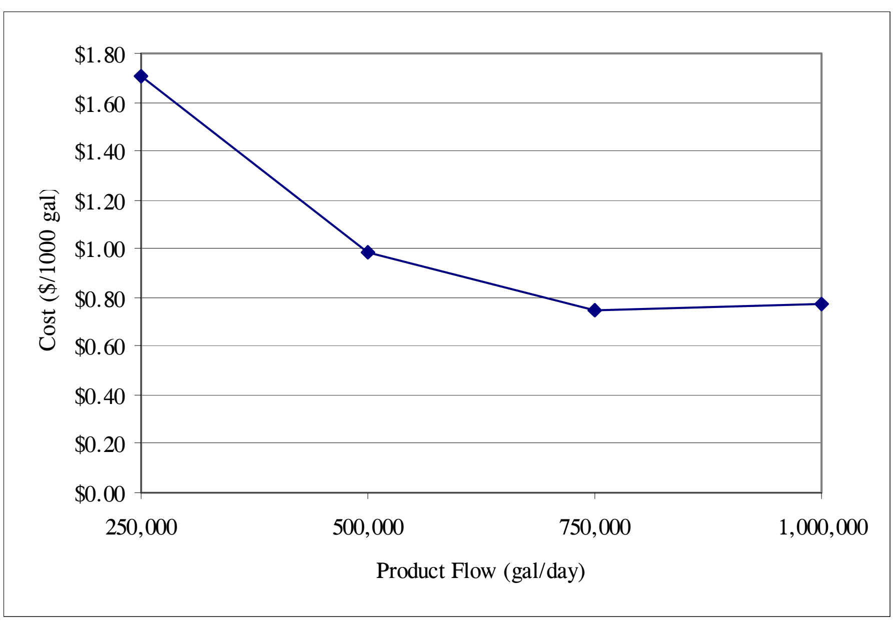
Maintenance - Monitor rejection percentage to ensure contaminant removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

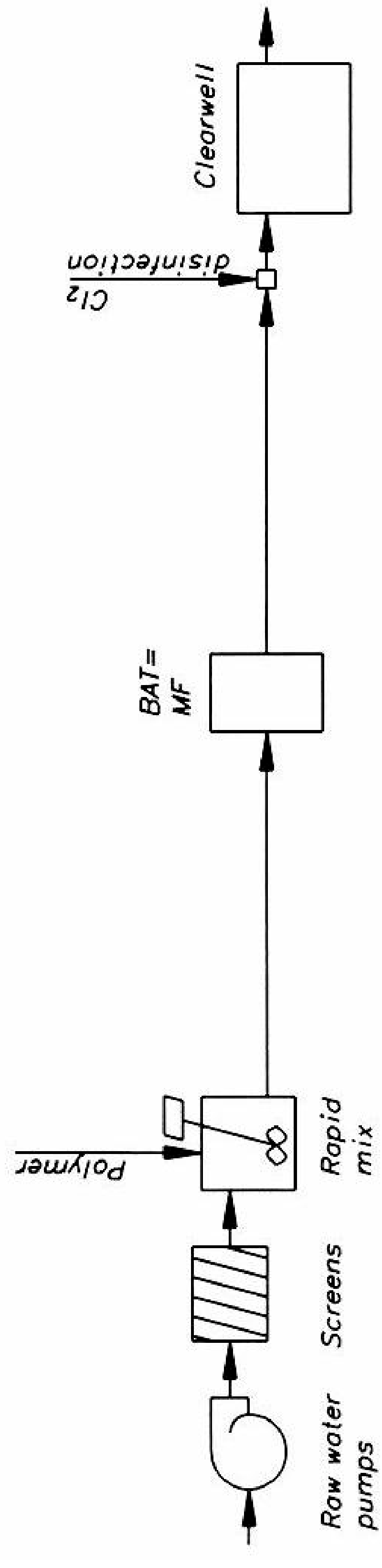
Waste Disposal - Pretreatment waste streams, concentrate flows, and spent filters and membrane elements all require approved disposal.

Advantages -
- Low pressure process.
- Can typically produce water of satisfactory turbidity with feed waters exceeding 100 NTU.
- *Giardia* removal as high as 6 logs is reported. Bacteria removal is satisfactorily high. *Cryptosporidium* is satisfactory. Virus removal of 0.5 log (68 percent).
- Disinfection byproduct removal is about 10 percent.

Disadvantages -
- Membrane integrity and testing protocols are still under development.
- Some regulatory agencies slow to accept MF applications.

TPC - $/1000 gal




Raw water pumps
Screens
Polymer
Rapid mix
BAT= MF
Cl2
disinfection
Clearwell

WaTER PROGRAM

FOR CONTAMINANT FACT SHEETS

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

Water Treatment Estimation Routine (WaTER)

Some cost estimates used to develop some of the contaminant Fact Sheet cost curves and the Total Plant Cost curves were derived from Reclamation's WaTER program. WaTER is an Excel spreadsheet application developed for use with Reclamation's MTP. The program is a result of a cooperative effort between Reclamation and the National Institute of Standards and Technology.

Unlike other cost estimation programs that require the user to have information about the size of equipment and chemical dosage rates, the only inputs required for the WaTER program are the production capacity and raw water quality composition. The program employs cost indices as established by the *Engineering News Record*, Bureau of Labor Statistics, and the Producer Price Index, and derives cost data from *Estimating Water Treatment Costs*; volumes 1 and 2; EPA-600/2-79-162a; August 1979. Refer to the Cost Assumptions Fact Sheet for detailed cost data information.

The program has the following capabilities: (1) provides cost estimates for all treatment processes used in the MTP; (2) contains default values which can be customized if more accurate values are available; (3) is expandable to include new processes as they are developed; and (4) is user friendly.

The following processes are included in the program: pumping systems; centrifugal pumps; metering pumps; alum coagulation (dry/liquid); ferric sulfate coagulation; lime-soda ash softening; acid feed; polymer addition; potassium permanganate oxidation; ion exchange; upflow solids contact clarifier; gravity filtration (sand/dual/mixed); granular activated carbon filtration; microfiltration; reverse osmosis; nanofiltration; electrodialysis; clearwell storage; chlorine disinfection; chloramine disinfection; and ozone disinfection.

The program (suitable for PC or Mac environments) and user manual are available for distribution to interested parties. Or they can be accessed at:
http://www.usbr.gov/water/desal.html - Task E (separate program for PC users and Mac users)
http://www.usbr.gov/water/reports.html - #43 (user manual)

As discussed on the Cost Assumptions Fact Sheet, construction and annual O&M costs not estimated by the WaTER program were derived from *Estimating Water Treatment Costs*, volumes 1 and 2, EPA-600/2-79-162a, August 1979; or from equipment manufacturer's product data information.

ALKALINITY

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: Alkalis are substances that when dissolved in water turn litmus paper blue and include the soluble CO_3^{-2}, HCO_3^-, and OH^- salts of Ca, Mg, K, and Na. Alkalinity is the quantitative capacity of water to neutralize an acid, or the measure of how much acid can be added to a liquid without causing a significant change in pH. Water does not have to be strongly basic (high pH) to have high alkalinity. Generally, in the water industry, the three types of alkalinity include: CO_3^{-2}, HCO_3^-, and OH^-. Total alkalinity is the sum of these three types and is expressed in mg/L of $CaCO_3$ equivalent. There are three different tests used for measuring alkalinity, usually performed in this order: pH (to obtain OH^- alkalinity), phenolphthalein test (to obtain OH^- and CO_3^{-2} alkalinity), and methyl orange test (to obtain total alkalinity).

B. Source in Nature: In the environment, alkalinity in the soil (limestone) and ground and surface waters is a combination of the naturally occurring alkalis: CO_3^{-2}, HCO_3^-, and OH^- salts of Ca, Mg, K, and Na. Most natural waters have an alkalinity in the range of 10 to 500 mg/L. Wastewater is normally alkaline, receiving alkalinity from the water supply, groundwater, and materials added during domestic use including detergents and soap-based products which are alkaline. Acid rain also contributes to the alkalinity of waters. Alkalinity is often related to hardness. Ca^{+2} and Mg^{+2} ions are primarily responsible for hardness. However, in most waters, alkalinity and hardness have similar values because the CO_3^{-2} and HCO_3^- responsible for total alkalinity are usually brought into the water in the form of $CaCO_3$ or $MgCO_3$. The three forms of alkalinity are also strongly related to the amount of carbon dioxide present in the water.

C. SDWA Limits: Alkalinity is not a primary or a secondary drinking water contaminant. No federal limits exist.

D. Health Effects of Contamination: Alkalis, when dissolved in water, create a bitter taste and a slippery feel. Highly alkaline waters, above pH 7.0, can cause drying of the skin. Alkalinity is important for fish and aquatic life because it protects or buffers against rapid pH changes and makes water less vulnerable to acid rain, protecting a major source of human consumption.

2. REMOVAL TECHNIQUES

A. USEPA BAT: BAT's are not assigned.

B. Alternative Methods of Treatment: Generally, there are three processes for reducing alkalinity: lime softening, Cl^- anion exchange (dealkalization), and weak acid cation exchange (dealkalization).

- Lime softening to reduce alkalinity results in a partial reduction of water hardness, and uses controlled amounts of $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate CO_3^{-2} hardness, after which the precipitated alkalinity is filtered out. The precipitated alkalinity is then removed as a sludge. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal
- Anion IX to reduce alkalinity uses charged anion resin to exchange acceptable ions from the resin for the undesirable alkalinity in the water. Benefits: acid addition, degasification, and repressurization is not required; effective; well developed. Limitations: pretreatment lime softening may be required; restocking of regenerate supply; regular regeneration; concentrate disposal.
- Cation IX to reduce alkalinity uses charged cation resin to exchange acceptable ions from the resin for hardness ions (Ca and Mg) plus some of the undesirable alkalinity in the water. Benefits: most suitable for low flows; therefore, cost curves are not presented in this Fact Sheet. Limitations: requires a hardness-to-alkalinity ratio greater than 1.

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. 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 CO_3^{-2} hardness and reduce the solubility of alkalinity. Alkalinity precipitates as sludge. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including alkalinity, 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.

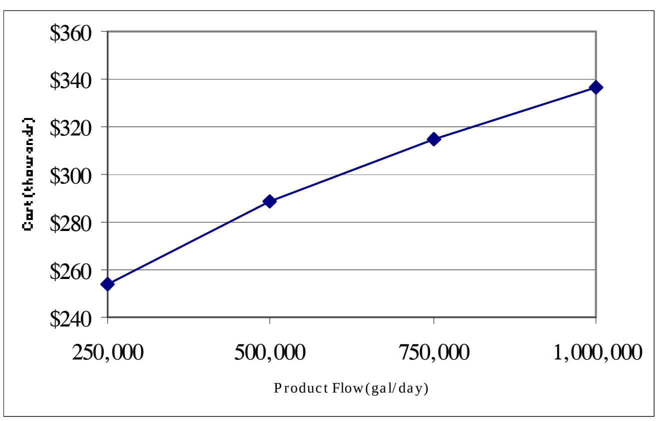
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 alkaline sludge: incineration, landfill, and ocean disposal.

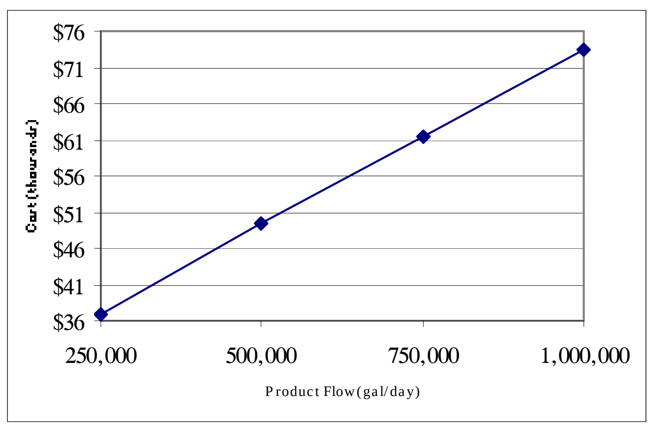
Advantages -
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- Produces high sludge volume.

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. Ion Exchange:

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. 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 alkalinity reduction, operation begins with a fully recharged resin bed, having enough negatively or positively charged ions to carry out the ion 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 negatively or positively charged ions are released into the water, being substituted or replaced with the alkalinity anions in the water (ion exchange). When the resin becomes exhausted of charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the alkalinity ions. Many different types of anion and cation resins can be used to reduce dissolved alkalinity concentrations. The use of IX to reduce concentrations of alkalinity will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-alkalinity is greater than 1.

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 the raw water characteristics and the alkalinity 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 alkaline 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.

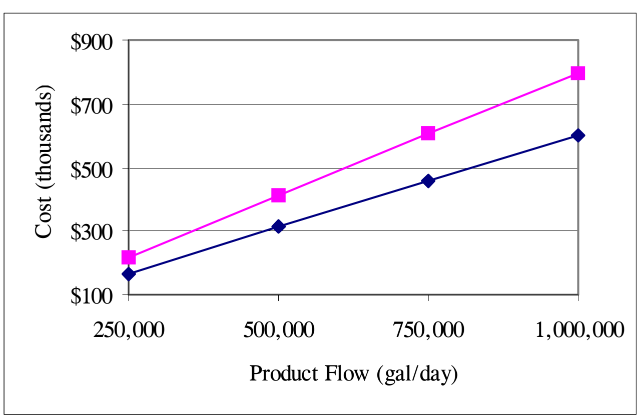
Advantages -

- Acid addition, degasification, and repressurization is not required.
- 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.
- Variety of specific resins are available for removing specific contaminants.

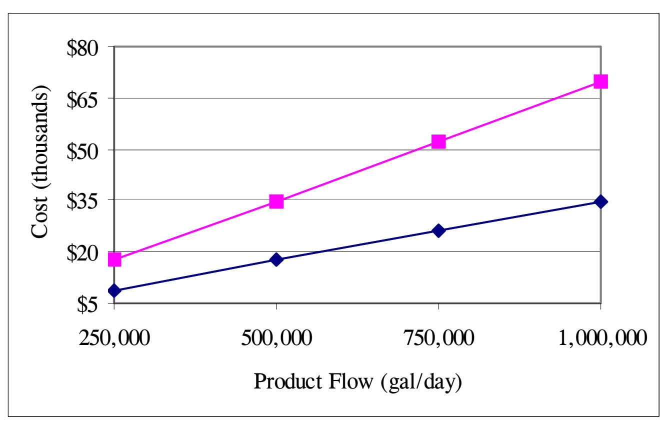
Disadvantages -

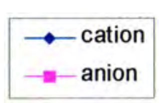
- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Strongly basic anion resins are susceptible to organic fouling; reduced life; thermodynamically unstable.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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.

ANTIMONY

FACT SHEET

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

1. CONTAMINANT DATA

A. Chemical Data: Antimony (Sb), atomic number: 51, atomic weight: 121.75, is a silvery-white, brittle, semimetallic element. Alloyed with other metals to increase their hardness and strength, also used as a fire retardant.

B. Source in Nature: Sb is found at very low levels throughout the environment, the general population is exposed to low levels of it everyday, primarily in food, drinking water, and the air. More Sb is found in food and air than water. Sb occurs in nature only in a combined state and found in over 100 mineral species. It is sometimes found native, but more frequently as the sulfide stibnite, and the trioxide, valentinite. Other ores include cervantite, livingstonite, jamisonite, and kermesite. Sb is also a common component of coal and petroleum. Industrial plants, auto emissions, and exhausts from oil fuels are the main sources of Sb in urban air, where it eventually finds its way to lakes and streams, adhering to the sediments. Sb trioxides are also released into the atmosphere by factories that convert antimony ores into metal by smelting, molding, and incineration of the Sb materials. Sb may appear in water from corrosion of lead pipes and fittings, but is rarely detectable.

C. SDWA Limits: MCLG/MCL for Sb is 0.006 mg/L.

D. Health Effects of Contamination: Sb, in short-term exposure levels above the MCL: gastrointestinal disorders, nausea, vomiting, and diarrhea can occur. Sb, when left on the skin can irritate it. In long-term exposures at levels above the MCL: decreased longevity, cardiovascular problems, and altered blood levels of glucose and cholesterol can be expected. Sb is beneficial when used for medical purposes. It has been used as a medicine to treat people infected with parasites. Sb is not known to be or classified as a carcinogen.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Coagulation and filtration or reverse osmosis.

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

B. Alternative Methods of Treatment: Distillation (for home drinking water only), heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Sb remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon are certified to reduce Sb are available.

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 Sb 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 Sb 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.

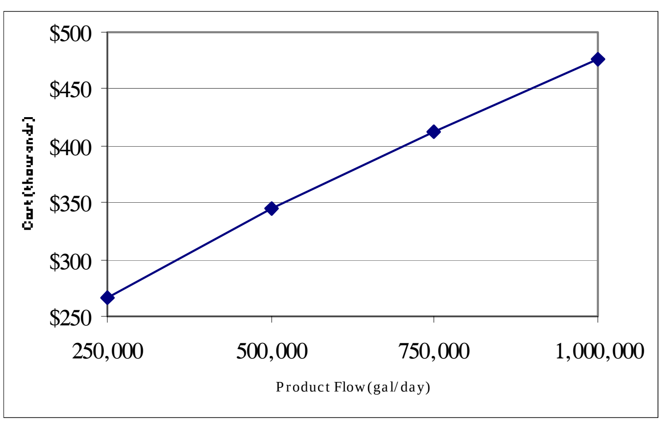
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

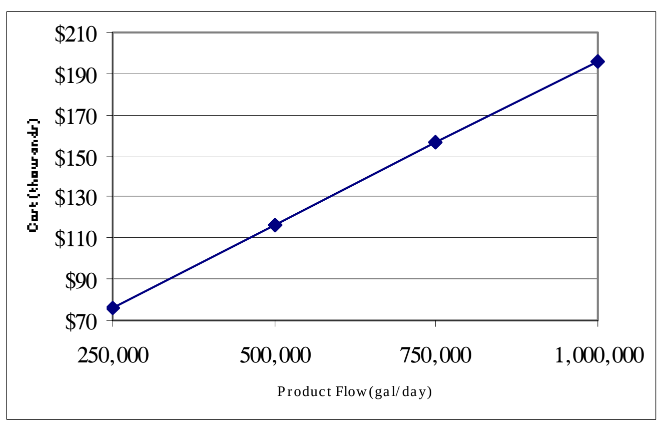
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- 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 filtration plus flocculation). Costs for coagulation and filtration would be less since flocculation is omitted.

3B. 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.

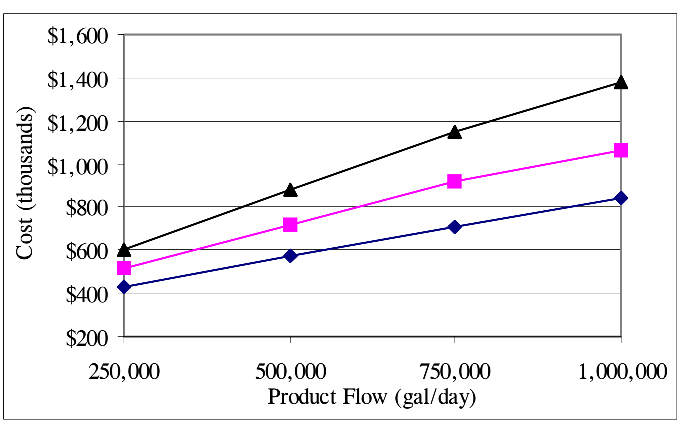
Maintenance - Monitor rejection percentage to ensure Sb removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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.

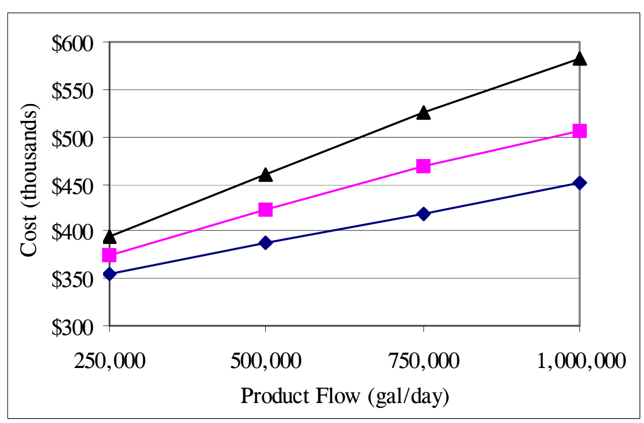
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

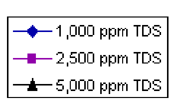
Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Sb removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

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.

ARSENIC

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: Arsenic (As), inorganic element, semi-metal, stable and sparingly soluble, atomic number 33, atomic weight 74.92. Inorganic oxidation states (in water): +3 (Arsenite-most toxic) and +5 (Arsenate). As has no taste, smell, or color in water.
B. Source in Nature: As is a naturally occurring element found in soils, surface water, and groundwater, with the highest natural concentrations of As usually found in areas of geothermal activity. However, very little is known about the geologic, hydrologic, and biogeochemical conditions which favor dissolution of arsenic into groundwaters. As is found in varying levels in most food groups with the major sources being marine plants and shellfish. In industry, As is used in the production of pesticides and herbicides, from cotton and wool processing, as a wood preservative, a feed additive, in various metal alloys, and in mining. As can result from pesticide runoff; from seepages from hazardous waste sites; and from areas near cemetaries where burials were conducted from about 1880 to 1910 when As was used as an embalming fluid. As is ingested by either drinking contaminated water, eating food that has been washed in the water, or ingestion in small doses by way of the human food chain.
C. SDWA Limits: MCL for As is 0.01 mg/L. MCLG is 0 mg/L for drinking water.
D. Health Effects of Contamination: As is a known carcinogen and poisoning can be either acute or chronic. As is a teratogen, meaning it can enter the metabolic system of unborn babies. Acute poisoning results from ingestion of large quantities of As at one time resulting in stomach pain, nausea, vomiting, or diarrhea which may lead to shock, coma, and even death. Chronic poisoning occurs over long periods of time often resulting in skin lesions, thickening or discoloration of the skin, and numbness in the feet and hands (neuritis). As poisoning has been linked to higher rates of cancer of the lungs, bladder, kidney, liver, and skin. Young children, the elderly, unborn babies, and people with long-term illnesses are at greater risk of As poisoning.

2. REMOVAL TECHNIQUES

Optimal As removal is dependent on many individual water characterisitics, including source water pH, TDS, sulfides, other salts, quantity of water to treat, and amount of As present. As^{+5} is most effectively removed, therefore As^{+3} may be converted through preoxidation with Cl_2, $FeCl_3$, or $KMnO_4$ to As^{+5}. Preoxidation with Cl_2 may create undesireable concentrations of disinfection by-products.
A. USEPA BAT: Coagulation and filtration; lime softening; reverse osmosis; or activated alumina.

- Coagulation and filtration uses the conventional treatment 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 As 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, Na_2CO_3 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 As removal, along with high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- AA uses extremely porous and highly adsorptive aluminum ore media to adsorb As^{+5}. Benefits: containment of As^{+5} in adsorption bed. Limitations: highly selective to As^{+5} resulting in frequent regeneration; results in creation of hazardous waste requiring disposal. AA cost curves will be included in a future revision.

B. Alternative Methods of Treatment: Ion exchange can remove As however efficieny is affected by SO_4^{-2}, TDS, Se, F^-, and NO_3^-. Electrodialysis reversal can achieve removal of As at about 80%. Nanofiltration can achieve removal of As at about 90%. In the presence of dissolved Fe and Mg, As will co-precipitate and can be removed with Greensand or other specialized Fe and Mg filtration media.
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). $Fe_2(SO_4)_3$ has been proven to be the most effective coagulant for As^{+5} removal. Filtration provides final removal by dual media filtering of all floc and suspended solids.

Pretreatment - Preoxidation to convert As^{+3} to As^{+5}. Jar tests to determine optimum pH for coagulation, and resulting pH adjustment, may be required.

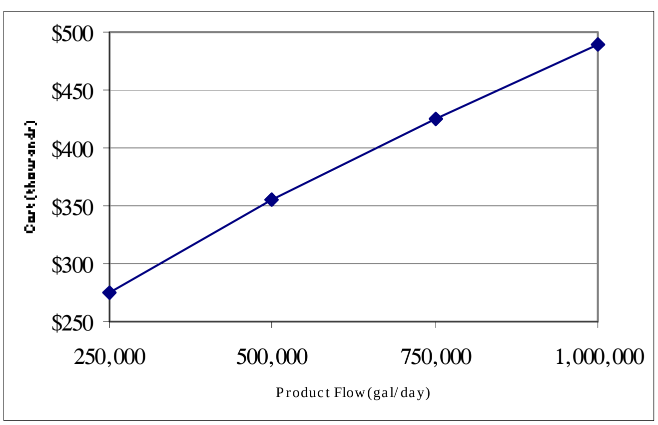
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

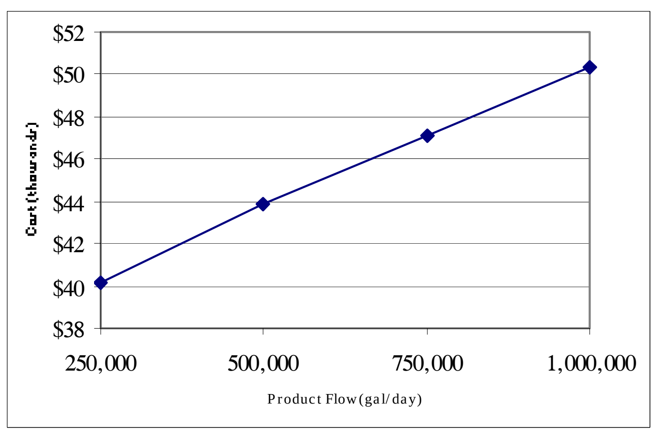
Advantages -
- Lowest capital costs for larger systems.
- Lowest overall operating costs for larger systems.
- Proven and reliable.
- Most effective for As^{+5}.

Disadvantages -
- Not appropriate for smaller systems.
- Operator care required with chemical handling.
- Produces high As-contaminated sludge volume.
- High or low pH reduces treatment efficiency; secondary treatment may be required.

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 $Ca(OH)_2$ to precipitate carbonate and Na_2CO_3 to precipitate noncarbonate hardness. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including As, 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 10.5 or higher.

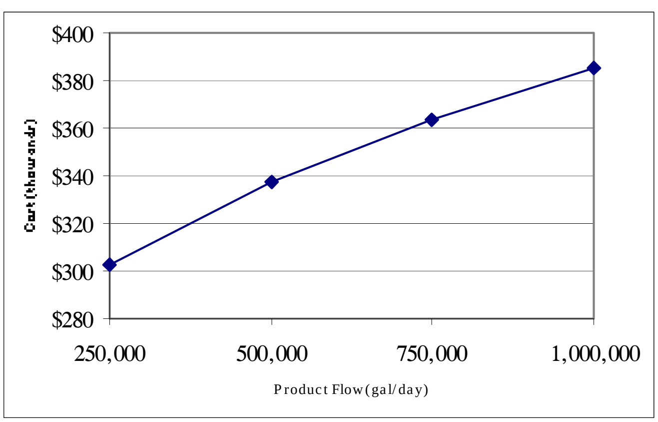
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 As-contaminated sludges: incineration, landfill, and ocean disposal.

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 As-contaminated sludge volume.
- Secondary treatment may be required.
- Waters high in sulfate may cause significant interference with removal efficiencies.

BAT Equipment Cost*



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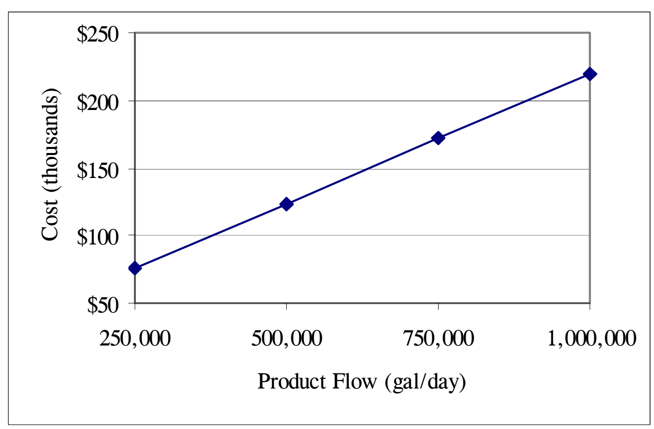


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

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 As 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.

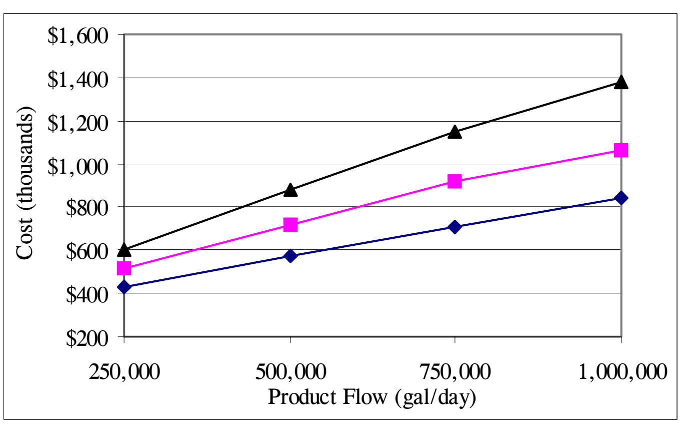
Advantages -

- Produces highest As 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.

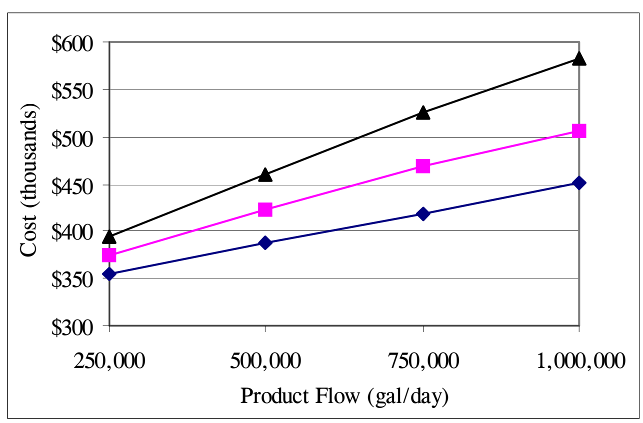
Disadvantages -

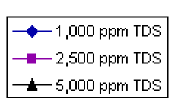
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for As removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

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. 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 may be the responsibility of a contractor providing 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.

ASBESTOS

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: White, gray, green or brown crystalline fibers. Asbestos consists of six different fibrous minerals (amosite, chrysotile, crocidolite, tremolite, actinolite, and anthophyllite) and occurs in natural deposits. It was introduced into our environment about 100 years ago. Asbestos fibers vary in length and may be straight or curled, they have no detectable odor or taste. Asbestos fibers are very strong, resistant to heat, corrosion, thermal effects, and most chemicals. Asbestos fibers are very stable in the environment and do not evaporate into the air or dissolve in water, considered to be non-biodegradable by aquatic organisms.

B. Source in Nature: Asbestos fibers are released into the atmosphere and water from natural sources such as erosion of asbestos-containing ores, and the wearing down of manufactured asbestos products, but the primary source of contamination is through the breakdown of asbestos-containing materials from wastewaters of factories and mining operations, and the use of asbestos laden cement pipes in water conveyance systems, also from filtering through asbestos-containing filters.

C. SDWA Limits: MCLG/MCL for asbestos is 7 million fibers per liter. (Fibers > 10 microns in length for MCLG)

D. Health Effects of Contamination: Asbestos is a known carcinogen. No Health advisories are established for short term exposures. At levels above the MCL, Asbestos has the potential to cause lung disease, Asbestosis (cancer of the lung tissue), Mesothelioma (cancer of the thin membrane surrounding the lung), and cancer to other internal organs from a lifetime exposure. Studies of people who have been exposed to Asbestos fibers in drinking water have a higher-than-average death rate from cancer of the esophagus, stomach, and intestines, but it has not been confirmed whether this is caused by asbestos alone or something else. Humidifiers could add to the hazard posed by asbestos contaminated water.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Coagulation and filtration, direct filtration, or diatomaceous earth filtration.

- Coagulation and filtration uses the conventional treatment processes of chemical addition, coagulation, and dual media filtration. Benefits: low capital costs for proven, reliable process. Limitations: operator care required with chemical usage and sludge disposal.
- Direct filtration is a process for separating solid particles from the liquid in which they are suspended using chemical addition, coagulation/flocculation, and dual media filtration. Benefits: proven; reliable. Limitations: initial investment.
- Diatomaceous earth filtration uses a thin coat of diatomaceous earth over a fabric to screen out particles. Benefits: significant savings in equipment cost and required space. Limitations: Does not remove smaller particles, such as viruses. DE cost curves will be included in a future revision.

B. Alternative Methods of Treatment: Corrosion Control, reduces the amount of asbestos by changing the water chemistry to reduce the asbestos solubility. Distillation (for home drinking water only), heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The asbestos remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon are certified to reduce asbestos are available.

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. Direct Filtration:

Process - Direct filtration for asbestos 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 asbestos 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.

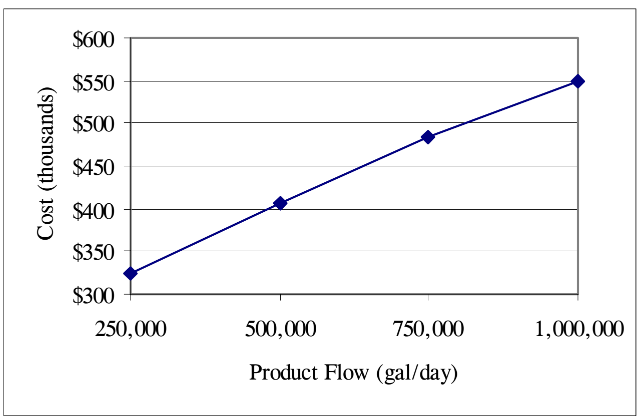
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 media require approved disposal.

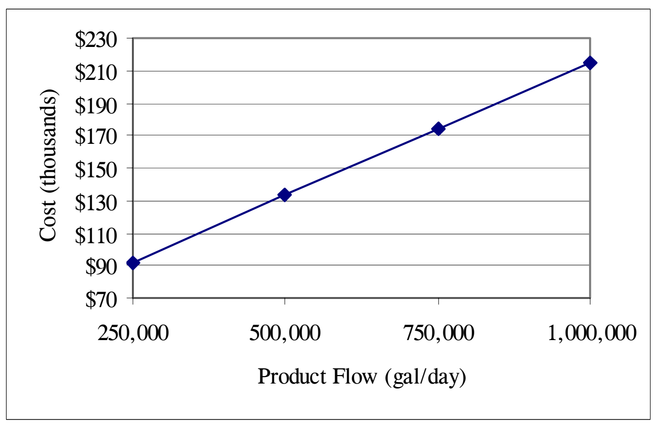
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

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

3B. Coagulation and Filtration:

Process - Coagulation and filtration for insoluble Asbestos 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 Asbestos 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.

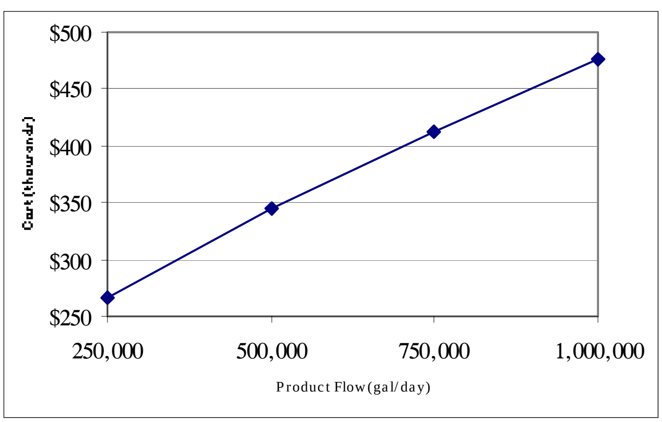
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 media require approved disposal.

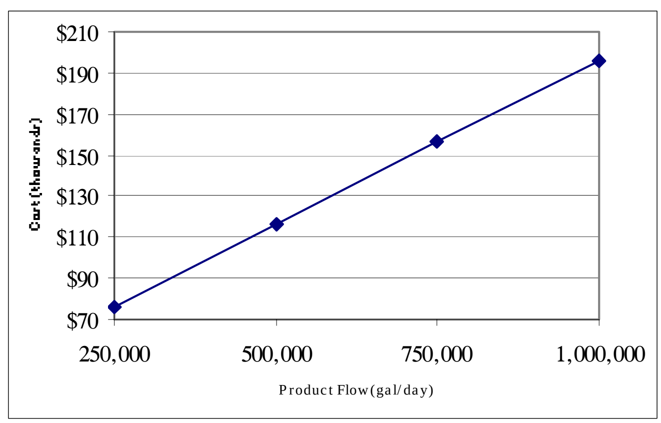
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- Suitable only for insoluble Asbestos.
- 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.

BARIUM

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: Barium (Ba) , atomic number: 56, atomic weight: 137.327, oxidation state: +2, metallic element, soft, and when pure is silvery white similar to lead. Occurring naturally, Ba is a mixture of seven stable isotopes. Oxidizes very easily and is decomposed by water and alcohol.

B. Source in Nature: Ba is a naturally occurring alkaline earth metal found primarily in the Midwest, in combination form with other chemicals such as sulfur or carbon and oxygen. Traces of the element are found in most surface and ground waters. It can also be produced by industry in oil and gas drilling muds, smelting of copper, waste from coal fired power plants, jet fuels, and automotive paints and accessories.

C. SDWA Limits: MCL/MCLG for Ba is 2.0 mg/L.

D. Health Effects of Contamination: The health effects of the different barium compounds depend on how well the compound dissolves in water. Ba compounds that do not dissolve well in water are not generally harmful and are often used by doctors for medical purposes. All Ba compounds that are water or acid soluble are toxic when its salts are ingested. Ba in short-term exposures above the MCL potentially cause gastrointestinal disturbances and nerve block, causing muscular weakness. Ba in long-term exposures above the MCL have the potential to cause high blood pressure, changes in heart rhythm, brain swelling, and damage to the liver, kidney, heart, and spleen.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Ion exchange, reverse osmosis, lime softening, or electrodialysis.

- IX for soluble Ba uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Ba in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.
- RO for soluble Ba uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Ba), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- Lime softening for soluble Ba uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Ba. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Ba compounds may be formed at low carbonate levels requiring coagulation and flocculation.
- 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.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Ba remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce Ba are available.

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. 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 Ba reduction, operation begins with a fully recharged cation 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 Ba ions 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 Ba ions with Na or K ions. Many different types of cation resins can be used to reduce dissolved Ba concentrations. The use of IX to reduce concentrations of Ba will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-Ba is greater than 1.

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 Ba 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 alkaline 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.

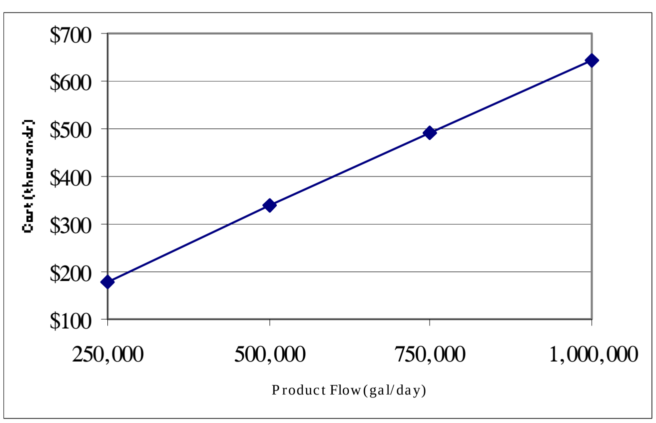
Advantages -

- Acid addition, degasification, and repressurization is not required.
- 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.
- Variety of specific resins are available for removing specific contaminants.

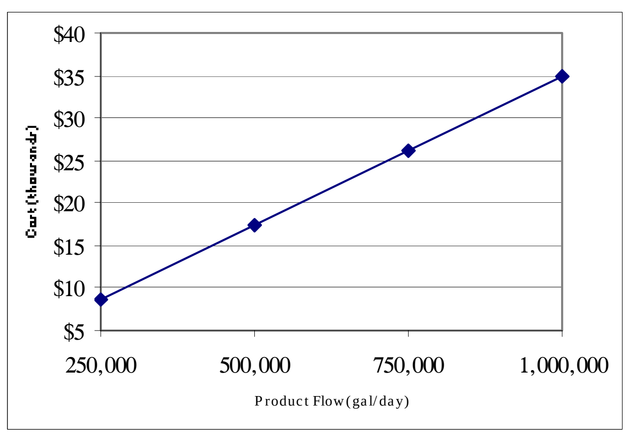
Disadvantages -

- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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. 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 Ba 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.

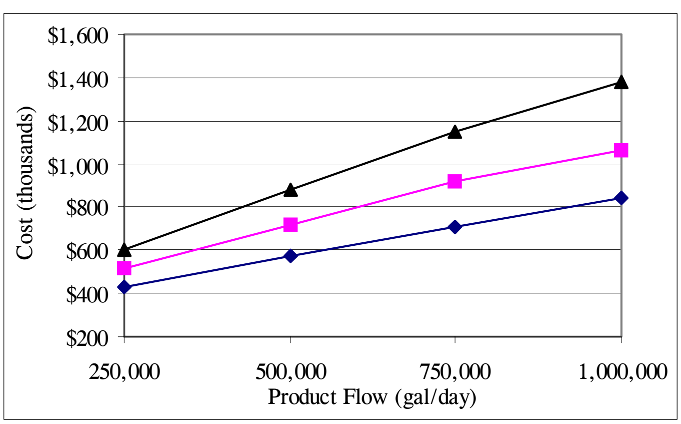
Advantages -

- 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 Ba removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

BAT Equipment Cost*



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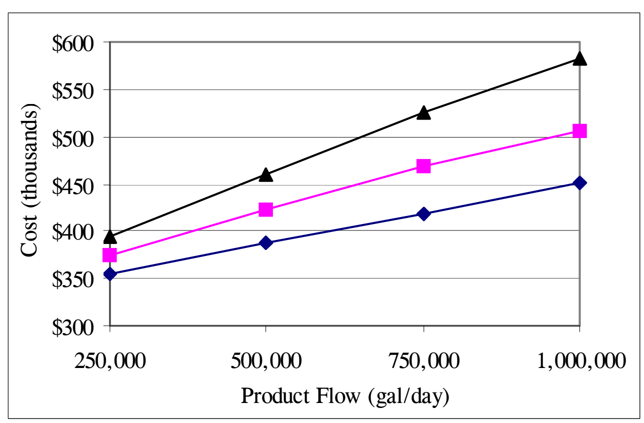
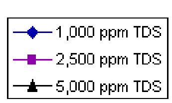




*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3C. 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 Ba, precipitate as $Ba(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Ba, 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.

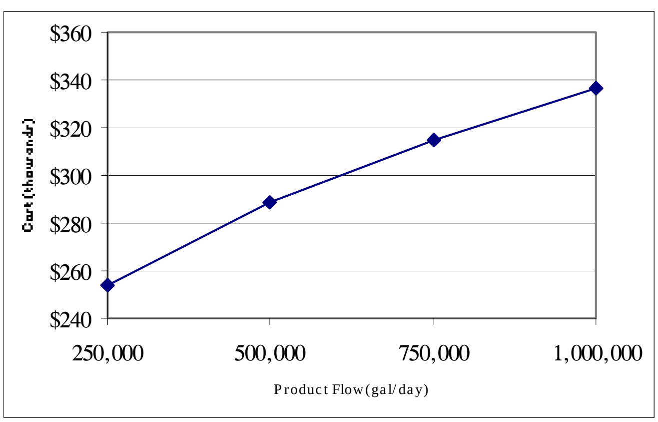
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which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

BAT Equipment Cost*



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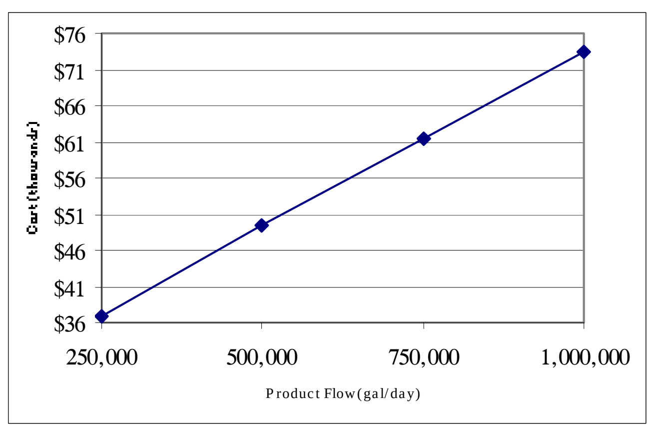


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3D. 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. 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.

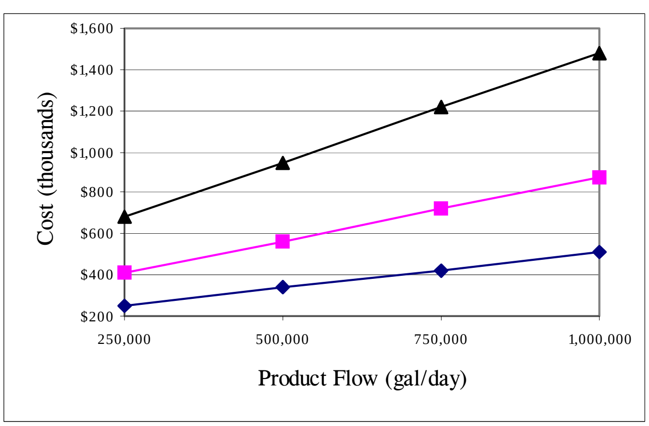
Maintenance - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode 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 Ba 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.

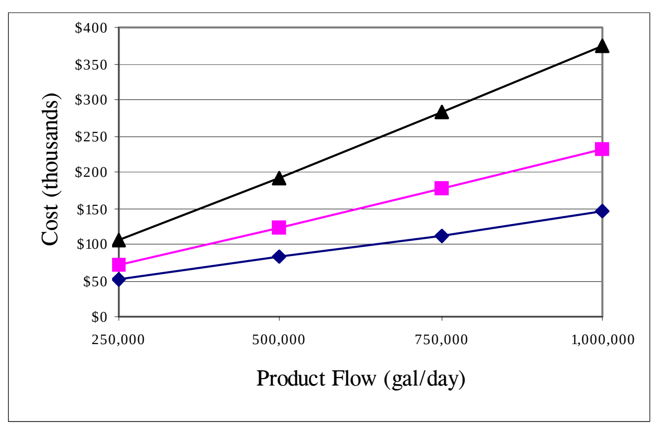
Advantages -
- EDR can operate with minimal fouling or scaling, or chemical addition.
- Low pressure requirements; typically quieter than RO.
- Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

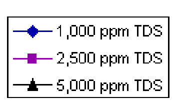
Disadvantages -
- Not suitable for high levels of Fe and Mn, H_2S, chlorine, or hardness.
- Limited current density; current leakage; back diffusion.
- At 50% rejection of TDS per pass, process favors low TDS water.

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.

BERYLLIUM

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: Beryllium (Be), atomic number: 4, atomic weight: 9.01218, oxidation state: +2, a brittle, hard grayish metal. Some Be compounds have a sweet taste, but no particular smell. Some Be compounds are water soluble, but most settle to the bottom as particles.

B. Source in Nature: Be is found in compounds in silicate mineral rocks, coal, soil, and volcanic dust. Not found naturally in surface water, but enters waters by erosion from rocks and soil, and industrial waste by coal combustion from slag and ash dumps.

C. SDWA Limits: MCL/MCLG for Be is 0.004 mg/L.

D. Health Effects of Contamination: Be in short-term exposures above the MCL causes a sensitivity to Be, acute chemical pneumonitis, and chronic beryllium disease, making a person feel week and tired, with difficulty breathing. Be in long-term exposures above the MCL can cause lung damage, damage to bones, and cancer. Be contact with cut or broken skin can cause rashes or ulcers.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Activated alumina, coagulation and filtration, ion exchange, lime softening, or reverse osmosis.

- AA uses extremely porous and highly adsorptive aluminum ore media to adsorb Be. Benefits: containment of Be in adsorption bed. Limitations: when used with Be^{+4} results in creation of hazardous waste requiring disposal. AA cost curves will be included in a future revision.
- Coagulation and filtration for 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.
- IX for soluble Be uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Be in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.
- Lime softening for soluble Be uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Be. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Be compounds may be formed at low carbonate levels requiring coagulation and flocculation.
- RO for soluble Be uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Be), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Be remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce Be are available.

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. 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 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 cost curves for AA equipment and annual operation and maintenance are being developed and will be included in a future revision.

3B. Coagulation and Filtration:

Process - Coagulation and filtration for insoluble Be 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 Be 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.

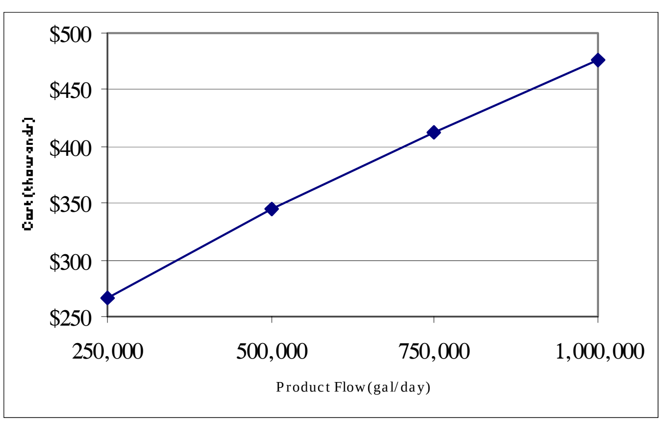
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

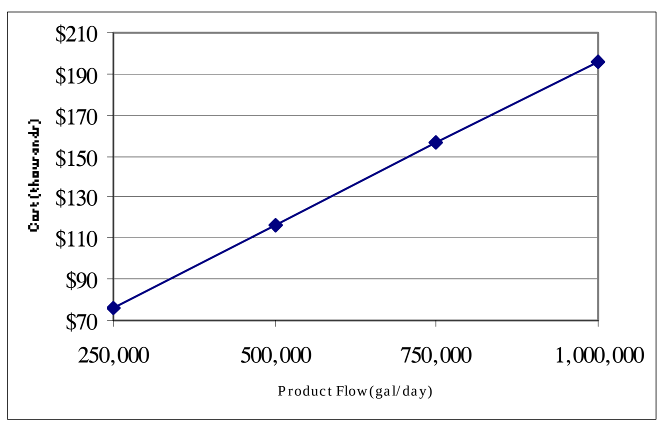
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- 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 filtration plus flocculation). Costs for coagulation and filtration would be less since flocculation is omitted.

3C. 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 Be reduction, operation begins with a fully recharged cation 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 Be ions 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 Be ions with Na or K ions. Many different types of cation resins can be used to reduce dissolved Be concentrations. The use of IX to reduce concentrations of Be will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-Be is greater than 1.

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 Be 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 alkaline 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.

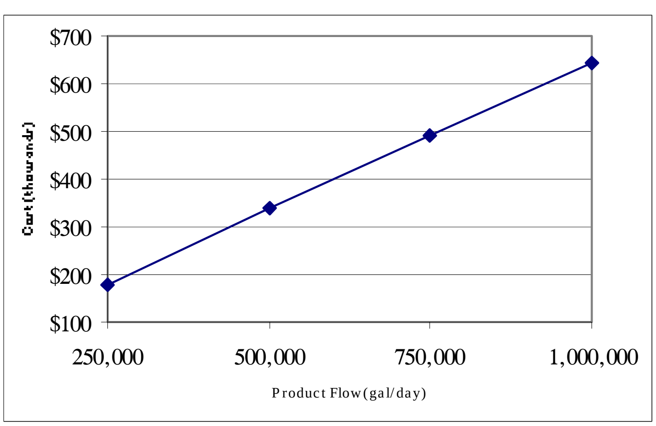
Advantages -

- Acid addition, degasification, and repressurization is not required.
- 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.
- Variety of specific resins are available for removing specific contaminants.

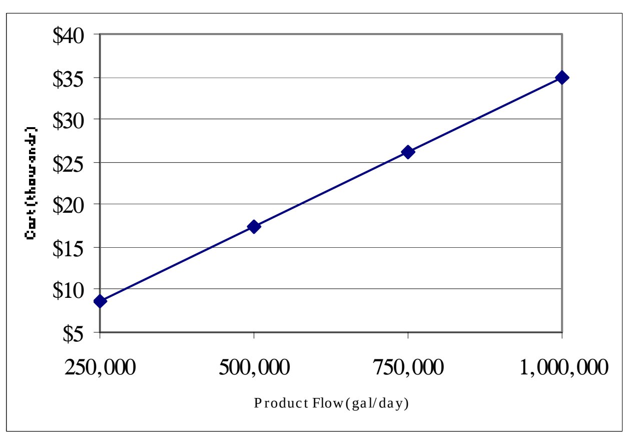
Disadvantages -

- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

BAT Equipment Cost*



BAT Annual O&M Cost*



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3D. 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 Be, precipitate as $Be(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Be, 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.

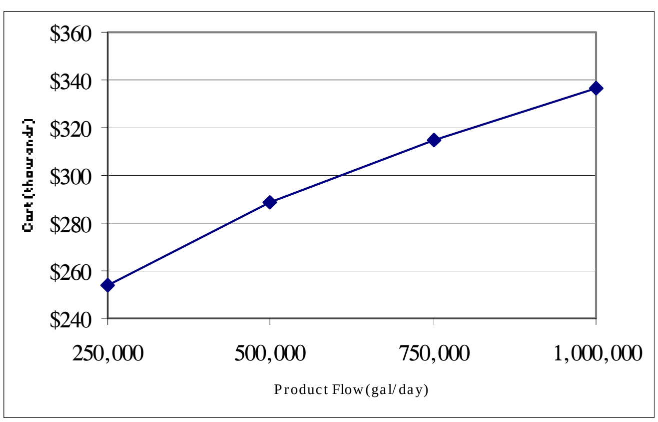
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 Be sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Be 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.

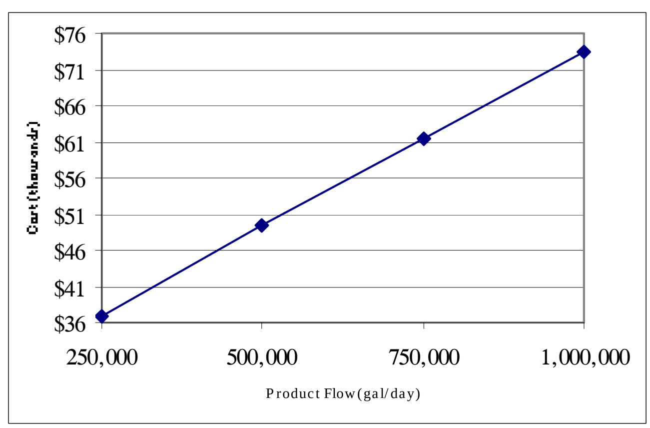
Advantages -
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Excessive insoluble Be may be formed requiring coagulation and filtration.
- Operator care required with chemical handling.
- Produces high sludge volume.

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. 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.

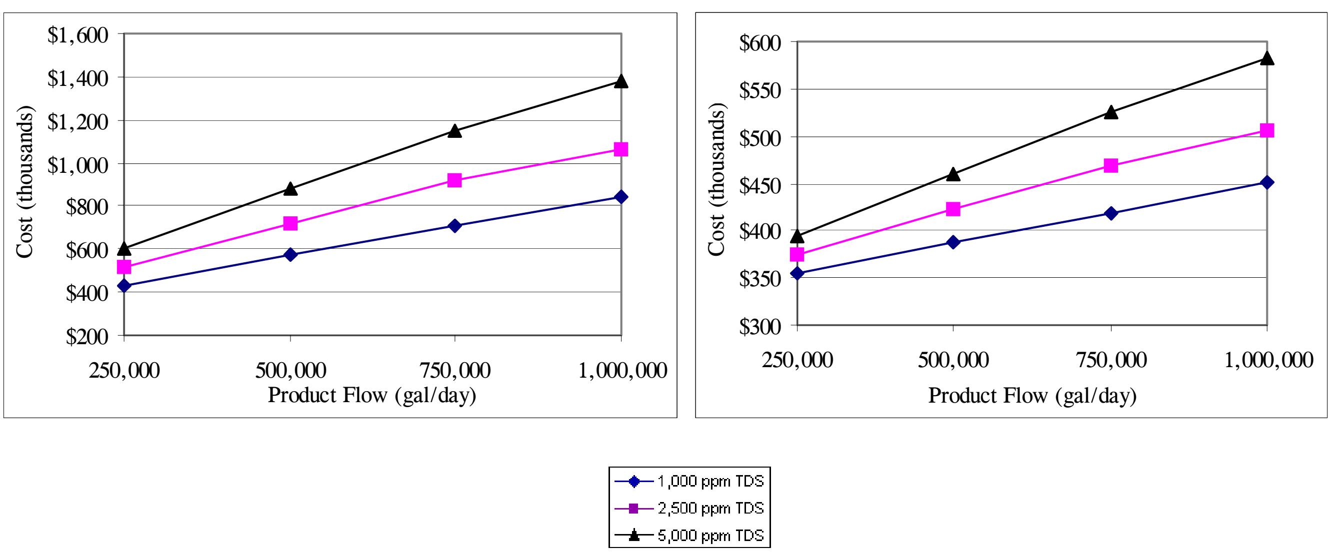
Maintenance - Monitor rejection percentage to ensure Be removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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 Be 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.

CHROMIUM

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: Chromium (Cr), atomic number: 24, atomic weight: 51.996, a steel-gray metallic element with a high melting point. It is a micronutrient (essential trace element).

B. Source in Nature: Cr is a naturally occurring ubiquitous element found in the air, water, rocks, soil, animals, and in volcanic dust and gases. Cr is found in the environment in three major forms or oxidation states: trivalent Cr (III), hexavalent Cr (VI), and metallic Cr (0), the first two being the most important and most common. The form depends on the pH level. Very small amounts of Cr III are found in food. Cr is deposited into the environment through steel, refractory and chemical manufacturing, chrome plating, and municipal sewage wastes via surface runoff. Cr may be found in tap water as a result of plumbing fixtures.

C. SDWA Limits: MCL/MCLG for Cr is 0.1 mg/L.

D. Health Effects of Contamination: In very small amounts, Cr (III) is an essential nutrient in our diet, helping maintain normal metabolism of glucose, cholesterol, and fat in human bodies. All forms of Cr can be toxic at high levels, but Cr (VI) is the most toxic. At short-term exposure levels above the MCL, Cr causes skin and stomach irritation, or ulceration. Long-term exposure at levels above the MCL can cause dermatitis, damage to the liver, kidney circulation and nerve tissue damage, and death in large doses. Skin contact with liquids containing Cr (VI) may lead to allergic reactions.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Coagulation and filtration, ion exchange, reverse osmosis, or lime softening (for Cr III only).

- Coagulation and filtration uses the conventional treatment 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.
- IX for Cr uses a charged anion resin to exchange acceptable ions from the resin for the undesirable Cr in the water. Benefits: acid addition, degasification, and repressurization is not required; effective; well developed. Limitations: pretreatment lime softening may be required; restocking of regenerate supply; regular regeneration; concentrate disposal.
- RO for soluble Cr uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Cr), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- Lime softening for soluble Cr uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Cr. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Cr compounds may be formed at low carbonate levels requiring coagulation and flocculation.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Cr remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce Cr are available.

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 Cr 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 Cr 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.

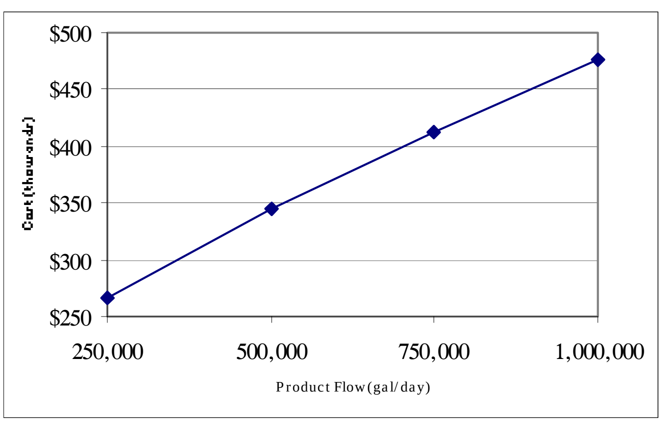
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

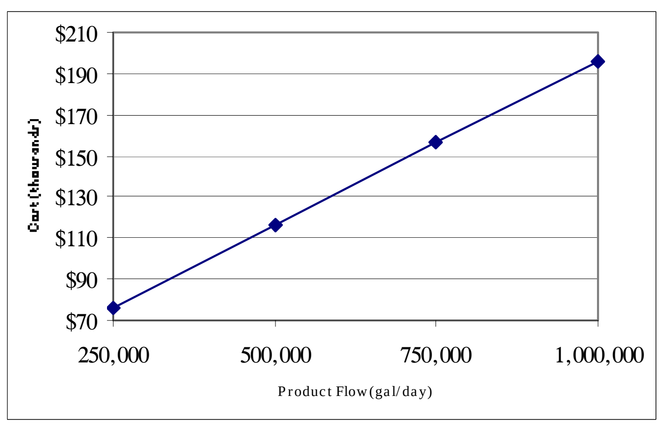
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- 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 filtration plus flocculation). Costs for coagulation and filtration would be less since flocculation is omitted.

3B. Ion Exchange:

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. Anion 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 Cr reduction, operation begins with a fully recharged anion resin bed, having enough negatively charged ions to carry out the anion 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 negatively charged ions are released into the water, being substituted or replaced with the Cr anions in the water (ion exchange). When the resin becomes exhausted of negatively charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the Cr ions with Cl^- ions. Many different types of anion resins can be used to reduce dissolved Cr concentrations. The use of IX to reduce concentrations of Cr will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-Cr is greater than 1.

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.

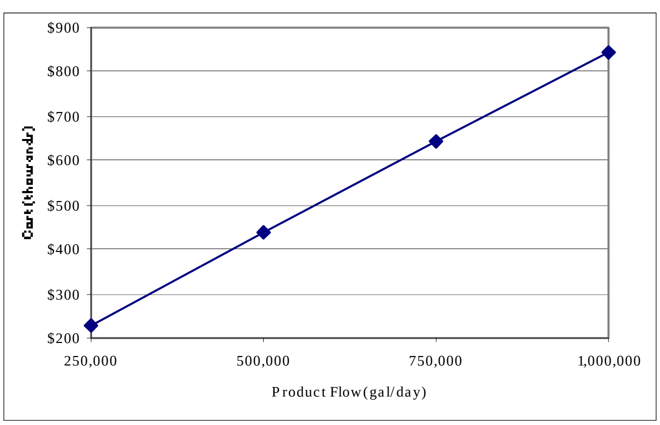
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Cr concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline 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.

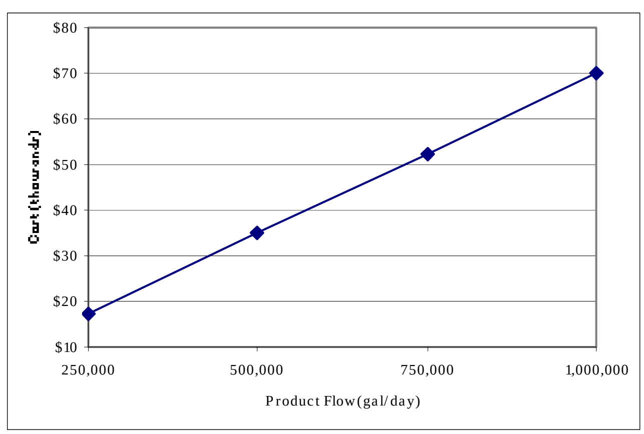
Advantages -
- Acid addition, degasification, and repressurization is not required.
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Strongly basic anion resins are susceptible to organic fouling; reduced life; thermodynamically unstable.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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.

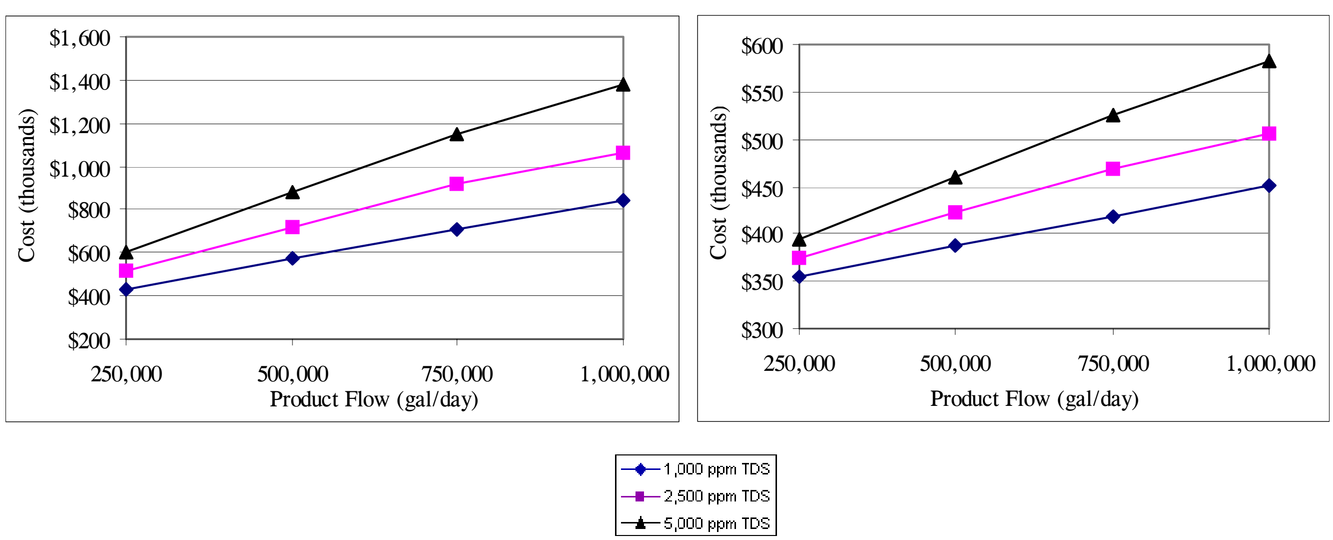
Maintenance - Monitor rejection percentage to ensure Cr removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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 Cr 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. 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 Cr, precipitate as $Cr(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Cr, 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.

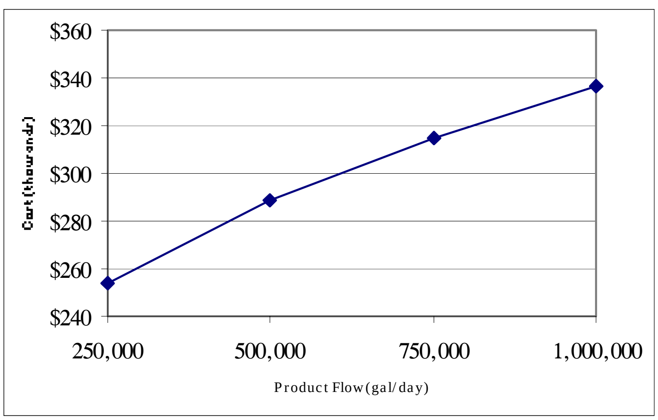
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 Cr sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Cr 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.

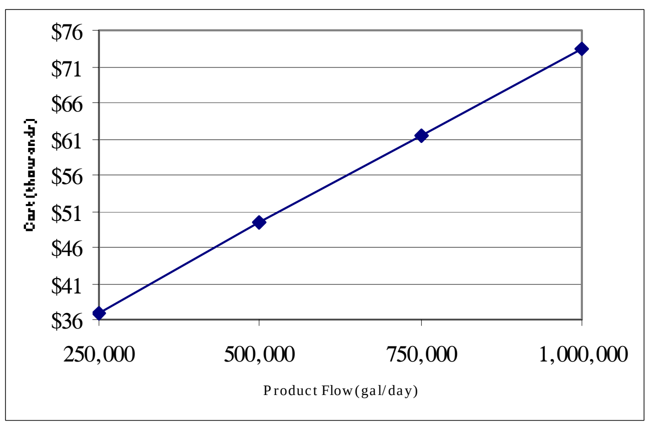
Advantages -
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Excessive insoluble Cr may be formed requiring coagulation and filtration.
- Operator care required with chemical handling.
- Produces high sludge volume.

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.

COPPER

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: Copper (Cu), atomic number: 29, atomic weight: 63.546, most stable oxidation state is +2, is a reddish-brown, ductile, malleable metal. Cu is distributed in an elemental state; and in sulfides, arsenates, chlorides, and carbonates.

B. Source in Nature: Cu is widely distributed in the natural environment, constituting about 70 ppm of the earth's crust. Cu is found in some natural waters, particularly in areas where copper and ore deposits have been mined, and where municipal incineration and smelting operations are active. Excessive amounts of Cu usually occur in drinking water sources as a result of contamination, or more commonly, in copper distribution systems by leaching as a result of corrosion.

C. SDWA Limits: TT action level for Cu is 1.3 mg/L.

D. Health Effects of Contamination: Cu, in small amounts, is an essential nutrient which can be obtained from eating a balanced diet. Excessive Cu can give drinking water an undesirable taste. Studies have shown that Cu may cause nausea, vomiting, diarrhea, headache, and dizziness in children. Persons with Wilson's disease, a hereditary disorder in which excessive and lethally toxic amounts of Cu accumulate in the liver and brain, are at a higher risk of Cu toxicity.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Ion exchange, reverse osmosis, lime softening, or coagulation and filtration.

- IX for soluble Cu uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Cu in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.
- RO for soluble Cu uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Cu), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- Lime softening for soluble Cu uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Cu. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Cu compounds may be formed at low carbonate levels requiring coagulation and flocculation.
- Coagulation and filtration for insoluble Cu 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.

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 Cu remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce Cu are available.

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. 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 Cu, 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 Cu 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 Cu^{+2} ions with $2Na^{+}$ ions. Typically, Cu 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.

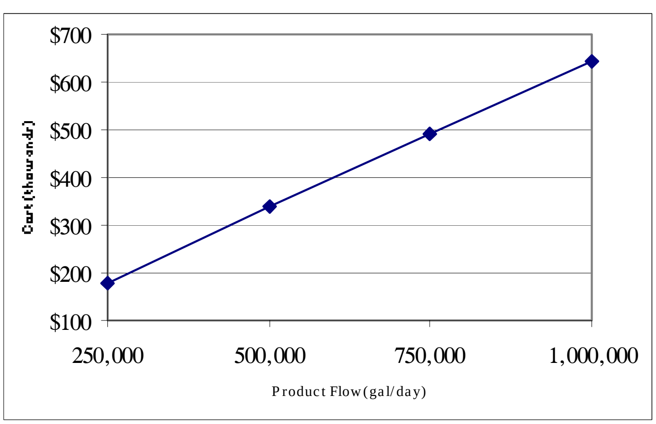
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Cu concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated Cu 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.

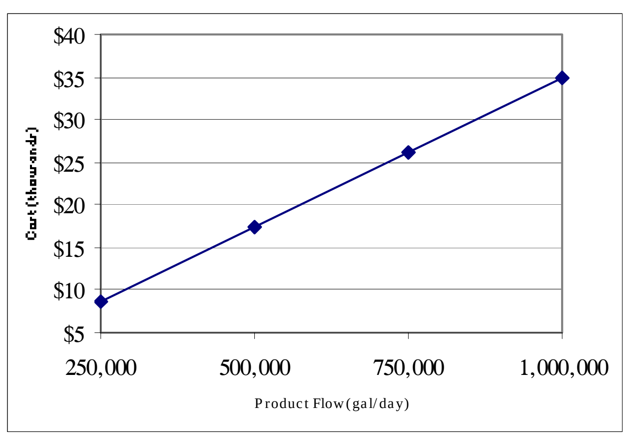
Advantages -
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Requires salt storage.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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. 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.

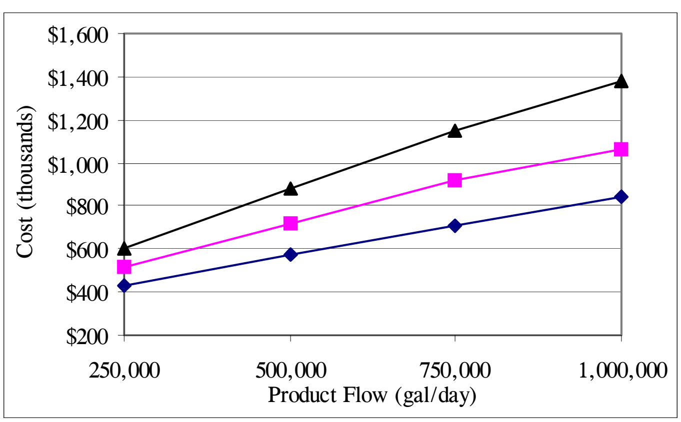
Maintenance - Monitor rejection percentage to ensure Cu removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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.

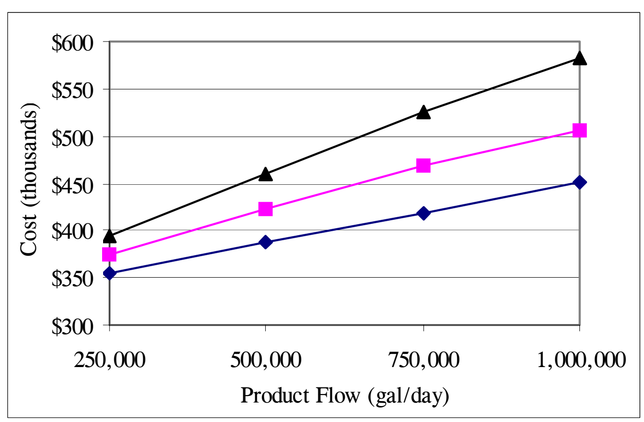
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

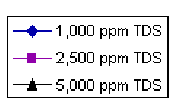
Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Cu removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

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.

3C. 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 Cu, precipitate as $Cu(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Cu, 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 Cu sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Cu 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.

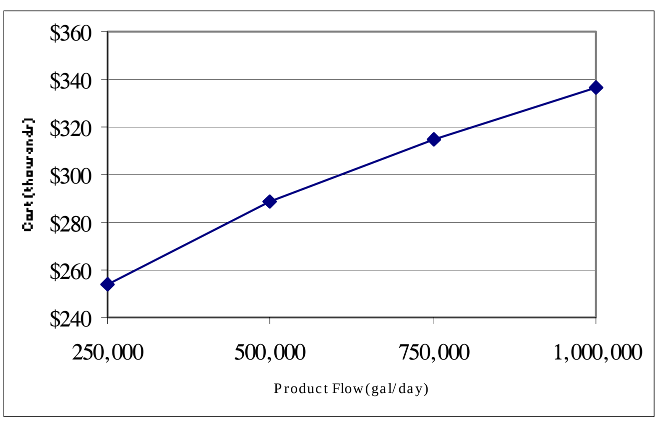
Advantages -

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

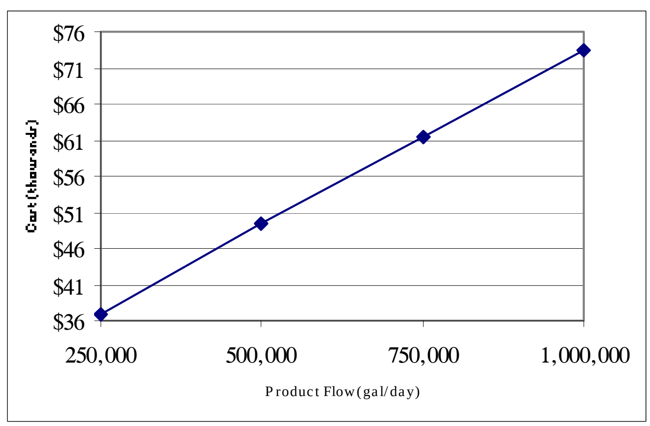
Disadvantages -

- Excessive insoluble Cu may be formed requiring coagulation and filtration.
- Operator care required with chemical handling.
- Produces high sludge volume.

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. Coagulation and Filtration:

Process - Coagulation and filtration for insoluble Cu 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 Cu 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.

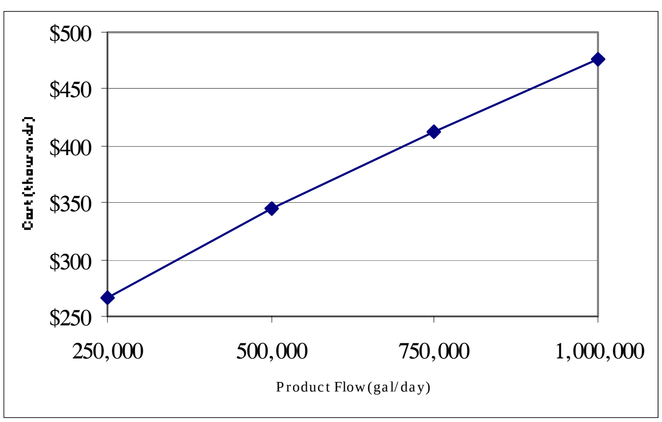
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 media require approved disposal.

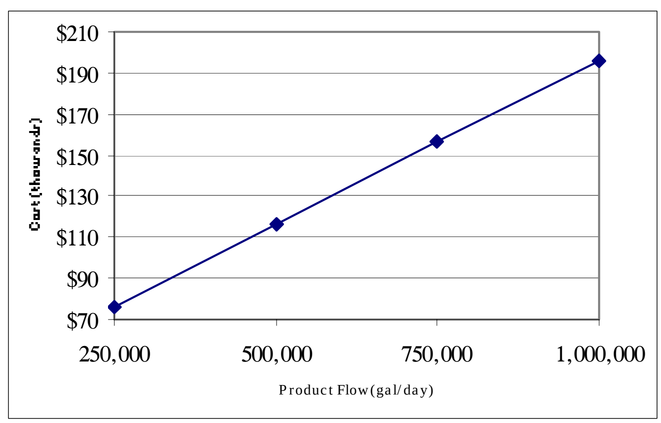
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- Suitable only for insoluble Cu.
- 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.

CRYPTOSPORIDIUM and GIARDIA

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: *Cryptosporidium parvum* (crypto) and *Giardia lamblia* (giardia) are waterborne, pathogenic, parasitic, single-celled, animal-like organisms called protozoa. Both species are resistant to adverse environmental factors and can survive months under optimum environmental conditions, and are resistant to minor exposure to disinfectants.

B. Source in Nature: Crypto and giardia are naturally occurring in the intestines of most mammals, including humans. The highly contagious and infectious form, as found in water, is a hard-shelled cyst in the case of giardia, about 5-8 microns in diameter; and an oocyst for crypto, about 3-5 microns (which is pliable and capable of folding to 1 micron). Once ingested by a host, the hard shell is dissolved, releasing the organisms. Both then reproduce in the intestines, and form new cysts/oocysts which are passed from the body in the feces. Both are found in water contaminated by mammal feces. Surface (most common) and groundwater contamination can occur as a result of surface runoff through urban areas, woodlands, pastures, or feedlots; on-site septic tank/sewage disposal system leakage/failure; sewage treatment plant/disposal system overload or malfunction; or raw sewage deep well injection. Treatment plant process contamination can occur as a result of filter breakthrough; improper coagulation; use of recycled, concentrated backwash water; process overload; or improper maintenance. Distribution system contamination can occur as a result of cross-connection, broken or leaking waterlines, or back-siphonage.

C. SDWA Limits: TT MCLG for crypto and giardia is 0 cysts/oocysts per 100 mL sample of finished drinking water, using the Presence/Absence rule procedures for indicator organisms. Future amendments to the SDWA, and related rules, will further regulate contamination limits, and monitoring, detection, and enumeration methods.

D. Health Effects of Contamination: Cryptosporidiosis and Giardiasis are contagious waterborne diseases characterized by acute gastrointestinal illness, including diarrhea and abdominal discomfort; fever; weight loss; malabsorption; or anemia. Although not life threatening to healthy adults, both diseases can be fatal to infants, the elderly, pregnant women, and immunocompromised persons. Both diseases are transmitted through fecal-oral ingestion of the cysts/oocysts, through direct ingestion (i.e. drinking), primary contact recreation (i.e. swimming), or secondary contact (i.e. fishing).

2. REMOVAL TECHNIQUES

A. USEPA BAT: For community surface and groundwater (under the direct influence of surface water) systems, treatment technique is applied. In this case, the accepted TT is use of the conventional treatment processes of screening, coagulation and flocculation, clarification, filtration, and disinfection. Benefits: proven; reliable. Limitations: initial investment.

B. Alternative Methods of Treatment: Both species are generally resistant to most chemical disinfectants, like chlorine or iodine, at usual treatment doses, contact times, and other parameters (temperature, pH, etc.). Temporary, short term super chlorination (or iodine disinfection) with increased doses and contact time can be effective. UV and ozonation can be effective at controlled flows, high doses, and extended contact times. Distillation is effective. Commercially available microfilters are effective, but require careful operation and maintenance. Crypto can be removed by NSF approved filters which capture particles of less than 1 micron, and giardia can be removed by NSF approved filters which capture particles of 4 micron or less. The FDA recommends use of a 1 micron medical grade filter to remove both. Improving well casing/sealing or drilling deeper wells can improve groundwater quality. Boiling water for 1 minute (5 minutes at higher elevations) is the traditional POU treatment method. Bottled water may be used, although is not regulated for testing for microbial contaminants. Raw water quality can also be improved through complex planning of waste treatment/disposal methods, public watershed, and land management, especially during periods of high precipitation or heavy runoff.

C. Safety and Health Requirements for Treatment Processes: General industry safety, health, and self protection practices for process equipment should be followed, including proper use of chemicals and tools. When dealing with waterborne diseases, take precautions to prevent infection through open cuts/wounds, or illnesses from ingestion. Wear PPE and wash hands thoroughly.

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. TT:

Process - For community surface and groundwater (under the direct influence of surface water) systems, conventional treatment techniques, including presedimentation or screening, chemical coagulation and flocculation, final settling or clarification, filtration, and disinfection ensure protection of both surface and groundwaters prior to entering distribution systems. These TTs work to remove and inactivate pathogens before they enter the distribution system. Not all processes are required in every case, so actual process selection depends on careful review of overall raw water quality and characteristics. Presedimentation or screening consists of removing the largest/heaviest suspended solids from the raw water. Chemical coagulation and flocculation consists of adding a chemical coagulant ($Al_2(SO_4)_3$ and polymer) combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). Costs presented below include alum (230 ppm) as the coagulant, rapid mix for 30 seconds, and flocculation for 30 minutes. Final settling or clarification consists of settling of the floc matter. Filtration consists of final removal by dual media filtering (or membrane) of all floc; suspended; and, based on filtration method/size, most dissolved solids, including pathogens. These TTs result in lowering overall TSS/TDS and turbidity, which in turn allows greater disinfection contact time on remaining pathogens. Disinfection consists of chemical inactivation (killing) of pathogens, bacteria, and viruses, usually by chlorination. As a result of crypto/giardia occurrences, investigations into the effectiveness of various water treatment processes for oocyst/cyst removal/inactivation are continuing.

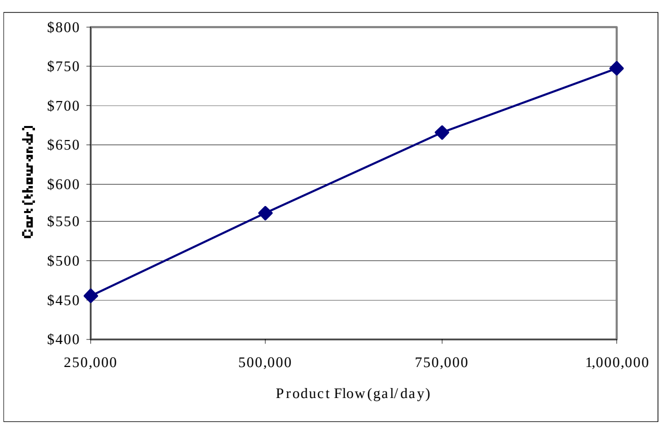
Maintenance - Proper monitoring, operation, and maintenance procedures, especially of the final filter, are essential to ensure the reliability of these TT processes. Recycled filter backwash or membrane cleaning methods may concentrate oocyst/cysts and result in a significant source of increased turbidity and crypto/giardia infestation. As a result, a period of filter-to-waste flow may be required after post-backwash/membrane cleaning periods. Because turbidity removal can parallel oocyst/cyst removal, finished water turbidity monitoring (<0.5 NTU) may be a useful tool for indicating the degree of pathogen removal. Depending on filtration process, recharging or clean installation of media is required.

Waste Disposal - Pretreatment waste streams and spent filters or filter material require approved disposal.

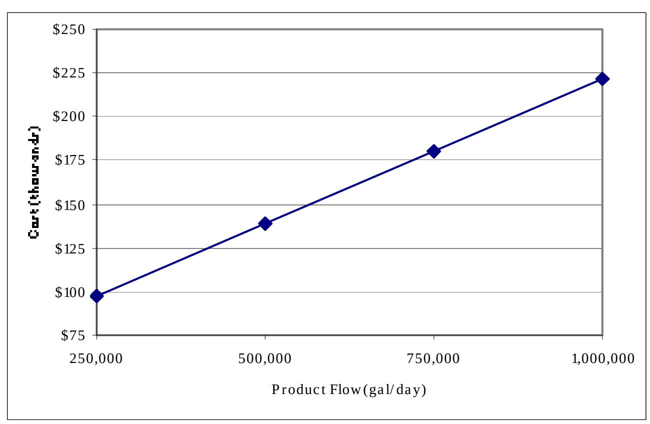
Advantages -
- Well established and reliable.
- Low operator requirements.

Disadvantages -
- Costly initial investment and land intensive.
- Lack of accepted testing and monitoring techniques may cause confusion.

BAT Equipment Cost*



BAT Annual O&M Cost*



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

CYANIDE

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: Cyanide is a carbon-nitrogen radical, which may be found in a wide variety of organic and inorganic compounds. A common form, hydrogen cyanide is a colorless gas or liquid with a faint, bitter, almond-like odor. Cyanide may exist as an ion with a valence of -1, and when combined carries a positive or negative charge. Cyanide, in some forms, is a very powerful and fast acting toxin. When combined with metals and organic compounds forms simple and complex salts and compounds, the most commonly used forms being hydrogen cyanide, sodium cyanide, and potassium cyanide. Hydrogen cyanide is a very dangerous fire hazard when exposed to heat, flame, or oxidizers.

B. Source in Nature: Cyanides are produced by certain bacteria, fungi, and algae, and may be found in plants and some foods, such as lima beans and almonds. Cyanide occurs naturally in cassava roots, potato-like tubers grown in tropical countries. Cyanide can enter surface water through releases from metal finishing industries, iron and steel mills, runoff from disposal of cyanide wastes in landfills, pesticides, and the use of cyanide-containing road salts. Most cyanide in surface water will form hydrogen cyanide and evaporate. It is not found commonly in drinking water at any significant concentration.

C. SDWA Limits: MCL/MCLG for cyanide is 0.2 mg/L.

D. Health Effects of Contamination: All forms of cyanide can be toxic at high levels, but hydrogen cyanide is the deadliest form of the toxins. At short-term exposure levels above the MCL, cyanide causes rapid breathing, tremors, and other neurological effects. Long-term exposure at levels above the MCL, cyanide can cause weight loss, thyroid effects, nerve damage and death. Skin contact with liquids containing cyanide may produce irritation and sores.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Ion exchange, reverse osmosis, or chlorine treatment

- IX for cyanide uses a charged anion resin to exchange acceptable ions from the resin for the undesirable cyanide in the water. Benefits: acid addition, degasification, and repressurization is not required; effective; well developed. Limitations: pretreatment lime softening may be required; restocking of regenerate supply; regular regeneration; concentrate disposal.
- RO for soluble cyanide uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble cyanide), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- For community surface and groundwater (under the direct influence of surface water) systems, treatment technique is applied. In this case, the accepted TT is the use of chlorine (Cl_2). Inorganic materials, such as cyanide, are oxidized by Cl_2 and converted to more manageable insoluable forms. Cl_2 reacts with organic matter breaking it down to simpler substances. Benefits: proven; reliable. Limitations: product water has objectionable taste; can react to organic compounds to form THMs.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The cyanide remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce cyanide are available.

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. Ion Exchange:

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. Anion 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 cyanide reduction, operation begins with a fully recharged anion resin bed, having enough negatively charged ions to carry out the anion 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 negatively charged ions are released into the water, being substituted or replaced with the cyanide anions in the water (ion exchange). When the resin becomes exhausted of negatively charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the cyanide ions with Cl^- ions. Many different types of anion resins can be used to reduce dissolved cyanide concentrations. The use of IX to reduce concentrations of cyanide will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-cyanide is greater than 1.

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.

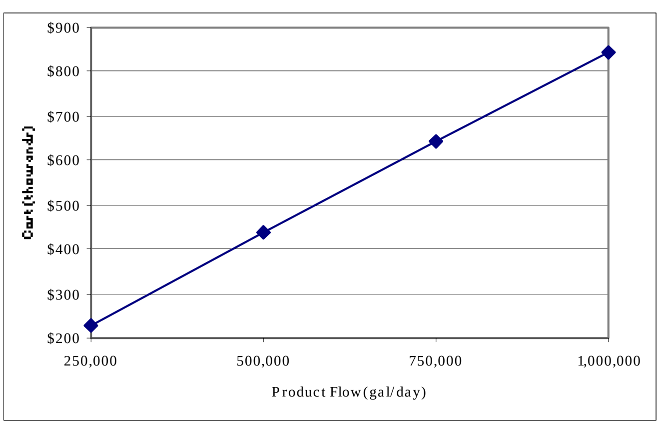
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the cyanide concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline 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.

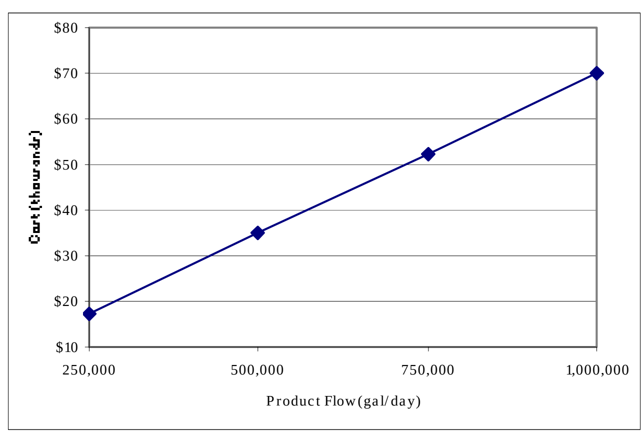
Advantages -
- Acid addition, degasification, and repressurization is not required.
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Strongly basic anion resins are susceptible to organic fouling; reduced life; thermodynamically unstable.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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. 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.

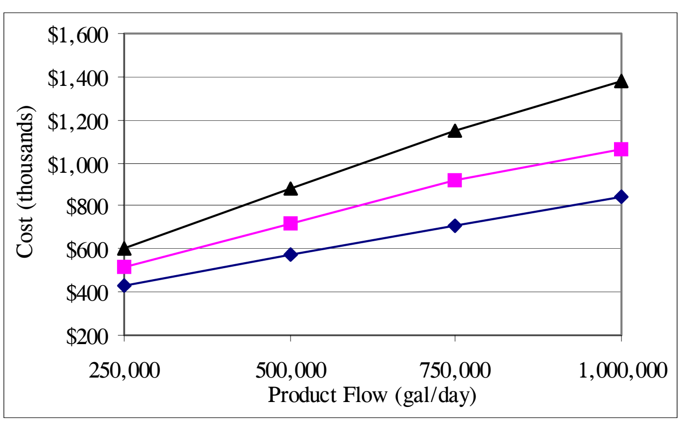
Maintenance - Monitor rejection percentage to ensure cyanide removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are 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.

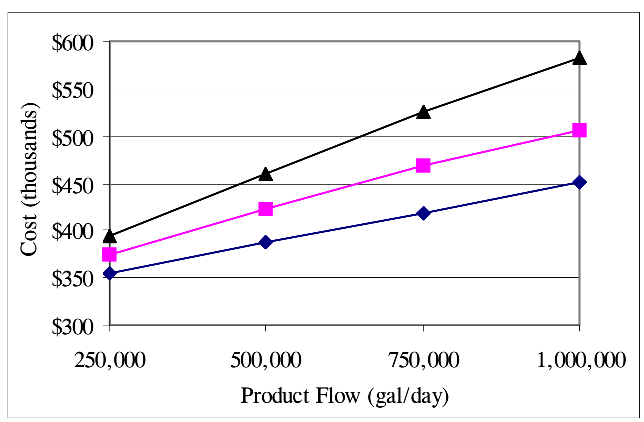
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

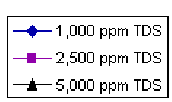
Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for cyanide removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

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.

3C. Chlorine Treatment:

Process - Depending on raw water quality and characteristics, Cl_2 can effectively treat cyanide. In chlorination treatment, Cl_2 is typically injected into the flow stream and reacts with any inorganic materials such as hydrogen sulfide, iron, or manganese, that may exist in the water. Any residual chlorine remaining, that is not reacted, will react with any organic matter present. The feed rate of Cl_2 is adjusted so that enough Cl_2 is available to react fully with the organics present in the water. Upon completion of mineral and organic reactions, any residual Cl_2 remains in the drinking water. Chlorination can be accomplished by using either liquid, tablet, or gaseous Cl_2.

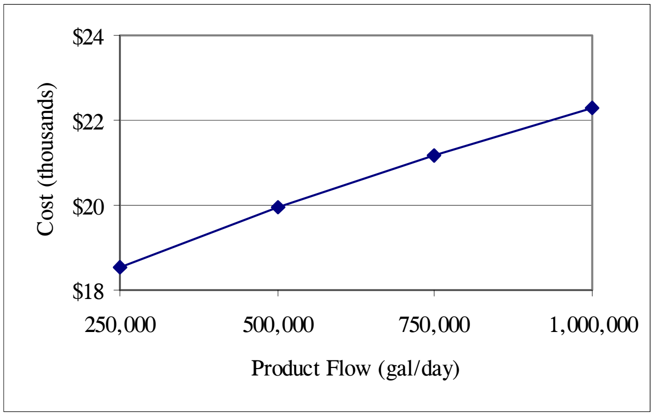
Maintenance - Proper monitoring, operation, and maintenance procedures are essential to ensure the reliability of the treatment processes. Periodic cleaning of metering pump, tubing, injector, and mix tank is recommended.

Waste Disposal - None

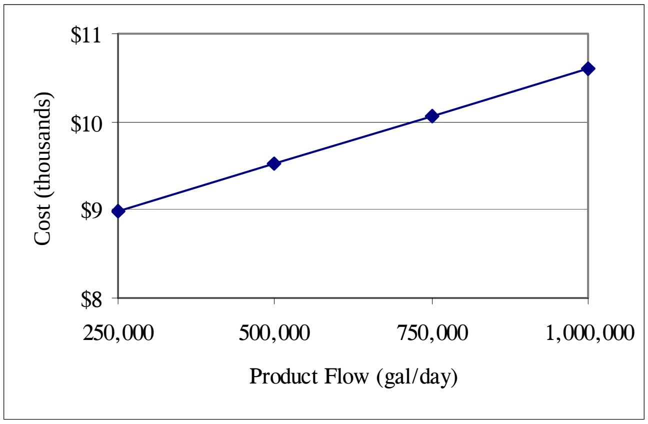
Advantages -
- Well established, conventional treatment process; readily available.
- Reliable, if properly operated and maintained; provides residual disinfectant.
- Suitable for community or on-site systems.

Disadvantages -
- Requires proper Cl_2 contact times; can give a chlorine after-taste and smell.
- Requires careful handling and proper storage of chlorine.
- Cl_2 may combine with organic precursors, natural organic material, to form THMs.

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.

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.

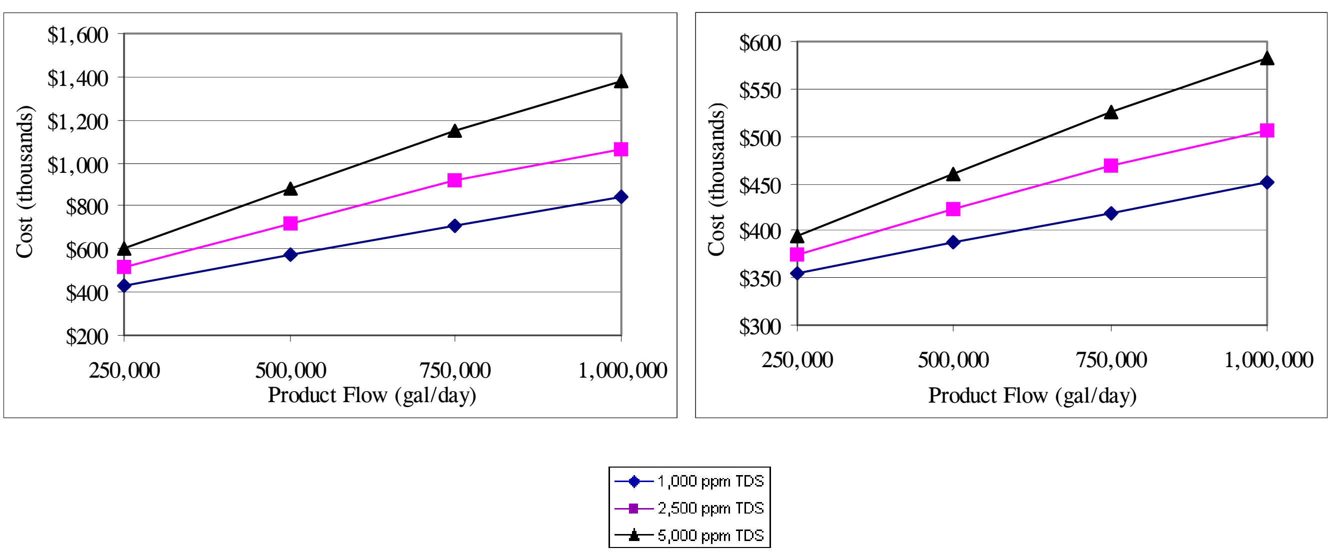
Maintenance - Monitor rejection percentage to ensure F^- removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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°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.

IRON and MANGANESE

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: Iron (Fe), atomic number: 26, atomic weight: 55.847; and Manganese (Mn), atomic number: 25, atomic weight: 54.938. Both minerals are soluble in their reduced state (+2), and insoluble in their oxidized state (+3).

B. Source in Nature: Both minerals are naturally occurring and present in varying quantities in most soils and rocks, and in surface and groundwaters. The ferrous and manganous (+2) soluble ions are present in water and when exposed to the oxygen in air (oxidized) turn into the ferric and manganic (+3) insoluble ions which will precipitate. While the soluble forms are usually colorless, the ferric precipitate is usually reddish-brown, and the manganic precipitate is usually brownish-black. Additionally, Fe can be added to a distribution system by corroded water pipes, and Mn can occur as a result of landfills or other waste disposal which acidifies groundwater and reduces its oxygen content.

C. SDWA Limits: SMCL for Fe is 0.3 mg/L, and 0.05 mg/L for Mn.

D. Health Effects of Contamination: As secondary drinking water contaminants, neither Fe or Mn pose any health risks, and in small concentrations are essential to human health. Higher concentrations will give water a medicinal or metallic taste; are a nuisance and will cause staining problems in laundry and plumbing fixtures; may precipitate and clog distribution piping; or may cause the development of Fe or Mn bacteria, a harmless bacteria that may give water an offensive taste or color but still is safe to drink.

2. REMOVAL TECHNIQUES

A. USEPA BAT: As secondary drinking water contaminants, BATs are not assigned.

B. Alternative Methods of Treatment: The most common treatment process for removing Fe and Mn is oxidation with $KMnO_4$ followed by greensand filtration. Oxidation of Fe^{+2} and Mn^{+2} ions with $KMnO_4$ occurs after a brief retention time, when an insoluble solid particle is formed which can be removed by the greensand filter. Benefits: proven; reliable. Limitations: chemical dosages and metering required.

Alternative oxidation processes include aeration with oxygen, chlorine, ozone, and hydrogen peroxide. Simple aeration may be the most economical, but may not be as effective.

In-home water softeners may be used when centralized treatment is not available, when the combined Fe and Mn concentrations are below 1 mg/L, and when the Fe and Mn are still in their soluble reduced states (+2).

C. Related WTTP Publications: WTTP Report #8, "Lake Havasu City Water Treatment Research Study." This report pilot tested two processes, including $KMnO_4$ oxidation followed by greensand filtration and nanofiltration to remove Mn^{+2}.

D. 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. Oxidation with $KMnO_4$ followed by Greensand Filtration:

Process - Oxidation is a chemical process and filtration is a physical process. $KMnO_4$ is added to the raw water which oxidizes the soluble Fe and Mn into insoluble ferric and manganic oxides which will settle and are filterable. $KMnO_4$ (without prechlorination) is usually used according to the following stoichiometry:

0.94 mg/L $KMnO_4$ per mg/L of Fe^{+2} removed and

1.92 mg/L $KMnO_4$ per mg/L of Mn^{+2} removed.

After the oxidation process is complete, the greensand filter removes the insoluble material. Greensand is a green clay material whose active mineral is glauconite, a natural zeolite with ion exchange properties. Greensand is layered loosely to form the media bed. As water passes through the filter, any remaining soluble Fe and Mn are pulled from the solution by the ion exchange properties of the greensand, and the insoluble Fe and Mn are filtered by the greensand media. Periodically, the greensand media is regenerated by continually feeding $KMnO_4$ just before the filter to recharge the glauconite, regenerating the ion exchange properties. Additionally, periodic backwashing of the filter media to remove the Fe and Mn is required.

Pretreatment - Feeding chlorine ahead of the $KMnO_4$ can make the process more economical. $Ca(OH)_2$ addition may be necessary to achieve the desired pH level or to remove CO_2.

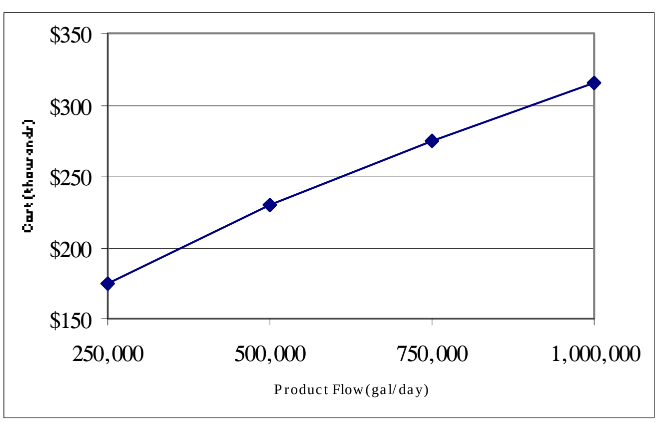
Maintenance - Tests should be conducted at least monthly on samples of the water entering the filter to ensure the Fe and Mn are in their insoluble oxidized states (+3) and to verify $KMnO_4$ dosages. Regeneration and backwashing should be done in accordance with the greensand media manufacturer's recommendations. Perform system pressure and flowrate checks to verify backwashing capabilities. Perform routine maintenance checks of valves, pipes, and pumps.

Waste Disposal - Filter regeneration and backwash waters, and spent media require approved disposal.

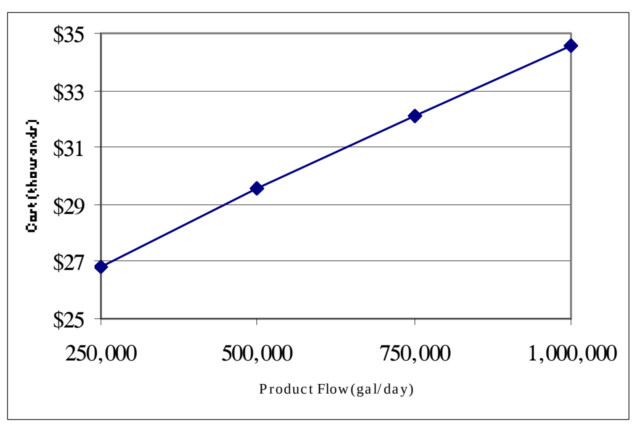
Advantages -
- Low cost.
- Efficient; proven; reliable.

Disadvantages -
- $KMnO_4$ dosage must be exact; bench scale tests are required to determine exact dosage; monitoring of performance to ensure proper dosage.
- Sufficient pressure and flowrate required for backwashing; backwash disposal required.
- Regeneration required; regeneration disposal required.

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.

LEAD

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: Lead (Pb), atomic number: 82, atomic weight: 207.2, most stable oxidation state is +2, is a soft, malleable heavy metal resistant to physical deterioration

B. Source in Nature: Pb is generally not present in source water, but is usually introduced into the water by corrosive water leaching Pb from household plumbing (lead pipe, lead solder, or galvanized pipes). Corrosive (acidic or low pH) and higher temperature waters can dissolve Pb materials within the distribution, plumbing, and wastewater conveyance systems. Pb in the environment is a result of chemical and physical weathering of igneous and metamorphic rocks and soils. Domestic wastewater and industrial effluents can contribute to Pb concentrations in surface (more common) and groundwater.

C. SDWA Limits: TT action level for Pb is 0.015 mg/L.

D. Health Effects of Contamination: Pb has no beneficial effect on humans. Chronic exposure over long periods to even low concentrations of Pb can have severe health effects, especially on infants, children, and pregnant women. Pb is accumulated and stored in the bone. When Pb exposure is so high that the bone become saturated, Pb displaces calcium in the blood effecting the central nervous system. Excessive levels on Pb in the blood contribute to reduced metal and skeletal development, interference with kidney and neurological functions, and hearing loss, especially in children under the age of 6.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Ion exchange, reverse osmosis, lime softening, or coagulation and filtration.

- IX for soluble Pb uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Pb in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.
- RO for soluble Pb uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Pb), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- Lime softening for soluble Pb uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10, keeping the levels of alkalinity relatively low, to precipitate carbonate hardness and heavy metals, like Pb. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Pb compounds may be formed at low carbonate levels requiring coagulation and flocculation.
- Coagulation and filtration for insoluble Pb 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.

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 Pb remains in the boiler section.

Allow tap water to run 3-5 minutes before drawing water for drinking or cooking. Do not use hot tap water for drinking or cooking. Boiling water concentrates Pb. Use bottled water.

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. 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 Pb, 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 Pb 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 Pb^{+2} ions with $2Na^{+}$ ions. Typically, Pb 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 Pb 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 Pb 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.

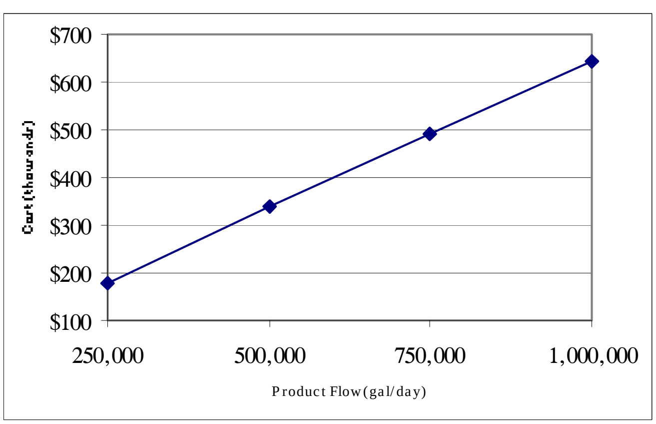
Advantages -

- 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.
- Variety of specific resins are available for removing specific contaminants.

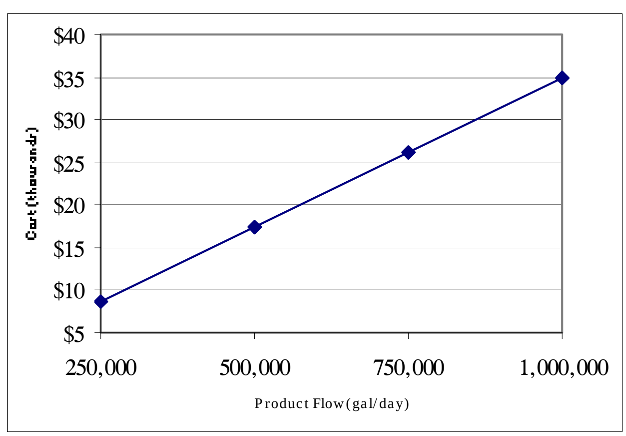
Disadvantages -

- Requires salt storage.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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. 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.

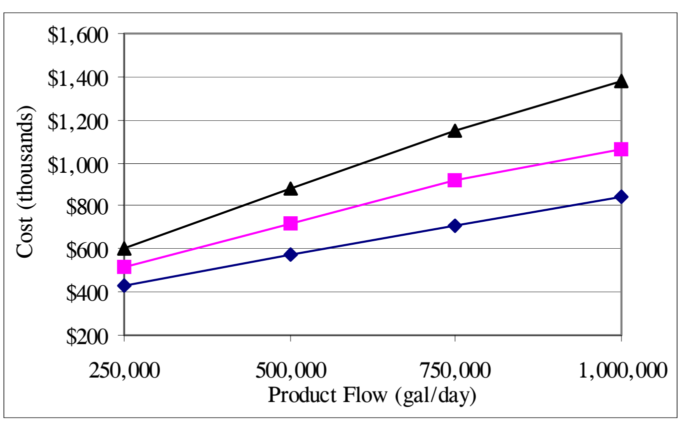
Maintenance - Monitor rejection percentage to ensure Pb removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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.

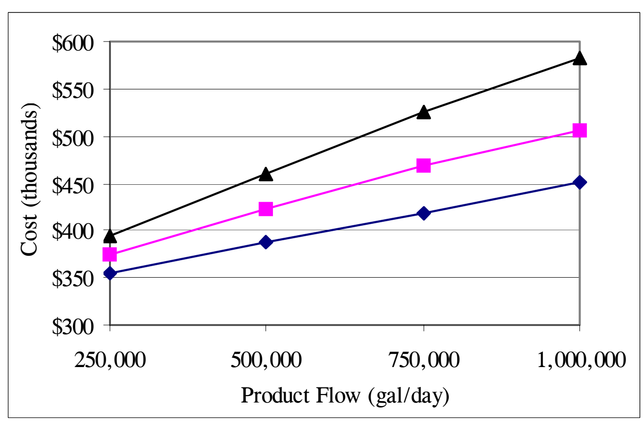
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

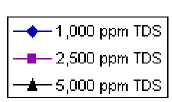
Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Pb removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

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.

3C. 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 Pb, precipitate as $Pb(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Pb, 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 Pb sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Pb 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.

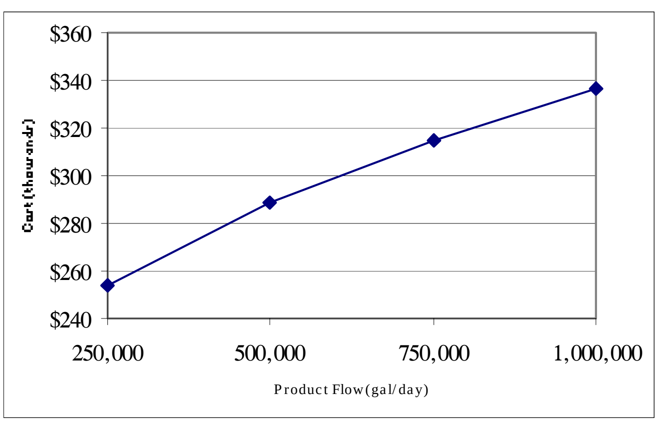
Advantages -

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

Disadvantages -

- Excessive insoluble Pb may be formed requiring coagulation and filtration.
- Operator care required with chemical handling.
- Produces high sludge volume.

BAT Equipment Cost*



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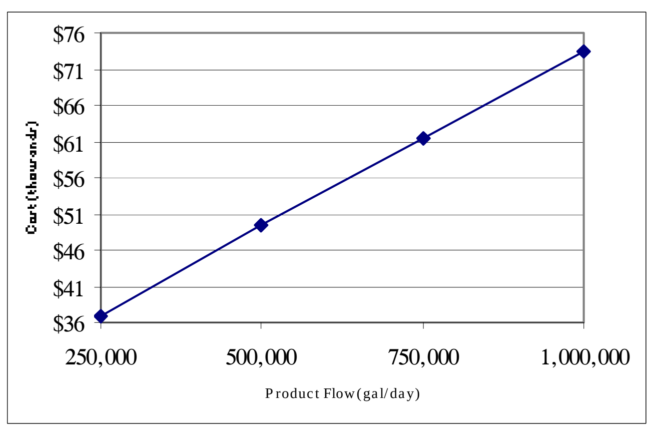


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3D. **Coagulation and Filtration:**

Process - Coagulation and filtration for insoluble Pb 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 Pb removal. Filtration consists of 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.

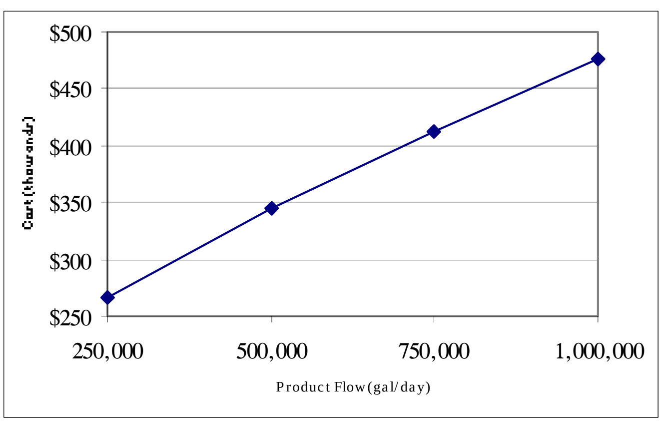
Advantages -

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

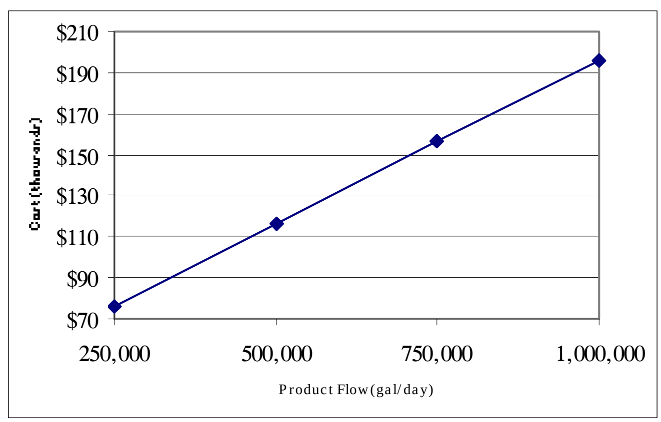
Disadvantages -

- Operator care required with chemical handling.
- Suitable only for insoluble Pb.
- 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.

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.

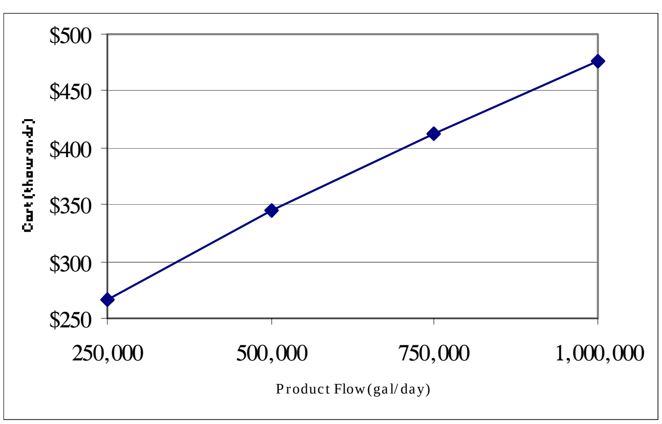
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

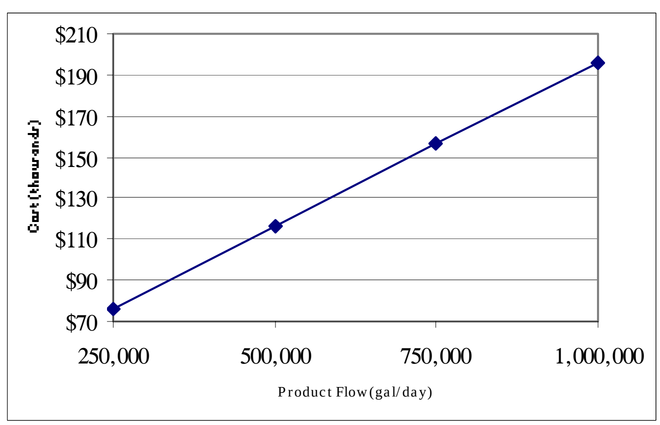
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

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*



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 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.

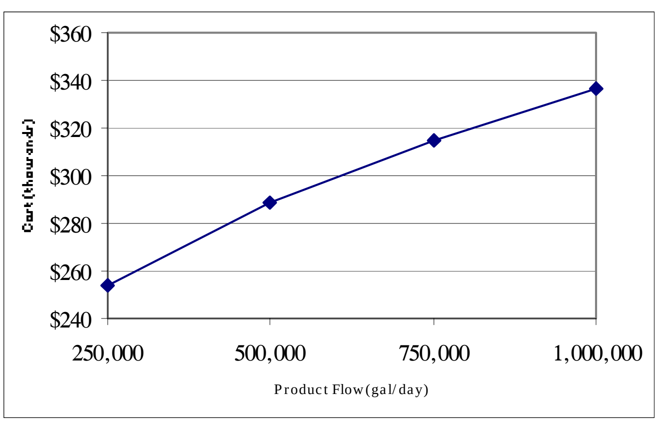
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

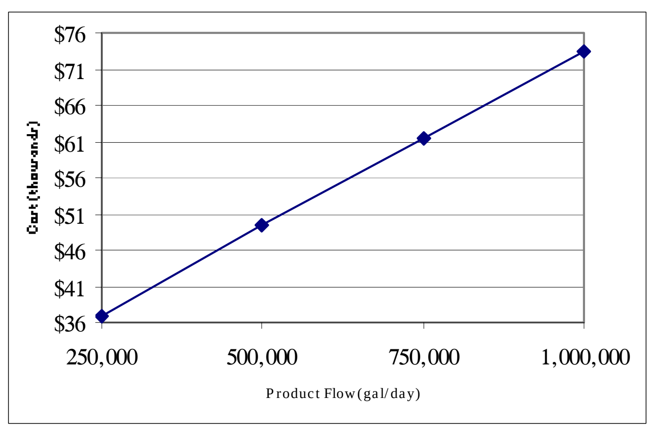
Advantages -
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

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*



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.

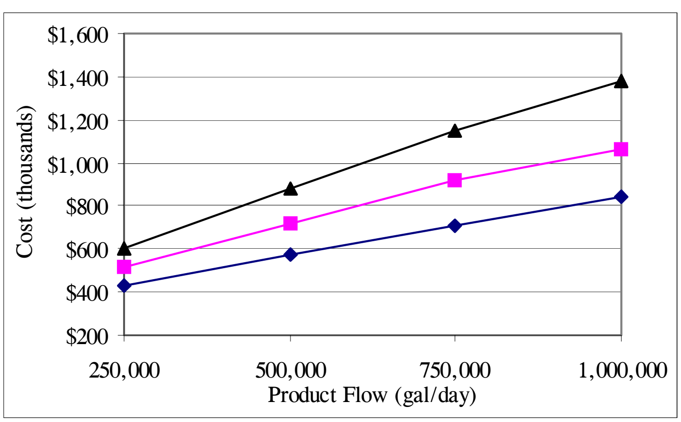
Maintenance - Monitor rejection percentage to ensure Hg and Cd removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions 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.

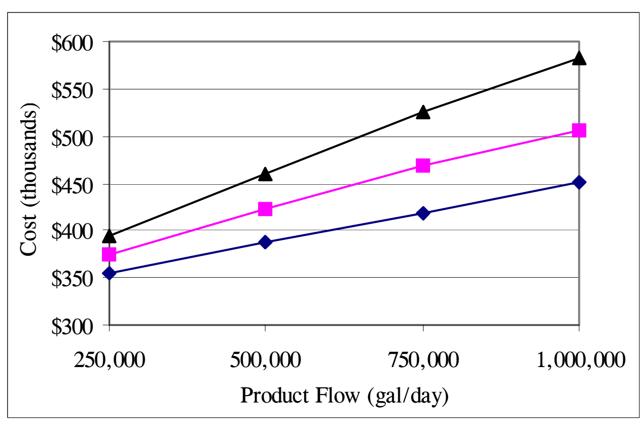
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

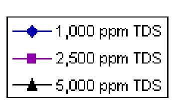
Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Hg and Cd removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

BAT Equipment Cost*



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. 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.

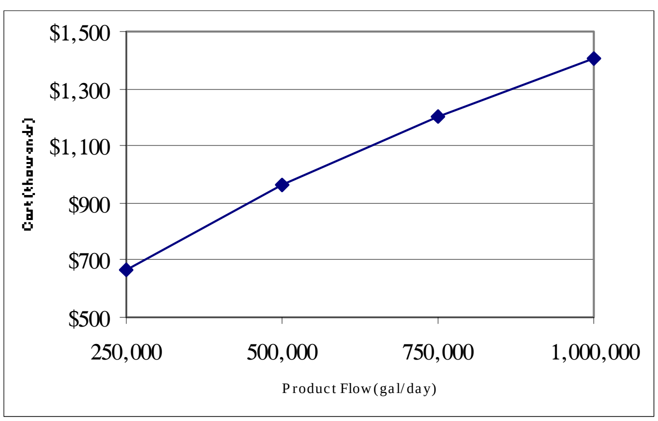
Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used. The manufacturer's recommendations for media replacement should be consulted. 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.

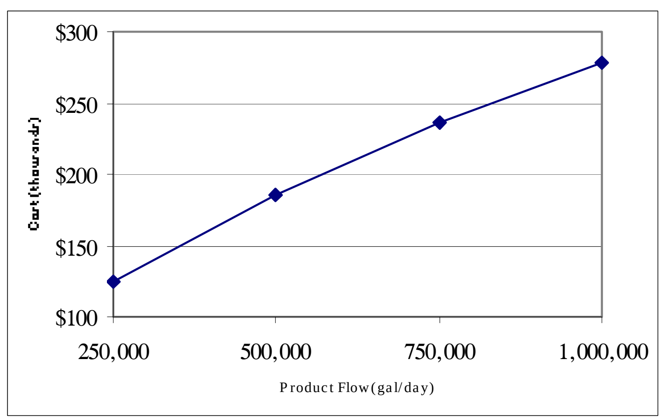
Advantages -
- Well established.
- Suitable for some organic chemicals, some pesticides, and THMs.
- Suitable for home use, typically inexpensive, with simple filter replacement requirements.
- Improves taste and smell; removes chlorine.

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.

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. 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.

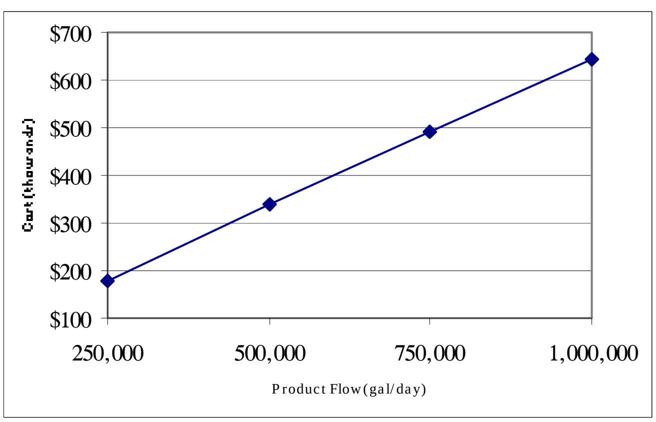
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Cd concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

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.

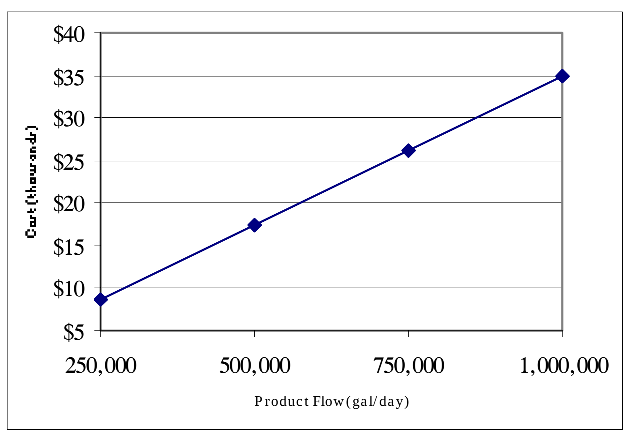
Advantages -
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.

Disadvantages -
- Requires salt storage.

BAT Equipment Cost*



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.

NICKEL

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: Nickel (Ni), atomic number: 28, atomic weight: 58.70, oxidation states: +2, and +3, silvery-white, hard, magnetic, malleable, ductile metallic element. Corrosion resistant and maintains its mechanical and physical characteristics in a wide range of temperatures. Combined with other metals, it forms mixtures called alloys. The most important alloying constituents being iron, chromium, copper, and molybdenum. Most salts of Ni, including Ni chloride, Ni sulfate, and Ni nitrate are soluble in water. Ni and its compounds have no characteristic odor or taste. Ni is one of the transition elements.

B. Source in Nature: Ni is a ubiquitous metal found everywhere. Ni makes up 0.007 percent of the earth's crust and is found in all soils in a combined form. Ni is emitted from volcanos and is a principle metal in meteors. Combined with oxygen (oxides) or sulfur (sulfides) in varying proportions in weathered ore is its more natural form. Ni occurs in several minerals, including pentlandite and pyrrhotite, the principle ores of Ni. Soil borne Ni may enter waters by surface runoff or by percolation into ground water. Ni carbonate, found in the mineral zaratite, is a potential surface water pollutant.

C. SDWA Limits: The MCL/MCLG for Ni were remanded on February 9, 1995. There is currently no EPA legal limit on the amount of Ni in drinking water. EPA is reconsidering the limit on Ni.

D. Health Effects of Contamination: Ni at short-term exposure levels above the MCL has not been found to cause adverse health effects. Long-term exposure at levels above the MCL, Ni can cause weight loss, heart and liver damage, stomachaches, effects to the blood and kidneys, and dermatitis. Exposure with liquids containing Ni may produce Ni sensitivity, causing allergic reactions, when Ni contact is made with the skin. The most common reaction is a skin rash at the site of contact.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Ion exchange, lime softening, or reverse osmosis.

- IX for soluble Ni uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Ni in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.
- Lime softening for soluble Ni uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Ni. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Ni compounds may be formed at low carbonate levels requiring coagulation and flocculation.
- RO for soluble Ni uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Ni), to pass through the membrane. Benefits: produces high quality water. Limitations: high cost; pretreatment/feed pump requirements; concentrate disposal.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Ni remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce Ni are available.

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. 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 Ni reduction, operation begins with a fully recharged cation 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 Ni ions 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 Ni ions with Na or K ions. Many different types of cation resins can be used to reduce dissolved Ni concentrations. The use of IX to reduce concentrations of Ni will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-Ni is greater than 1.

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.

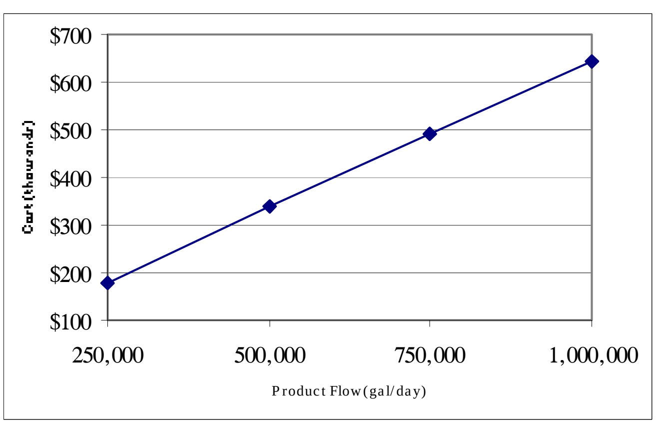
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Ni concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline 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.

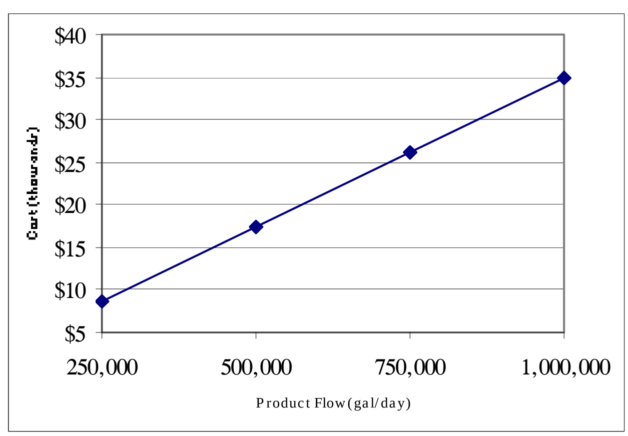
Advantages -
- Acid addition, degasification, and repressurization is not required.
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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. 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 Ni, precipitate as $Ni(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Ni, 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.

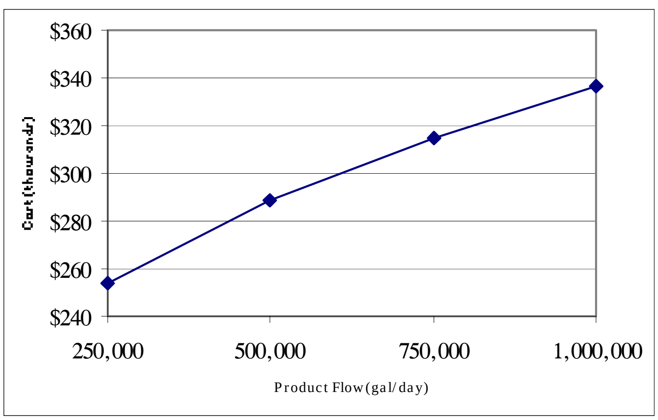
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 Ni sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Ni 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.

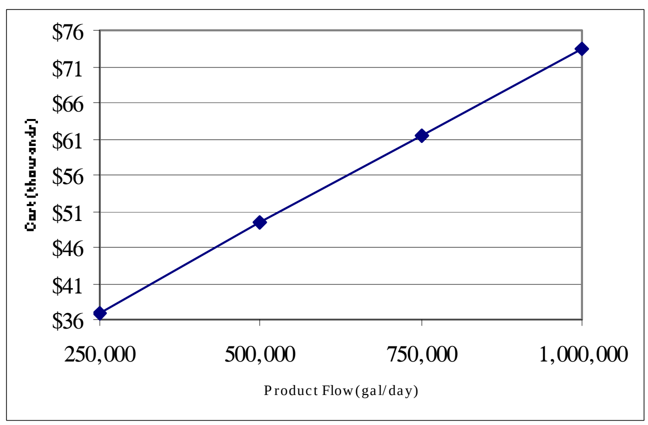
Advantages -
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Excessive insoluble Ni may be formed requiring coagulation and filtration.
- Operator care required with chemical handling.
- Produces high sludge volume.

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.

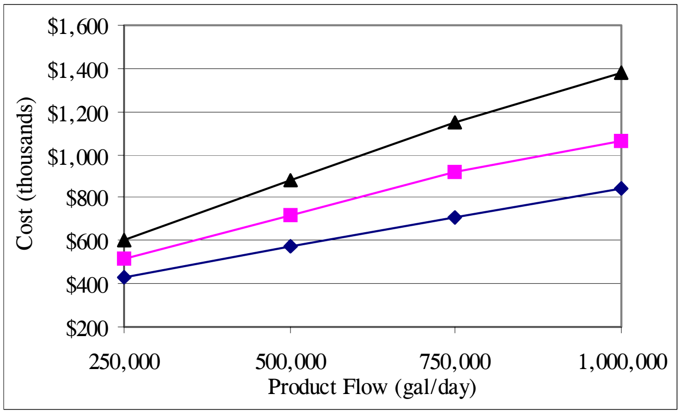
Maintenance - Monitor rejection percentage to ensure Ni removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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.

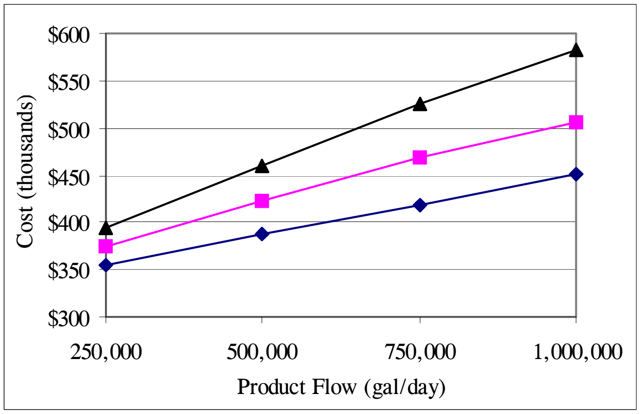
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

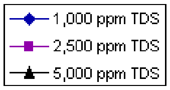
Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Ni removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

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.

NITRATE/NITRITE

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: Nitrate (NO_3^-) and Nitrite (NO_2^-) are inorganic anions. NO_3^- has an oxidation state of elemental nitrogen gas, molecular weight 62.00. NO_3^-/NO_2^- are water-soluble, colorless, odorless, and tasteless. NO_3^- is a macro-nutrient that is an essential part of proteins manufactured by bacteria and algae in water. NO_2^- is a nitrogen-oxygen radical.

B. Source in Nature: Nitrogen is a naturally occurring gas in the earth's atmosphere, at approximately 78% by volume. NO_3^- are naturally occurring nitrogen-oxygen units which combine with various organic and inorganic compounds in both water and plants. Natural sources of NO_3^- in waters include direct fixation of nitrogen gas by algae and bacteria, photochemical fixation, electrical discharge, and oxidation of ammonia and nitrite by nitrifying bacteria. NO_3^- are used by bacteria to form amino acids used in the synthesis of proteins for all plants and animals. Elevated levels of NO_3^- in today's surface and groundwaters are a result of overuse of nutrient-rich chemical fertilizers, municipal and industrial wastewaters, refuse dumps, and improper disposal of human and animal wastes. Both NO_3^- and NO_2^- are added to meat products as preservatives. NO_3^- are reduced to NO_2^- in the saliva of the mouth and upper GI tract.

C. SDWA Limits: MCL for NO_3^- as nitrogen is 10 mg/L (for NO_3^- as Nitrate, the MCL is 45 mg/L). MCL/MCLG for NO_2^- is 1 mg/L.

D. Health Effects of Contamination: The health effects of excessive NO_3^-/NO_2^- include Methemoglobinemia (blue baby syndrome - oxygen deprivation in infants under 6 months), and is generally considered a concern for children under age 5. Older children and adults are generally only susceptible if they also experience enzyme or erythrocyte metabolism deficiency, chronic anemia, or gastric diseases.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Ion exchange, reverse osmosis, or electrodialysis.

- IX uses charged anion resin to exchange acceptable ions from the resin for undesirable NO_3^- in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; competing ions.
- 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 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.

B. Alternative Methods of Treatment: Biological denitrification or chemical reduction; distillation; dilution by blending with higher quality water; or water source relocation. Note: Boiling water concentrates nitrates.

C. Related WTTP Publications:
1) WTTP Report #14, "Brighton ED Testing with Asahi Monovalent Selective Membranes." This report summarizes the pilot testing of an ED water treatment system with special membranes tailored for nitrate removal from water.
2) WTTP Report #15, "Maricopa Groundwater Treatment Study." This report summarizes the field study performed to determine the suitability of several water treatment processes, including RO, ED, and NF, on groundwater containing high levels of nitrate, chloride, and TDS; recommends the use of NF or ED for study area.

D. 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.

Bureau of Reclamation, Technical Service Center
Water Treatment Engineering and Research Group, D-8230
PO Box 25007, Denver CO 80225 (303) 445-2260
Revision Date: 9/21/01

3A. Ion Exchange:

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. Anion 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 NO_3^-/NO_2^-, operation begins with a fully recharged resin bed, having enough Cl^- or OH^- ions to carry out the anion exchange. Usually polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the Cl^- or OH^- anions are released into the water, being substituted or replaced with NO_3^- /NO_2^- anions (ion exchange). When the resin becomes exhausted of Cl^- or OH^- ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the NO_3^-/NO_2^- ions with Cl^- ions. Current resins are not completely NO_3^-/NO_2^- selective and may remove other anions, such as SO_4^{-2}, before removing the nitrate compounds. Therefore, NO_3^-/NO_2^- ion exchange requires careful consideration of the complete raw water characteristics. Typically, NO_3^- /NO_2^- ion exchange utilizes a Cl^- or OH^-, strongly basic anion 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.

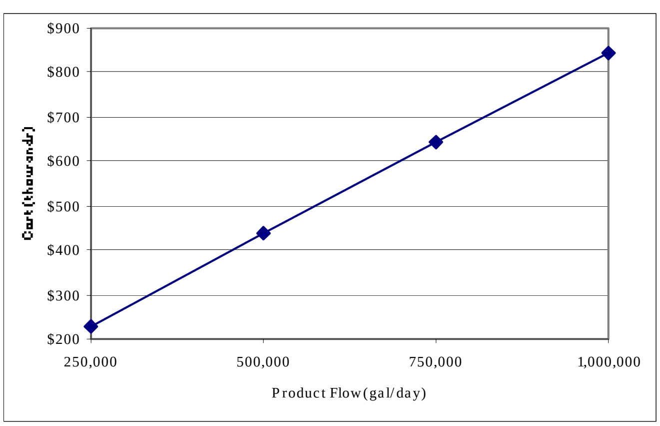
Maintenance - Depending on raw water characteristics and NO_3^-/NO_2^- concentration, the resin will require regular regeneration with a NaCl solution. Preparation of the NaCl solution is required. Frequent monitoring is required to ensure nitrate removal. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated NO_3^-/NO_2^- 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.

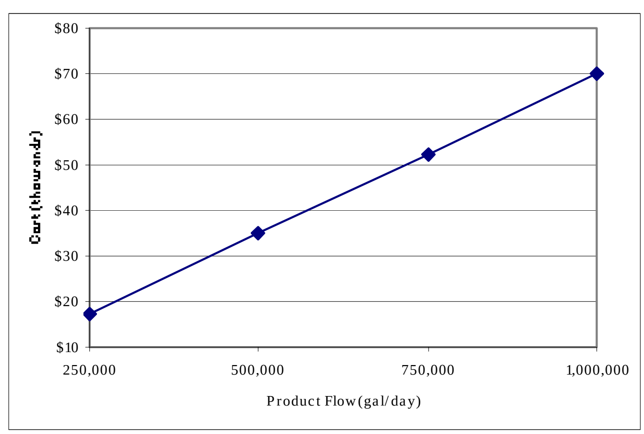
Advantages -
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.

Disadvantages -
- Does not completely eliminate all NO_3^-/NO_2^-.
- Requires frequent monitoring for nitrate removal.
- Requires salt storage.
- Strongly basic anion resins are susceptible to organic fouling; reduced life; thermodynamically unstable.

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. 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.

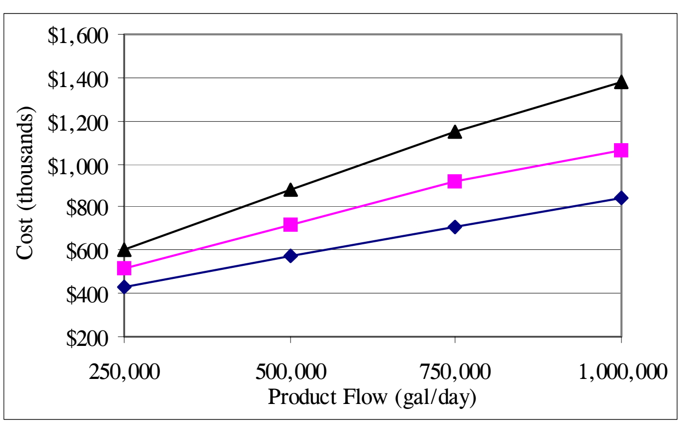
Maintenance - Monitor rejection percentage to ensure NO_3^-/NO_2^- removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions 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.

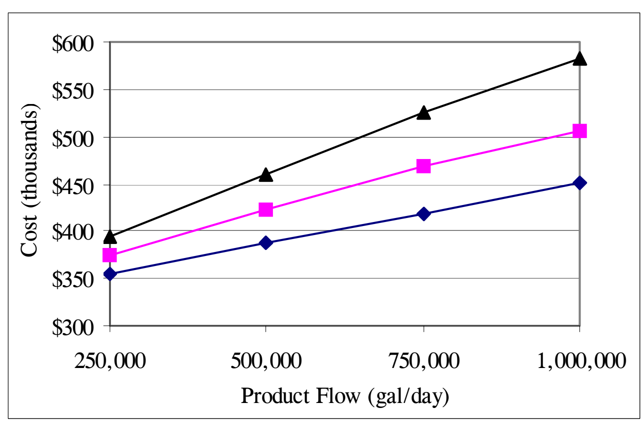
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

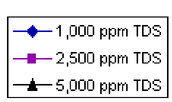
Disadvantages -
- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for NO_3^-/NO_2^- removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

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.

3C. Electrodialysis Reversal:

Process - EDR is an electrochemical process in which ions migrate through an ion-selective semipermeable membrane as a result of their attraction to the electrically charged membrane surface. A positive electrode (cathode) and a negative electrode (anode) are used to charge the membrane surfaces and to separate contaminant molecules into ions. The process relies on the fact that electrical charges are attracted to opposite poles. As a result of the removal process, reduction in ions (or TDS) is obtained. A common EDR system includes a membrane stack which layers several 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 prevent 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. EDR uses the technique of regularly reversing the polarity of the electrodes, thereby freeing accumulated ions for cleaning. 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.

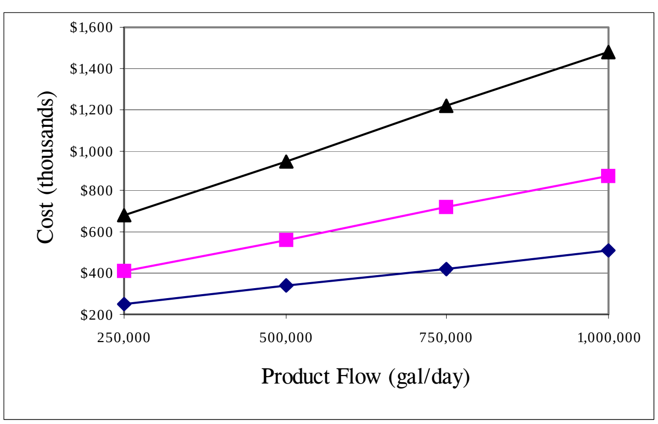
Maintenance - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode reaction. The byproducts are hydrogen, formed in the cathode spacer, 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 NO_3^-/NO_2^- concentration, the membranes will require regular maintenance or replacement. EDR requires system flushes at high volume/low pressure; EDR backwashing will be required.

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

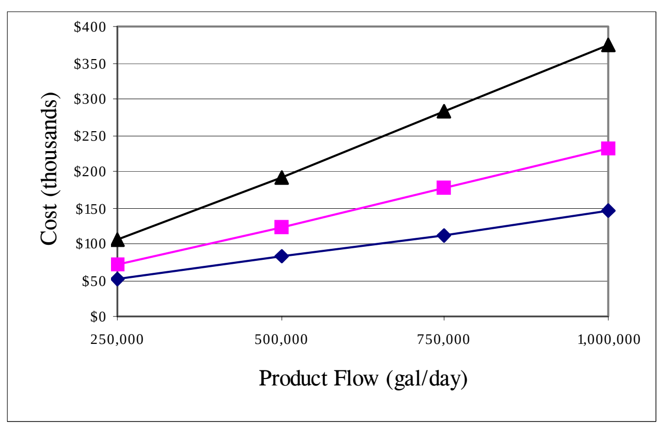
Advantages -
- EDR can operate without fouling or scaling, or chemical addition; suitable for higher TDS sources.
- Low pressure requirements; typically quieter than RO.
- Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

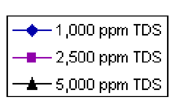
Disadvantages -
- EDR can operate without fouling or scaling, or chemical addition; suitable for higher TDS sources.
- Not suitable for high levels of Fe and Mn, H_2S, chlorine, or hardness.
- Limited current density; current leakage; back diffusion.
- At 50% rejection of TDS per pass, process is limited 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.

ORGANICS

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: Organics is a term often used to describe any and all compounds, natural or man-made, which chemical structures are based in carbon. Natural organics include matter derived from a living organism, plant or animal, and occur as a result of byproducts or biodegradation of plant and animal matter. Man-made organic substances are called synthetic organic chemicals (SOC) and are synthesized from carbon and other elements such as hydrogen, nitrogen, and chlorine. SOCs commonly include the complete range of pesticides, various industrial chemicals and solvents, and household products. SOCs which are capable of vaporizing at relatively low temperatures are called volatile organic chemicals (VOCs). SOCs vary in water solubility and may not necessarily result in odor, color, or taste changes. SOCs are the subject of this Fact Sheet. Section 4 of this Fact Sheet lists the regulated SOCs along with the MCLs and BATs.

B. Source in Nature: SOCs in groundwater and surface water occur as a result of widespread use of pesticides (herbicide, fungicide, insecticide, bactericide, etc.); use of industrial chemicals and solvents (petroleum, detergents, etc.) in industry, manufacturing, agriculture, and around the home; and manufacture and disposal of modern products (styrofoam, plastics, cleaning compounds, paints, fire retardants, hair spray, etc.). SOCs occur both intentionally (pesticide application or manufacturing and industrial drainage) and accidentally (leaking USTs, chemical spills, backflow, or boating operations). SOC contamination also occurs as a result of leaching from industrial waste dumps/municipal landfills and storm runoff from urban areas. SOCs which leach into groundwater are a particular concern because the lack of light, heat, and oxygen retard chemical breakdown and dilution is less likely.

C. SDWA Limits: Refer to Section 4 for contaminant specific MCLs.

D. Health Effects of Contamination: Health effects vary based on contaminant toxicity level; contaminant concentration in the water; amount of water consumed or exposed to; contaminant absorption efficiency; and age, weight, and health of person exposed. Health effects can range from minor to severe, and acute or chronic. Some minor effects can include: nausea; vomiting; dizziness; drowsiness; lung/mucous membrane irritation; or skin rash. Some severe effects can include: cancer; vital organ damage; birth defects; nervous system disorders; and immune system damage. Contaminants are metabolically broken down (detoxified), excreted (urine, feces, exhaled, or sweat), or accumulated by the body. Those contaminants which accumulate in the body fat or tissue of fish, birds, or animals may be passed on through the food chain. Exposure routes include direct ingestion, respiratory inhalation, and skin absorption.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Granular activated carbon or packed tower aeration (air stripping). (Glyphosate, Acrylamide, Epichlorohydrin, and THMs are exceptions, requiring alternate treatments and are not discussed in this Fact Sheet.) Refer to Section 4 for contaminant specific BAT. Consult with the equipment manufacturer and specifications to ensure the contaminant present will be removed.

- 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.
- Packed tower ASs use a tower filled with packing material, whereby water enters the top of the tower, is sprayed over the packing material exposing a thin layer of water to countercurrent air being blown in at the bottom. The process allows for mass transfer of the VOCs from water into air. AS off-gas is either discharged to the atmosphere or treated by vapor phase GAC. Benefits: well established; best suited for VOCs and large installations. Limitations: requires ample space; requires careful monitoring. GAC cost curves will be included in a future revision.

B. Alternative Methods of Treatment: Alternative AS types are available including countercurrent plate. Alternative treatment methods include carbon filtration, ultraviolet radiation, RO, ED, NF, and diatomaceous earth filtration.

C. Safety and Health Requirements for Treatment Processes: General industry safety, health, and self protection practices for process equipment should be followed, including proper use of chemicals and tools. When dealing with waterborne diseases, take precautions to prevent infection through open cuts/wounds, or illnesses from ingestion. Wear PPE and wash hands thoroughly.

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. 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; 4) the temperature and pH of the water, adsorption usually increases as temperature and pH decrease; 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. 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 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. 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 spent media may be offered by the contractor providing the media replacement services.

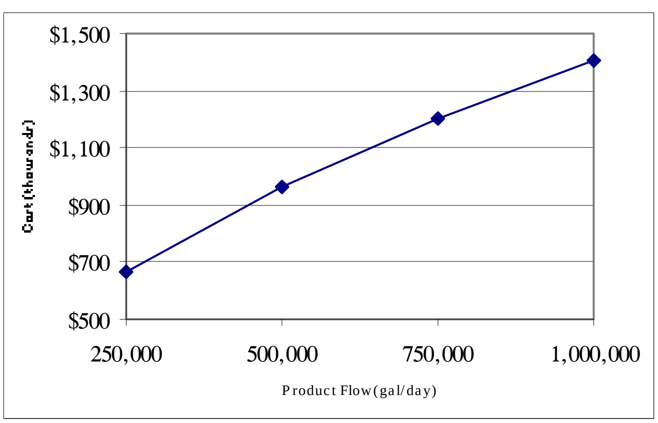
Advantages -

- 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.

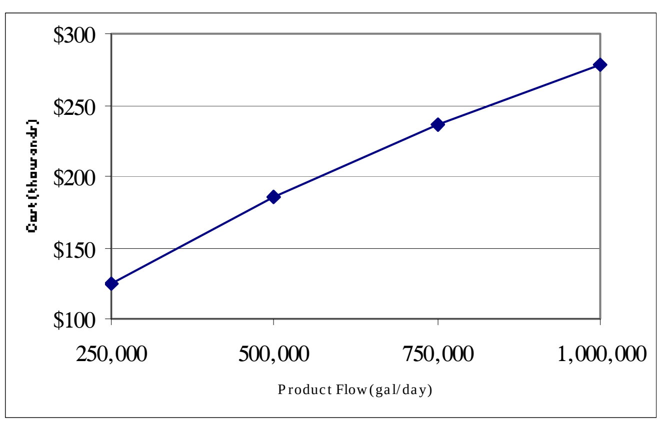
Disadvantages -

- 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.

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. Air Stripping:

Process - AS is a physical separation process. Packed tower AS may use a tall, cylindrical tower filled with packing material. Water enters the top of the tower and is sprayed over the packing material exposing a thin layer of water to the countercurrent air being blown in at the bottom of the tower. The process maximizes the surface area of the water and allows for mass transfer of the VOCs from water into air. Maximum volatilization occurs when the water is evenly distributed and the countercurrent air is evenly applied, even when a load change occurs. Treated water exits the bottom of the tower, while air containing the volatilized contaminants is vented to atmosphere or treated by vapor phase GAC. Air emissions above Clean Air Act standards must be treated prior to release. A variety of packing materials are available, or plastic elements may be used in place of packing material. Auxiliary equipment can include: automated controls and level switches or safety features such as differential pressure monitors. Alternate types of ASs include: aeration tanks, spray aeration, shallow trays, columns filled with chemical resistant ellipsoids, or cascade-type internal components.

Vapor phase GAC is similar to liquid phase GAC. It uses extremely porous carbon media in a process known as adsorption. As air passes through the highly porous media which has an extremely high surface area for adsorption, the volatilized contaminants adsorb on the solid surface. The treated air is discharged directly to the atmosphere. Careful selection of type of carbon to be used is based on the contaminants in the air, and manufacturer's recommendations.

Pretreatment - Chlorination and dechlorination for routine cleaning of scale, slime, and clogging may be required. With high TDS waters, prefiltration may be required.

Posttreatment - Postdisinfection of AS effluent may be required. Polishing of AS off-gas and air discharge monitoring equipment may be required.

Maintenance - Careful monitoring and testing to ensure contaminant removal. Packed tower ASs are subject to chemical/physical scaling of the equipment as a result of hardness or sliming of the packing material due biological growth. Regular replacement of vapor phase carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used.

Waste Disposal - Waste products (i.e. spent filters and cleaning solutions) require disposal in accordance with local, state, or Federal regulations.

Advantages -
- Well established.
- Effective, with removal efficiencies at 99% and greater.
- Best suited for VOCs and large installations.
- Packed towers are more effective, but tray configurations are less susceptible to fouling and are easier to clean.

Disadvantages -
- Requires design by knowledgeable, experienced individual with specifics on water flow rate, air-to-water ratio, influent concentrations, water temperature, and atmospheric pressure. Design is based on Henry's Law Constant, which describes the relation between the distribution of a substance in the liquid and the gas phases where ideal conditions exist. Computer programs are available to assist with modeling, and most manufacturer's have programs for modeling their specific equipment.
- Requires careful monitoring.
- Potential for inorganic/biological scaling, sliming, or clogging.
- Low volatility contaminants may require preheating; off-gas may require treatment.

Costs - The application of AS is extremely site specific. The costs of the equipment and operation and maintenance are based on the site specific organics and concentrations. Because the organics and concentrations vary greatly from location to location, a typical raw water analysis on which to base generic costs is impractical. For these reasons generic costs are not provided.

4. SOCs LIMITS AND BAT

CONTAMINANT	MCL (mg/L)	BAT
VOCs:		
Benzene	0.005	GAC, AS
Carbon Tetrachloride	0.005	GAC, AS
Dichlorobenzene (p-)	0.075	GAC, AS
Dichlorobenzene (o-)	0.6	GAC, AS
Dichloroethane (1,2-)	0.005	GAC, AS
Dichloroethylene (1,1-)	0.007	GAC, AS
Dichloroethylene (cis-1,2-)	0.07	GAC, AS
Dichloroethylene (trans-1,2-)	0.1	GAC, AS
Dichloromethane	0.005	AS
Dichloropropane (1,2-)	0.005	GAC, AS
Ethyl Benzene	0.7	GAC, AS
Monochlorobenzene	0.1	GAC, AS
Styrene	0.1	GAC, AS
Tetrachloroethylene	0.005	GAC, AS
Toluene	1	GAC, AS
Trichloroethane (1,1,1-)	0.2	GAC, AS
Trichloroethane (1,1,2-)	0.005	GAC, AS
Trichloroethene (TCE)	0.005	GAC, AS
Trichlorobenzene (1,2,4-)	0.07	GAC, AS
Vinyl Chloride	0.002	AS
Xylenes (Total)	10	GAC, AS
Pesticides/PCBs:		
Alachlor	0.002	GAC
Atrazine	0.003	GAC
Carbofuran	0.04	GAC
Chlordane	0.002	GAC
2,4-D	0.07	GAC
Dalapon	0.2	GAC
1,2-Dibromo-3-Chloropropane (DBCP)	0.0002	GAC, AS
Dinoseb	0.007	GAC
Diquat	0.02	GAC
Endothall	0.1	GAC
Endrin	0.002	GAC
Ethylenedibromide (EDB)	0.00005	GAC, AS
Glyphosate	0.7	Oxidation (chlorine or ozone)
Heptachlor	0.0004	GAC
Heptachlor Epoxide	0.0002	GAC
Lindane	0.0002	GAC
Methoxychlor	0.04	GAC
Oxamyl (Vydate)	0.2	GAC
Picloram	0.5	GAC
Polychlorinated byphenols (PCBs)	0.0005	GAC
Pentachlorophenol	0.001	GAC
Simazine	0.004	GAC
Toxaphene	0.003	GAC
2,4,5-TP (Silvex)	0.05	GAC
Other Organic Chemicals:		
Acrylamide	none set	TT with polymer
Benzo(a)pyrene (PAH)	0.0002	GAC
Di(2-ethylhexyl)adipate	0.4	GAC, AS
Di(2-ethylhexy)phthalate	0.006	GAC
Epichlorohydrin	none set	TT with polymer
Hexachlorobenzene	0.001	GAC
2,3,7,8-TCDD (Dioxin)	0.00003	GAC
THMs (Chloroform, Bromoform, Bromodichloromethane, Dibromochloromethane)	0.1	Chloramines, Chlorine Dioxide, improved clarification for THM precursor reduction, moving chlorination point to reduce TTHM, or powdered activated carbon.

The SDWA regulates contaminants in community water supply systems, therefore contamination is more likely to go undetected and untreated in unregulated private water systems.

RADIONUCLIDES

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: Radioactive elements are often called radioactive isotopes or radionuclides. Radionuclides emit radiant atomic energy caused by the spontaneous disintegration of the nuclei of their atoms, resulting in radioactive particles or decay products that are members of the radioactive elements. As radionuclides decay, they emit ionizing radiation in the form of alpha (α) or beta (β) particles and gamma (γ) photons. Alpha particles are relatively massive and easy to stop. They typically travel 100 μm into tissue while beta particles may travel several centimeters. Gamma rays, having no charge or mass, are simply a form of electromagnetic radiation, that travel at the speed of light. Gamma rays have short wavelengths and therefore are capable of causing ionizations; as such they are biologically damaging. Generally, the soluble radionuclides of concern in water include: Radon (Rn), atomic number 86, atomic weight 222, a gas; Uranium (U), atomic number 92, atomic weight 238.03, a metal; and combined Radium-226/228 (Radium (Ra), atomic number 88, atomic weight 226.03, a metal). The three forms of radioactivity, α, β, and γ are also a concern.

B. Source in Nature: Radionuclides are both natural and man-made and are found in air, water, soil, plants, and the human body. Rn gas is especially widespread in soils, rocks, and granite, and is created by the decay of the U and Ra series. Several small sources of radiation exist in the home and persons in many occupations encounter radiation. Medical uses for radiation include therapy and diagnosis. This Fact Sheet is concerned with the soluble natural radionuclides found in water. Radionuclides in water are ingested by either drinking contaminated water or eating food that has been washed in the water. In the case of Rn, exposure occurs from inhalation of the gas or decay products released from water during household use. Higher levels of Rn are generally found in groundwater rather than surface water.

C. SDWA Limits (currently under review): Current or proposed limits include: Rn=300 pCi/L; U=0.02 pCi/L; Alpha Emitters (including Radium-226 but excluding Rn and U)=15 pCi/L; Beta/Photon Emitters=4 mrem/yr; and combined Radium-226/228=5 pCi/L. When finalized, the Radionuclide Rule will exclude Rn and U, which will have their own individual standards.

USEPA is scheduled to propose revised standard for Rn by 8/1/1999 and promulgate final rule by 8/1/2001; and promulgate final rules for U and the complete Radionuclides Rule by 8/1/2000.

D. Health Effects of Contamination: Radionuclides are known human carcinogens. All three forms of radiation are dangerous to living things. Rn is associated with lung cancer; Radium-226 is associated with bone sarcomas and head carcinomas; and Radium-228 is associated with bone sarcomas. Other health effects include kidney damage and birth defects. Low level exposures can cause somatic and/or genetic defects. Somatic defects may include a higher risk of cancer, sterility, cataracts, or reduced life span. Genetic defects may include chromosome damage.

Protection against the three forms of radiation differ significantly. Our skin is sufficient protection for α emitters external to the body, however taken internally, such as inhalation, α particles can be extremely dangerous. Beta particles can be stopped with shielding (i.e. 1 cm of aluminum). Gamma rays may require several centimeters of lead to provide adequate shielding.

2. REMOVAL TECHNIQUES

A. USEPA BAT (currently under review):

BAT / Radionuclide	AS	GAC	IX	RO	Lime softening	Coagulation & filtration
Rn	X	X				
U			anion	X	X	X
α				X		
β			mixed bed	X		
Ra			cation	X	X	

- AS use towers filled with material, whereby water enters the top of the tower, is sprayed over the material exposing a thin layer of water to countercurrent air being blown in at the bottom. The process allows for mass transfer of the Rn from water into air. AS off-gas is either discharged to the atmosphere or treated by vapor phase GAC. Benefits: removal efficiencies greater than 99.9%; best suited large installations. Limitations: risks associated with off-gassed Rn; requires ample space; requires careful monitoring.

- 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: too expensive for large systems; less effective than aeration; requires careful monitoring. GAC cost curves will be included in a future revision.

- IX uses selectively charged resins to exchange acceptable ions from the resin for radionuclides in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.

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

- Lime softening uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Ra. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal.

- Coagulation and filtration uses the conventional treatment 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.

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 dissolved solids (radionuclides) remain in the boiler section. Distillation is not effective for Rn gas.

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. Air Stripping for Rn Removal:

Process - AS is a physical separation process. Packed tower AS may use a tall, cylindrical tower filled with packing material. Water enters the top of the tower and is sprayed over the packing material exposing a thin layer of water to the countercurrent air being blown in at the bottom of the tower. The process maximizes the surface area of the water and allows for mass transfer of the Rn from water into air. Maximum volatilization occurs when the water is evenly distributed and the countercurrent air is evenly applied, even when a load change occurs. Treated water exits the bottom of the tower, while air containing the volatilized contaminants is vented to atmosphere or treated by vapor phase GAC. Air emissions above Clean Air Act standards must be treated prior to release. A variety of packing materials are available, or plastic elements may be used in place of packing material. Auxiliary equipment can include: automated controls and level switches or safety features such as differential pressure monitors. Alternate types of ASs include: aeration tanks, spray aeration, shallow trays, columns filled with chemical resistant ellipsoids, or cascade-type internal components.

Vapor phase GAC is similar to liquid phase GAC. It uses extremely porous carbon media in a process known as adsorption. As air passes through the highly porous media which has an extremely high surface area for adsorption, the volatilized contaminants adsorb on the solid surface. The treated air is discharged directly to the atmosphere. Careful selection of type of carbon to be used is based on the contaminants in the air, and manufacturer's recommendations.

Pretreatment - Chlorination and dechlorination for routine cleaning of scale, slime, and clogging may be required. With high TSS waters, prefiltration may be required.

Posttreatment - Postdisinfection of AS effluent may be required. Polishing of AS off-gas may be required.

Maintenance - Careful monitoring and testing to ensure contaminant removal. Packed tower ASs are subject to chemical/physical scaling of the equipment as a result of hardness or sliming of the packing material due biological growth. Regular replacement of vapor phase carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. GAC and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. Costs associated with waste disposal should be considered significant.

Advantages -
- Well established.
- Rn readily escapes from water into air.
- Low air/water ratios are sufficient which leads to lower O&M requirements and costs.
- Packed towers are more effective, but tray configurations are less susceptible to fouling and are easier to clean.

Disadvantages -
- Requires design by knowledgeable, experienced individual with specifics on water flow rate, air-to-water ratio, influent concentrations, water temperature, and atmospheric pressure. Design is based on Henry's Law Constant, which describes the relation between the distribution of a substance in the liquid and the gas phases where ideal conditions exist. Computer programs are available to assist with modeling, and most manufacturer's have programs for modeling their specific equipment.
- Risks associated with the off-gassed Rn.
- Fouling potential from the precipitation of Mn and Fe oxides.
- Risks of increases of Pb and Cu in some tap water due to increases in corrosivity of treated water.

Costs - The application of AS is extremely site specific. The costs of the equipment and operation and maintenance are based on the site specific organics and Rn concentrations. Because the organics and Rn concentrations vary greatly from location to location, a typical raw water analysis on which to base generic costs is impractical. For these reasons generic costs are not provided.

3B. Granular Activated Carbon for Rn Removal:
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; 4) the temperature and pH of the water, adsorption usually increases as temperature and pH decrease; 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.

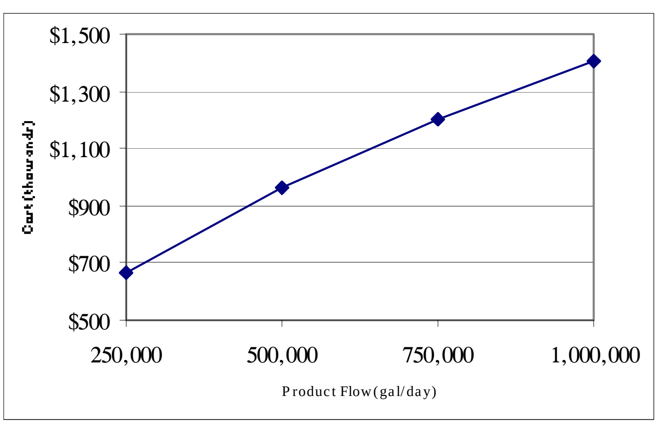
Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used. The manufacturer's recommendations for media replacement should be consulted. Recharging by backwashing or flushing with hot water (145°F) may release the adsorbed Rn gas and any organic chemicals. 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 - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. GAC, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant. Disposal of spent GAC may be offered by the contractor providing the media replacement services.

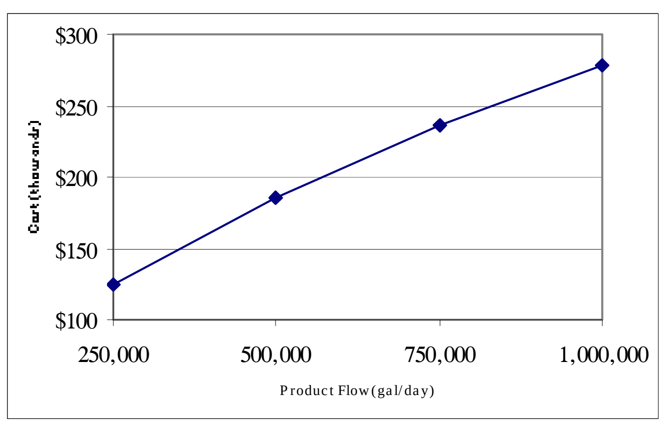
Advantages -
- Well established.
- Suitable for small systems, or even home use, providing disposal of spent carbon can be addressed.
- Typically inexpensive, with simple filter replacement requirements.
- Improves taste and smell; removes chlorine.

Disadvantages -
- Too expensive for large systems.
- Susceptible to sudden removal-efficiency drop-offs.
- Bacteria may grow on carbon surface.
- Adequate water flow and pressure required for backwashing/flushing.
- Requires careful monitoring and disposal of spent carbon.
- Less effective than aeration.

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-a. Anion Ion Exchange for U Removal:

Process - Anion 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. IX operation for U removal begins with a fully recharged resin bed, having enough Cl^- or OH^- ions to carry out the anion 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 negatively charged Cl^- or OH^- ions are released into the water, being substituted or replaced with the soluble, negatively charged U compounds in the water (ion exchange). When the resin becomes exhausted of Cl^- ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the negatively charged U compounds with Cl^- ions. Current resins are not compound selective and may remove other anions before removing negatively charged U compounds. Therefore IX requires careful consideration of the raw water characteristics. Typically, IX for negatively charged U compounds utilizes a Cl^- or OH^- strongly basic anion 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.

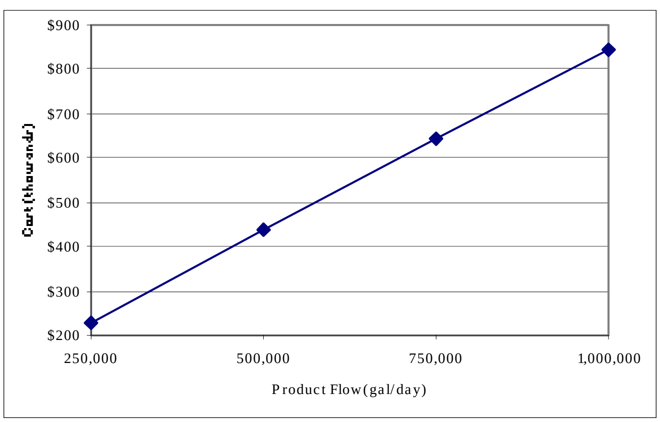
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the U concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. resin, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

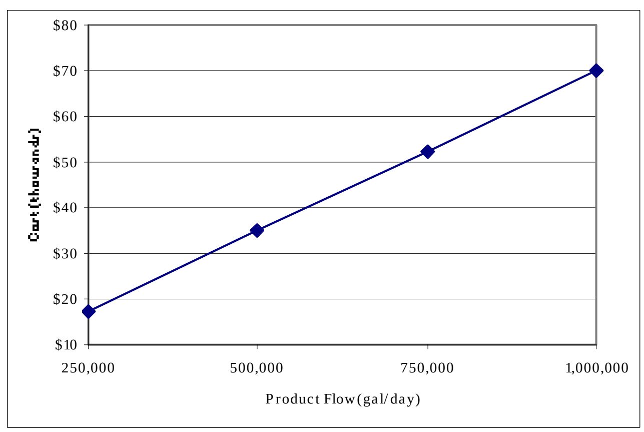
Advantages -
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Requires salt storage.
- Strongly basic anion resins are susceptible to organic fouling; reduced life; thermodynamically unstable.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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-b. Cation Ion Exchange for Ra Removal:

Process - 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. IX operation for Ra removal begins with a fully recharged resin bed, having enough Na^+ or K^+ 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 negatively charged Na^+ ions are released into the water, being substituted or replaced with the soluble, positively charged Ra compounds in the water (ion exchange). When the resin becomes exhausted of Na^+ ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the positively charged Ra compounds with Na^+ ions. Current resins are not compound selective and may remove other cations before removing positively charged Ra compounds. Therefore IX requires careful consideration of the raw water characteristics. Typically, IX for positively charged Ra compounds utilizes a Cl^- or OH^- strongly 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.

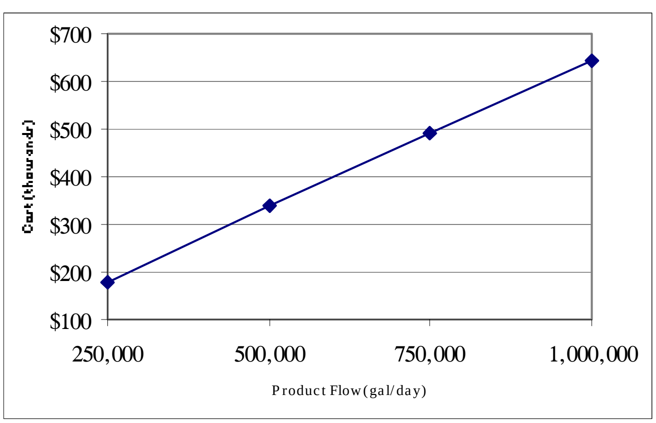
Maintenance - Depending on raw water characteristics and Ra concentration, the resin will require regular regeneration with a NaCl solution. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. resin, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

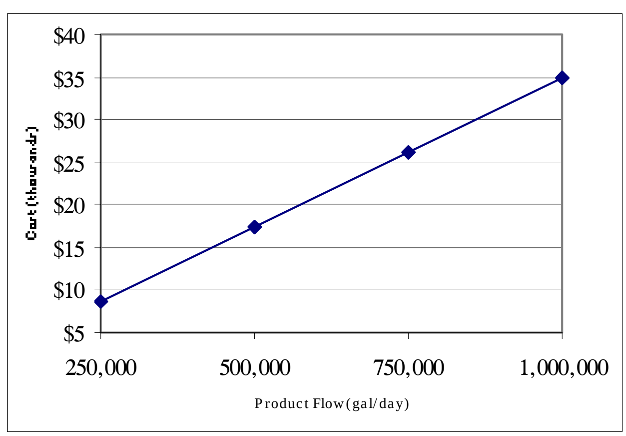
Advantages -
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Requires salt storage.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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-c. Mixed Bed Ion Exchange for β Removal:

<u>Process</u> - Mixed bed 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. IX operation for Gross Beta (β) Particle Activity and Photon Emitter removal begins with a fully recharged resin bed, having enough positive and negative ions to carry out the cation and anion 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 negatively charged Na^+ or Cl^- ions are released into the water, being substituted or replaced with the soluble, positively or negatively charged β compounds in the water (ion exchange). When the resin becomes exhausted of Na^+ or Cl^- ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the positively or negatively charged β compounds with Na^+ or Cl^- ions. Current resins are not compound selective and may remove other cations/anions before removing positively/negatively charged β compounds. Therefore IX requires careful consideration of the raw water characteristics. Typically, IX for β compounds utilizes a mixed Na^+ and Cl^- strongly acid/basic cation/anion resin bed.

<u>Pretreatment</u> - 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.

<u>Maintenance</u> - Depending on raw water characteristics and β concentration, the resin will require regular regeneration with a NaCl solution. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

<u>Waste Disposal</u> - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. resin, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

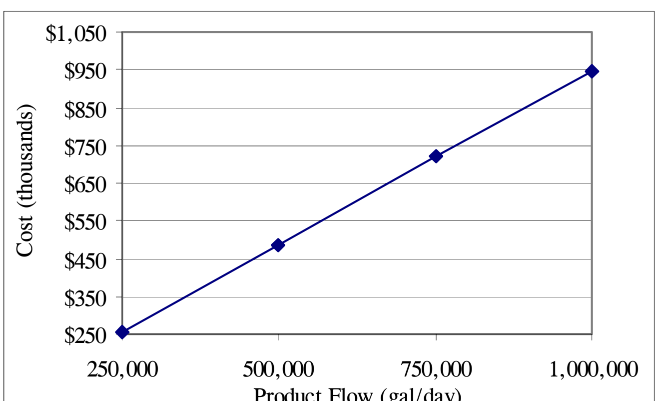
<u>Advantages</u> -

- 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.
- Variety of specific resins are available for removing specific contaminants.

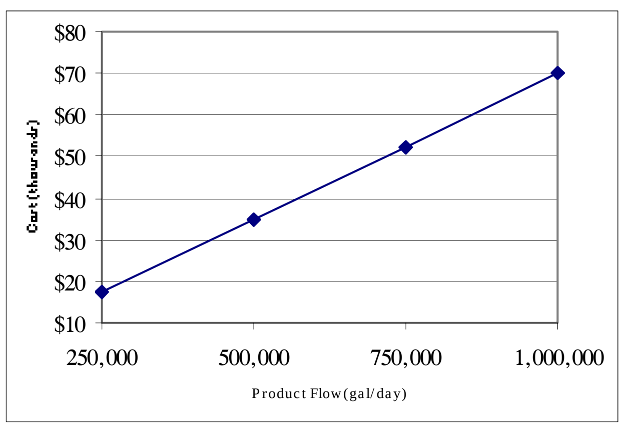
<u>Disadvantages</u> -

- Requires salt storage.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

<u>BAT Equipment Cost*</u>



<u>BAT Annual O&M Cost*</u>



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

3D. Reverse Osmosis for U, α, β, and Ra Removal:
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.

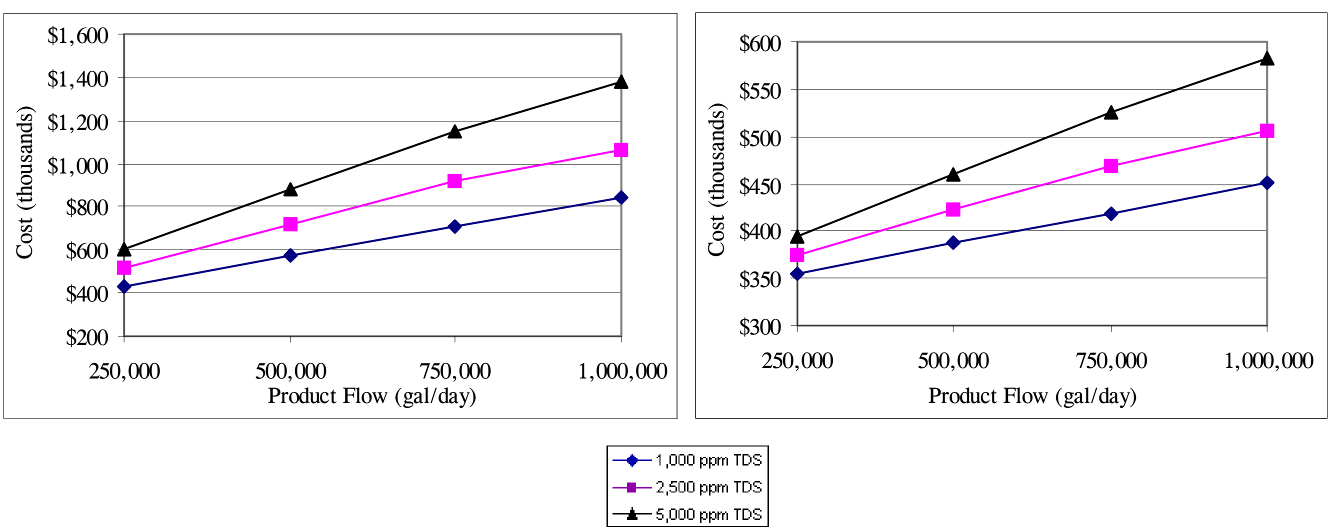
Maintenance - Monitor rejection percentage to ensure U and Ra removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions 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 - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. filters, elements, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

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 U and Ra 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.

3E. Lime Softening for U and Ra Removal:

Process - Lime softening uses chemical additions followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical additions include $Ca(OH)_2$ to precipitate carbonate and Na_2CO_3 to precipitate noncarbonate hardness. In the upflow SCC, coagulation, flocculation (agglomeration of the suspended material, including U and Ra, 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 10.5 or higher.

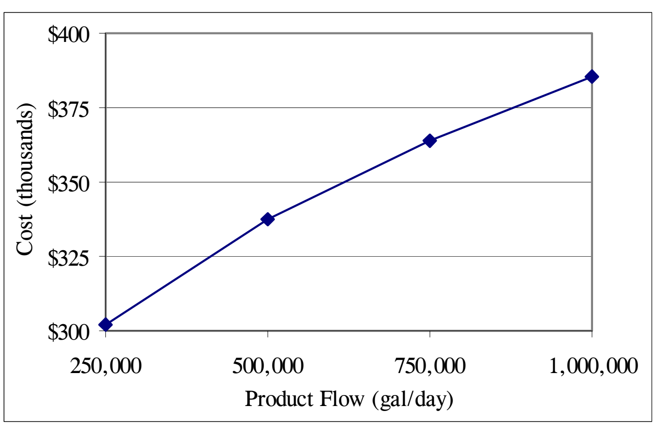
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. sludge and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

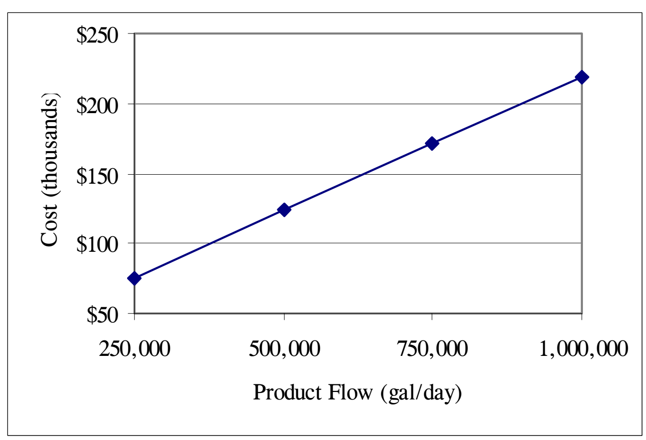
Advantages -
- Other heavy metals are also precipitated; reduces corrosion of pipes.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- Produces high U and Ra-contaminated sludge volume.
- 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.

3F. Coagulation and Filtration for U Removal:

Process - Coagulation and filtration for 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 U 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.

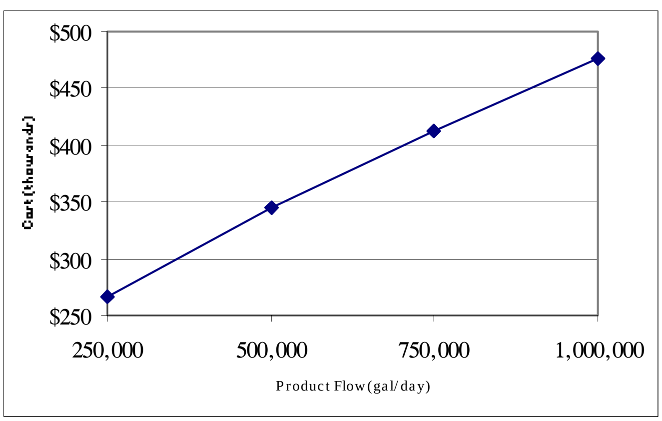
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 - When large amounts of raw water with high levels of radioactive materials are treated for sufficiently long periods of time, the waste products can become radioactive enough to cause concern about safe and legal disposal. Waste products (i.e. media, backwash water, and cleaning solutions) require disposal in accordance with local or state regulations. The USEPA guidance entitled *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*, dated June 1994, provides disposal information. As a result of the wide variances in local and state laws, the costs presented below do not address waste disposal. However, costs associated with waste disposal should be considered significant.

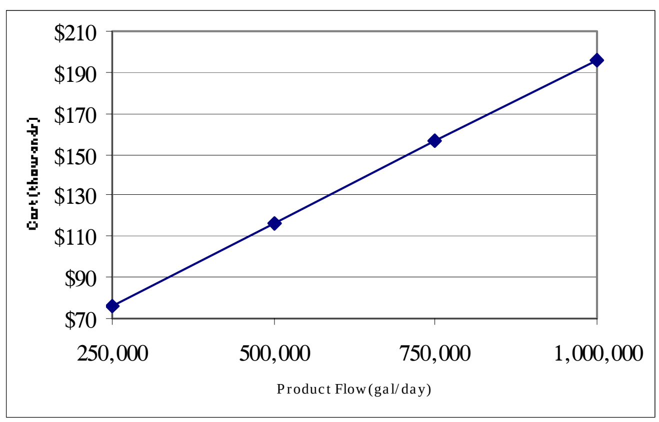
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

Disadvantages -
- Operator care required with chemical handling.
- Produces high sludge volume.
- 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.

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, Na_2CO_3 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). $Fe_2(SO_4)_3$ has been proven to be the most effective coagulant for Se^{+4} removal; while $Al_2(SO_4)_3$ 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.

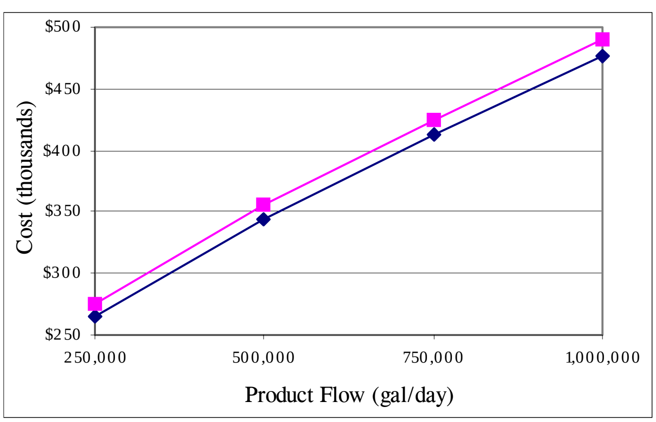
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

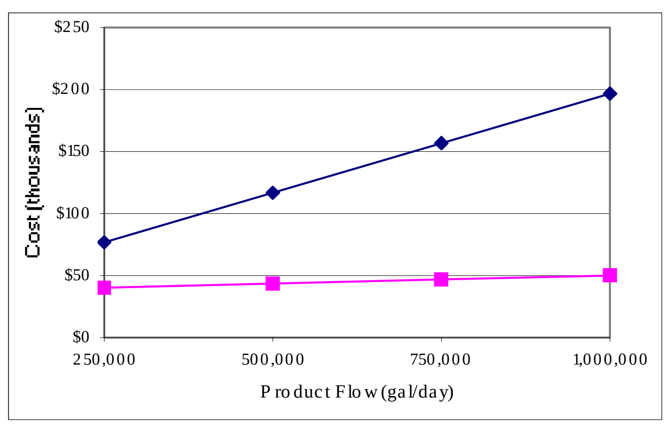
Advantages -
- Lowest capital costs.
- Lowest overall operating costs.
- Proven and reliable.
- Low pretreatment requirements.

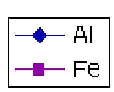
Disadvantages -
- Operator care required with chemical handling.
- Not suitable for Se^{+6} removal.
- Produces high sludge volume.
- Waters high in sulfate may cause significant interference with removal efficiencies.

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 $Ca(OH)_2$ 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.

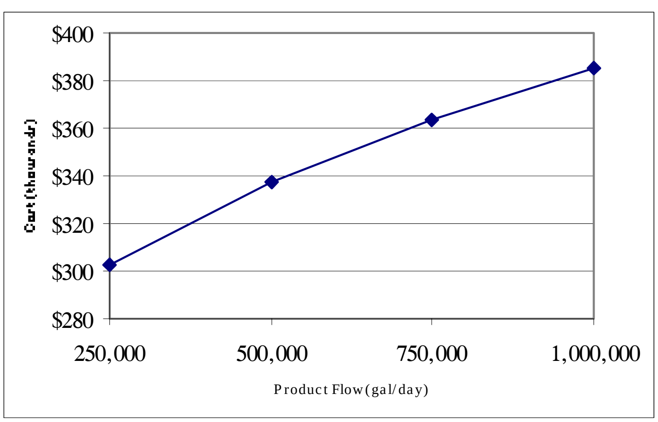
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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*



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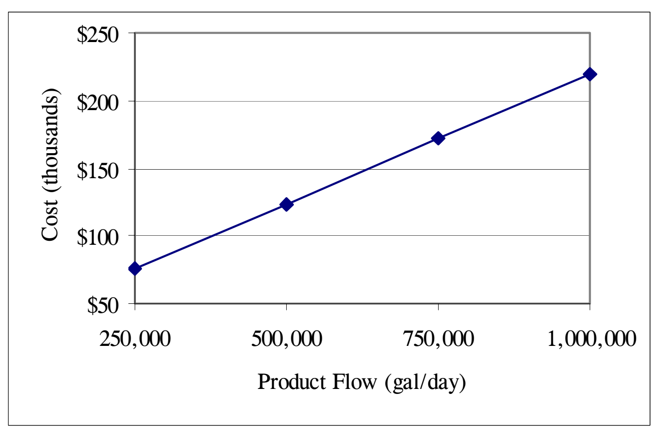


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

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.

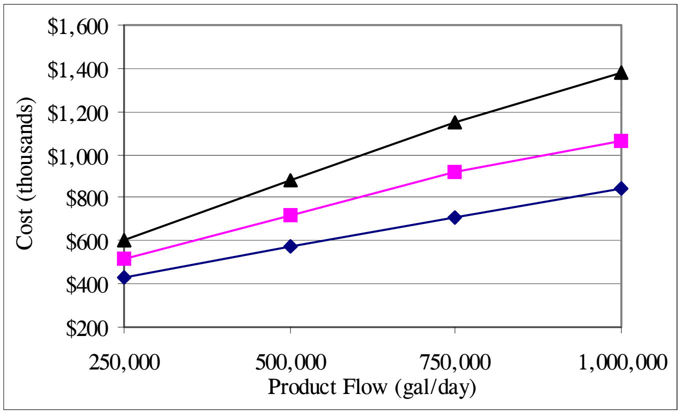
Maintenance - Monitor rejection percentage to ensure Se removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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. $NaHSO_3$ 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 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*



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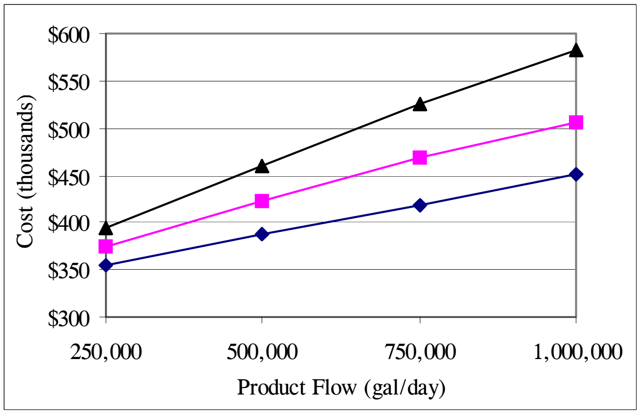
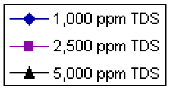




*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3D. Electrodialysis Reveral:
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.

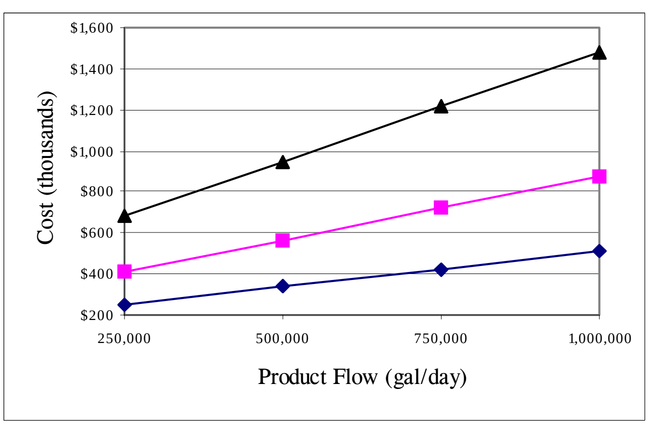
Maintenance - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode 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, H_2S, 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*



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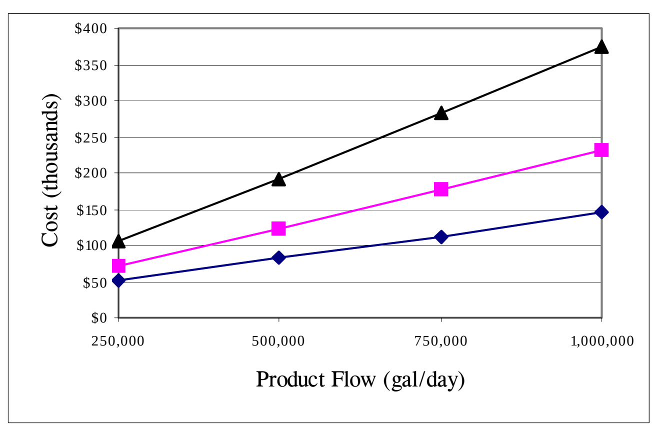
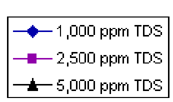




*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

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 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, 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.

THALLIUM

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: Thallium (Tl), atomic number: 81, atomic weight: 204.37, oxidation states: +3, and +1, soft, malleable, inelastic metal resembling lead in appearance. Becomes bluish-gray tinge when exposed to air. Very poisonous with not many uses. Odorless and tasteless, and gives no warning of its presence. It is a member of the aluminum family of metals. Tl and its compounds have water solubilities ranging from low to high, depending on the salt formed. Tl alone is highly persistent in water, as it has only slight solubility.

B. Source in Nature: Tl does not occur in the elemental state, but is found in trace amounts in the earth's crust as ores in potash minerals or as a by-product from the smelting of metals such as pyrites, zinc, blende, and hematite. It can also be found combined with other substances such as bromine, chlorine, fluorine, and iodine. Tl has been detected in volcanic rocks, meteorites, and plants. It occurs in small amounts in all living organisms.

C. SDWA Limits: MCL for Tl is 0.002 mg/L and the MCLG is 0.0005 mg/L.

D. Health Effects of Contamination: Tl at short-term exposure levels above the MCL can cause vomiting, diarrhea, gastrointestinal irritation, peripheral neuropathy. Long-term exposure at levels above the MCL, Tl can cause changes in blood chemistry, liver and kidney damage, damage to intestinal and testicular tissues, and hair loss. Contact with the metal with skin is dangerous. It has caused death.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Activated alumina or ion exchange.

- AA uses extremely porous and highly adsorptive aluminum ore media to adsorb Tl. Benefits: containment of Tl in adsorption bed. Limitations: when used with Tl^{+4} results in creation of hazardous waste requiring disposal. AA cost curves will be included in a future revision.
- IX for soluble Tl uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Tl in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Tl remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce Tl are available.

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.

Bureau of Reclamation, Technical Service Center
Water Treatment Engineering and Research Group, D-8230
PO Box 25007, Denver CO 80225 (303) 445-2260

Revision Date: 9/21/01

3A. 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 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.

3A. 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 Tl reduction, operation begins with a fully recharged cation 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 Tl ions 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 Tl ions with Na or K ions. Many different types of cation resins can be used to reduce dissolved Tl concentrations. The use of IX to reduce concentrations of Tl will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-Tl is greater than 1.

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.

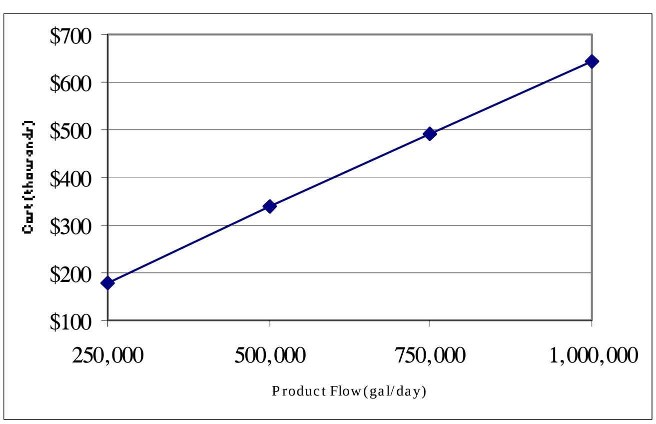
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Tl concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline 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.

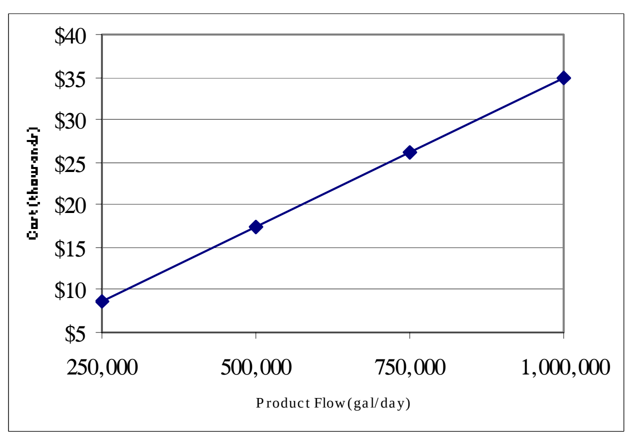
Advantages -
- Acid addition, degasification, and repressurization is not required.
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Pretreatment lime softening may be required.
- Requires salt storage; regular regeneration.
- Concentrate disposal.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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.

TOTAL COLIFORM and E-COLI

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: Fecal bacteria are single-celled microorganisms, virtually always associated with fecal contamination of water, but not always harmful. Fecal indicator bacteria are used in determining (indicating) the microbial quality of water. Total coliform bacteria and fecal coliform *Escherichia coli* 0157:H7 (E-Coli) are two types of fecal indicator bacteria. Total coliform bacteria, a particular group of waterborne microbiological contaminants regulated by the SDWA, is the most common indicator organism applied to drinking water. E-Coli is one type of pathogenic fecal coliform bacteria, and the most common facultative, disease-causing bacteria in the feces of warm-blooded animals.

B. Source in Nature: By definition, several bacteria can be classified as coliform, and are commonly found in soil, on the surface of leaves, in decaying matter, and can grow in water distribution mains. These types of coliform bacteria aren't fecal contamination related, and do not necessarily indicate unsafe water. The pathogenic fecal coliform bacteria, E-Coli, is naturally occurring in the intestines and feces of most warm-blooded animals, including humans, and when found in water is a direct result of fecal contamination. Almost all surface waters contain some bacteria, while groundwaters are generally free of bacteria unless under the direct influence of surface water. Surface and groundwater contamination can occur as a result of surface runoff through urban areas, woodlands, pastures, or feedlots; on-site septic tank/sewage disposal system leakage/failure; sewage treatment plant/disposal system overload or malfunction; or raw sewage deep well injection. Treatment plant process contamination can occur as a result of filter breakthrough; improper coagulation; use of recycled, concentrated backwash water; process overload; or improper maintenance. Distribution system contamination can occur as a result of cross-connection, broken or leaking waterlines, or back-siphonage.

C. SDWA Limits: The TT MCLG for both total coliform and E-Coli is 0 mg/L. For total coliform, >40 samples/month, less than 5% of the samples may be positive; <40 samples/month, no more than one sample may be positive. For E-Coli, the Positive Repeat Sample criteria is applied for MCL.

D. Health Effects of Contamination: Self-limiting effects of bacterial ingestion include abdominal cramps and diarrhea. Hemorrhagic colitis (HC) is the acute disease caused by E-Coli. HC results in severe abdominal cramps, watery diarrhea, and lower intestinal bleeding; with occasional vomiting and fever. In some cases, hemolytic uremic syndrome or renal failure can occur. Although not life threatening to healthy adults, these diseases can be fatal to young children, the elderly, and immunocompromised persons. E-Coli is transmitted through fecal-oral ingestion of the bacteria by direct ingestion (i.e. drinking), primary contact recreation (i.e. swimming), or secondary contact (i.e. fishing).

2. REMOVAL TECHNIQUES

A. USEPA BAT: For community surface and groundwater (under the direct influence of surface water) systems, treatment technique is applied. In this case, the accepted TT is use of the conventional treatment processes filtration and disinfection. Benefits: proven; reliable. Limitations: initial investment.

B. Alternative Methods of Treatment: Through proper siting of wells and waste disposal systems, manage, find, or eliminate the source of the contamination. Improving well casing/sealing or drilling deeper wells can improve groundwater quality. Distillation is effective. UV, ozone, and iodine can be effective disinfection methods. Boiling water for 1 minute (5 minutes at higher elevations) is the traditional POU treatment method. Bottled water may be used, although is not regulated for testing for microbial contaminants. Raw water quality can also be improved through complex planning of waste treatment/disposal methods, public watershed, and land management, especially during periods of high precipitation and heavy runoff.

C. Safety and Health Requirements for Treatment Processes: General industry safety, health, and self protection practices for process equipment should be followed, including proper use of chemicals and tools. When dealing with waterborne diseases, take precautions to prevent infection through open cuts/wounds, or illnesses from ingestion. Wear PPE and wash hands thoroughly.

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. Filtration and Disinfection:

Process - Filtration involves removing contaminant bacteria through screening, settling, or separating. Disinfection refers to inactivation (killing) of the bacteria. Depending on raw water quality and characteristics, filtration of bacteria can be a multi-step process, including screening; coagulation and flocculation; final settling; and final filtering. Screening consists of removing the largest/heaviest suspended solids from the raw water. 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). Final settling consists of settling of the floc matter. Final filtration consists of removal by filtering (often membrane) of all floc; suspended; and, based on filtration method/size, most dissolved solids, including bacteria. Filtration processes result in lowering overall TSS/TDS and turbidity, which in turn allows greater disinfection contact time on remaining bacteria. Disinfection consists of chemical inactivation of pathogens, bacteria, and viruses. Cl_2 effectively treats bacteria and is the most common disinfection method. Cl_2 demand refers to the amount of chlorine required to inactivate the bacteria and the amount required to allow an effective residual in the distribution system.

For on-site systems with one time groundwater contamination, whether by maintenance, poor construction, single event contamination, etc., concentrated disinfection of the well, casing, and piping is required; and flushing of the system.

The cost curves presented below are for dual media filtration and Cl_2 disinfection.

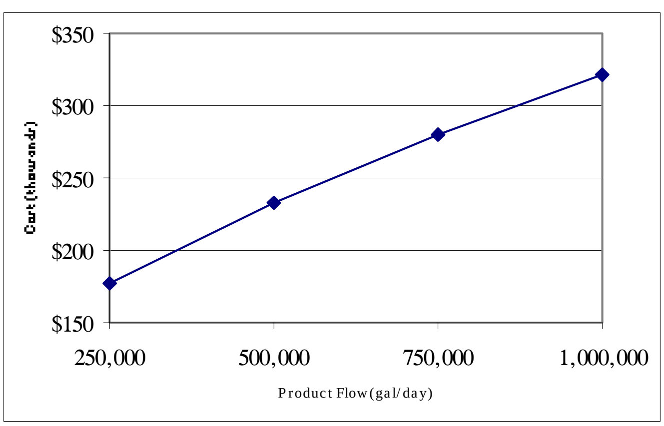
Maintenance - Proper monitoring, operation, and maintenance procedures, especially of the final filter, are essential to ensure the reliability of filtration processes. Recycled filter backwash or membrane cleaning methods may concentrate bacteria and result in a significant source of increased turbidity and bacteria infestation. As a result, a period of filter-to-waste flow may be required after post-backwash/membrane cleaning periods. Because turbidity removal can parallel bacteria removal, finished water turbidity monitoring (<0.5 NTU) may be a useful tool for indicating the degree of pathogen removal.

Waste Disposal - Pretreatment waste streams and spent filters require approved disposal.

Advantages -
- Well established, conventional treatment processes; readily available.
- Reliable, if properly operated and maintained; provides residual disinfectant.
- Suitable for community or on-site systems.

Disadvantages -
- Requires proper Cl_2 contact times; can give a chlorine after taste and smell.
- Requires careful handling and proper storage of chlorine.
- Cl_2 may combine with organic precursors to form THMs.
- Costly initial investment, and proper operation and maintenance.

BAT Equipment Cost*



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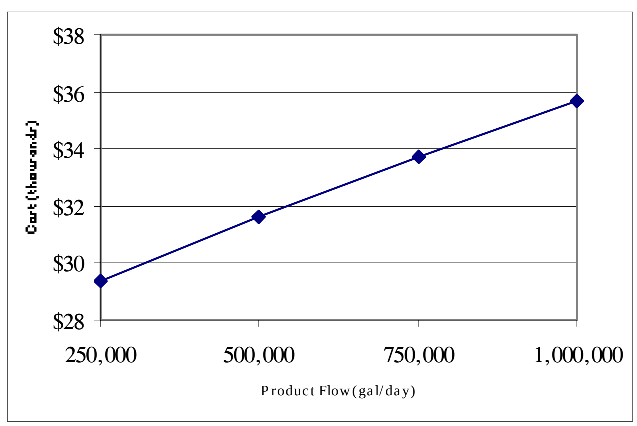


*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

TOTAL DISSOLVED SOLIDS

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: Total dissolved solids (TDS) or filterable residue are all of the dissolved solids in a water. TDS is measured on a sample of water that has been passed through a very fine filter (usually 0.45 micron) to remove the suspended solids. The water passing through the filter is evaporated (usually 103-105ºC) and the residue represents the TDS concentration (in mg/L). TDS is usually comprised of inorganic minerals (salts), small amounts of organic material, and can include small amounts of soluble minerals (Fe and Mn). A conductivity test of water provides only an estimate of TDS, as conductivity is not directly proportional to the weight of an ion, and non-conductive substances cannot be measured by electrical tests.

B. Source in Nature: Inorganic minerals (salts) are commonly found in nature, consisting of positive ions (sodium and calcium) bonded to negative ions (chloride and carbonate). The inorganic mineral compounds, and small amounts of minerals that comprise TDS, are soluble in water, and are deposited by the weathering of the sedimentary rocks and erosion of the earth's surface. Organic material is also naturally occurring in nature, as a result of decaying organisms, plants, and animals. Those organic materials in TDS are also water soluble. Higher concentrations of TDS may occur during and after precipitation events.

C. SDWA Limits: SMCL for TDS is 500 mg/L.

D. Health Effects of Contamination: As a secondary drinking water contaminant, TDS does not pose any health risks. Secondary standards refer to those contaminants which cause aesthetic problems. The inorganic minerals and organic material, and small amounts of soluble minerals, in TDS have no notable ill health effects. Na_2SO_4 concentrations above 250 mg/L may produce a laxative effect. Excess sodium may affect those restricted to low sodium diets or pregnant women suffering from toxemia. High levels of TDS may present an objectionable taste, odor, and color to drinking water. Other aesthetic concerns include an indicator of corrosivity, scaling, and limiting the effectiveness of detergents.

2. REMOVAL TECHNIQUES

A. USEPA BAT: As a secondary drinking water contaminant, BATs are not assigned.
B. Alternative Methods of Treatment: The most common treatment processes for removing TDS are reverse osmosis and electrodialysis.

- RO uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or most dissolved solids, to pass through the membrane. Benefits: produces 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.
- Freezing and distillation can be used for higher concentrations of TDS, as found in sea water or brackish water (<3000 mg/L); and ion exchange can also be used, but has limited effectiveness in concentrations <3000 mg/L.

C. Related WTTP Publications:
1) WTTP Report #6, "Preliminary Research Study of a Water Desalination System for the East Montana Area Subdivisions of El Paso County, El Paso, Texas." This report summarizes the field study performed to determine the economics of several water treatment processes, including RO, ED, and multistage flash distillation, on brackish groundwater; concluded RO with surface water reject disposal was the most economical for the study area.
2) WTTP Report #15, "Maricopa Groundwater Treatment Study." This report summarizes the field study performed to determine the suitability of several water treatment processes, including RO, ED, and NF, on groundwater containing high levels of nitrate, chloride, and TDS; recommends the use of NF or ED for study area.

D. 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. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Recent membrane improvements by manufacturers have produced nanofiltration (NF) membranes that are less costly to purchase and operate.

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.

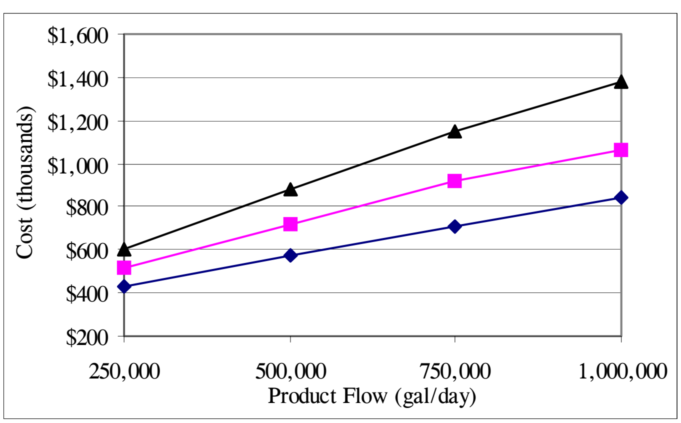
Maintenance - Monitor rejection percentage to ensure contaminant removal below SMCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions 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.

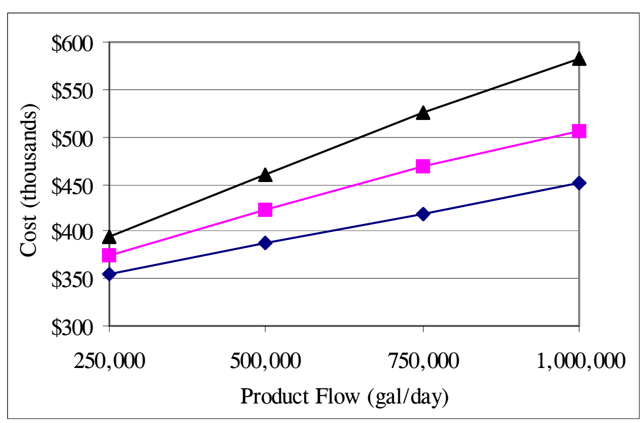
Advantages -
- Produces highest water quality.
- Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

Disadvantages -
- Relatively expensive to install and operate (however NF membranes and operations are less than RO).
- Frequent membrane monitoring and maintenance; monitoring of rejection percentage for contaminant 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. 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 membrane surface. 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.

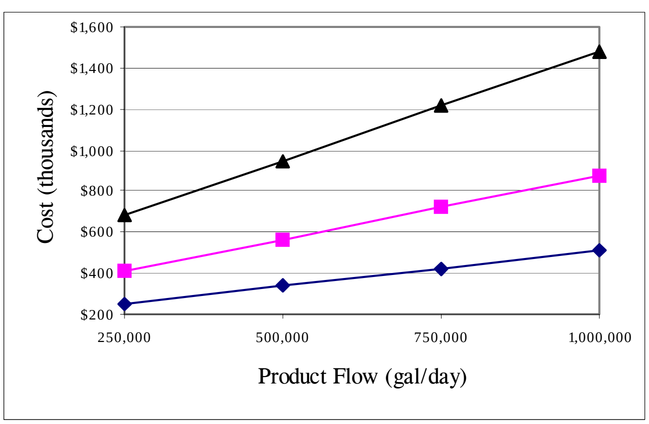
Maintenance - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode 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 TDS 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 stackmust 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.

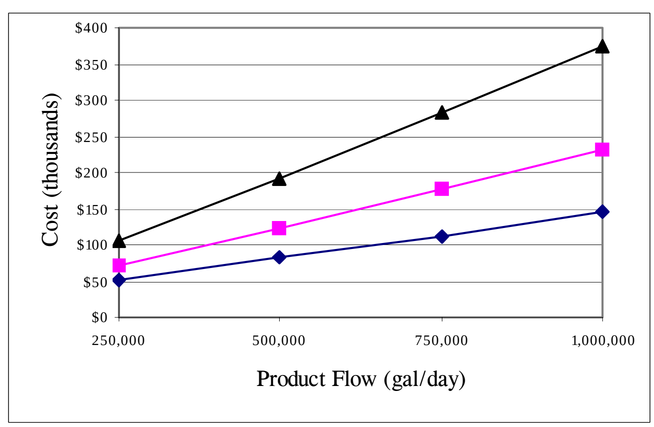
Advantages -
- Low pressure requirements; typically quieter than RO.
- Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

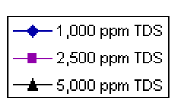
Disadvantages -
- EDR can operate without fouling or scaling, or chemical addition; suitable for higher TDS sources.
- Not suitable for high levels of Fe and Mn, H_2S, chlorine, or hardness.
- Limited current density; current leakage; back diffusion.
- At 50% rejection of TDS per pass, process is limited 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.

TRIHALOMETHANES

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: Trihalomethanes (THMs), are formed from a reaction that produces a "disinfection by-product" from the chlorination of drinking water that contains organic material. THMs are one of a family of organic compounds named as derivatives of methane. The four common THMs are trichloromethane (chloroform) by far the most common in most water systems, dibromochloromethane the most serious cancer risk, dichlorobromomethane, and tribromomethane (bromoform). THMs are colorless volatile liquid with a pleasant odor and a slightly sweet taste, flammable only when it reaches very high temperatures. THMs dissolve easily in water and may break down to other chemicals.

B. Source in Nature: THMs are found naturally in small amounts almost everywhere, most are synthetic. They form when chlorine, used to treat water, reacts with naturally occurring organic materials, such as humic acids from decaying vegetation commonly found in raw water supplies, particularly lakes and reservoirs. Other major sources of THMs in the environment come from chemical and pharmaceutical manufacturing processes such as, the bleaching of wood pulp by paper mills, the disinfection of drinking water, municipal wastewater, and cooling water.

C. SDWA Limits: MCL for total THMs is 0.08 mg/L.

D. Health Effects of Contamination: THMs at short-term exposure levels above the MCL have not shown to cause ill health effects. At long-term exposure levels above the MCL, THMs can cause damage to the nervous system, liver, and kidneys. It can cause sores if large amounts touch the skin. There have been studies that suggest a connection between chlorination by-products and particularly bladder and possibly colon and rectal cancer.

2. REMOVAL TECHNIQUES

A. USEPA BAT: THM control focuses primarily on the removal of THM precursors - natural organic material (NOM), and to a lesser extent, removal of THMs. Removal of NOM prior to chlorination prevents or minimizes the formation of THMs. The most common methods of treatment to control THMs include enhanced coagulation, activated carbon filters, and reverse osmosis.

- Coagulation and filtration for NOM removal uses the conventional treatment 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.
- THMs and NOM can be reduced by adsorption with an activated carbon filter. 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.
- RO for dissolved THMs and NOM uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble THMs), to pass through the membrane. Benefits: produces high quality water. Limitations: high cost; pretreatment/feed pump requirements; concentrate disposal.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The THMs remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce THMs are available.

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. Enhanced Coagulation and Filtration:

Process - Enhanced 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 decreasing pH (to levels as low as 4 or 5) and increasing the feed rate of a chemical coagulant combined with mechanical flocculation to allow fine suspended and some dissolved solids to clump together (floc). $Fe_2(SO_4)_3$ has been proven to be the most effective coagulant for NOM removal. Floc and other suspended solids are removed by filtration using dual media or mixed media filters.

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

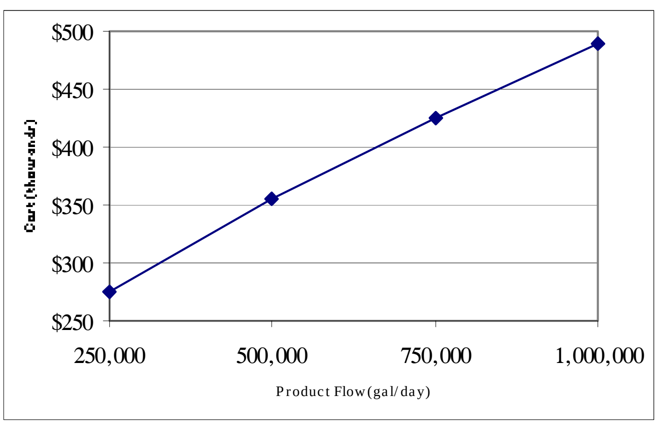
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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.

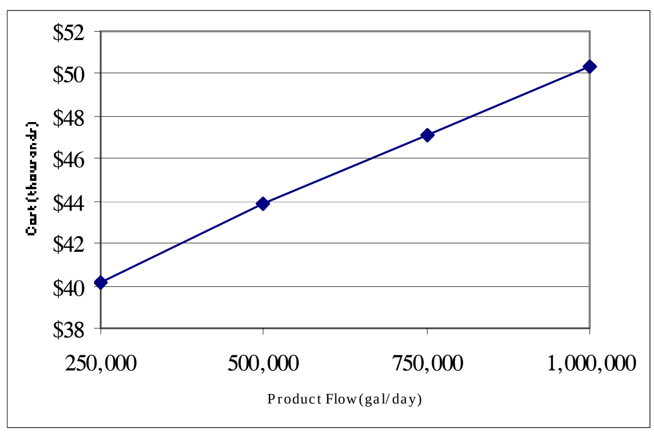
Advantages -
- Lowest capital costs for larger systems.
- Lowest overall operating costs for larger systems.
- Proven and reliable.
- Most effective for NOM removal.

Disadvantages -
- Not appropriate for smaller systems.
- Operator care required with chemical handling.
- High or low pH reduces treatment efficiency; secondary treatment may be required.

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 filtration plus flocculation). Costs for coagulation and filtration would be less since flocculation is omitted.

3B. 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.

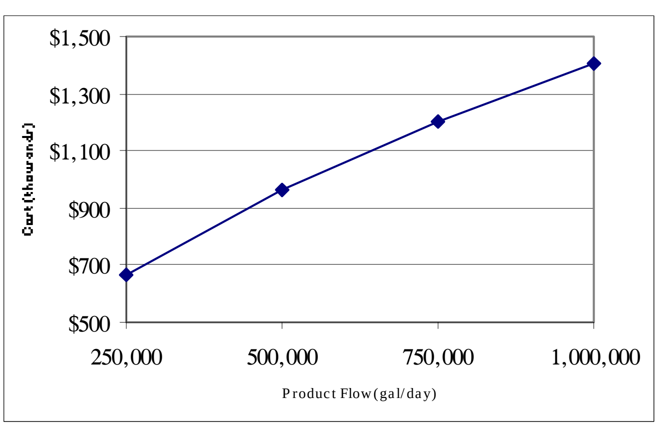
Maintenance - Careful monitoring and testing to ensure contaminant removal is required. Regular replacement of carbon media is required and is based on contaminant type, concentration, rate of water usage, and type of carbon used. The manufacturer's recommendations for media replacement should be consulted. 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 spent media is the responsibility of the contractor providing the media replacement services.

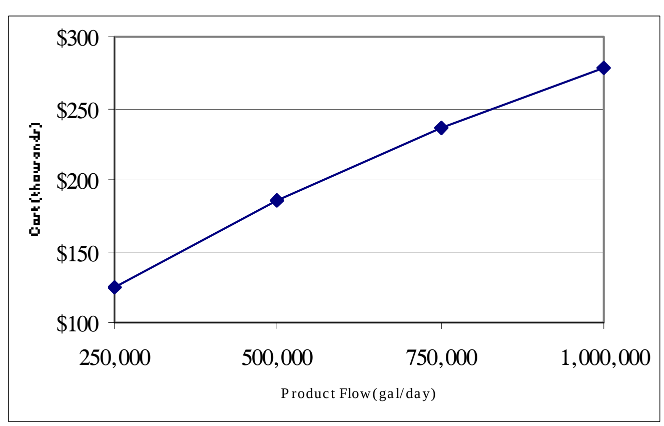
Advantages -
- Well established.
- Suitable for some organic chemicals, some pesticides, and THMs.
- Suitable for home use, typically inexpensive, with simple filter replacement requirements.
- Improves taste and smell; removes chlorine.

Disadvantages -
- Effectiveness is based on contaminant type, concentration, 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.

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.

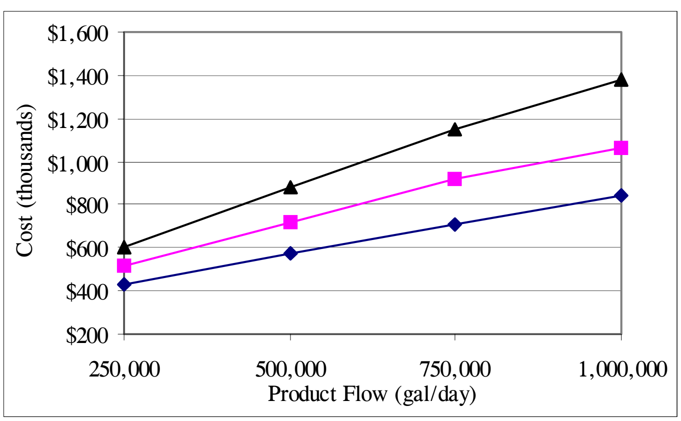
Maintenance - Monitor rejection percentage to ensure THM removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly 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 THM removal.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

BAT Equipment Cost*



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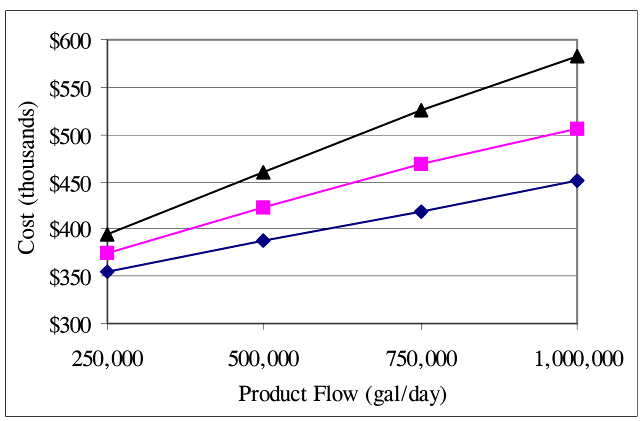

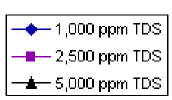

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TURBIDITY and TOTAL SUSPENDED SOLIDS

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: Turbidity is the reduction of clarity in water due to the presence of suspended or colloidal particles. Turbidity is measured by the amount of light which is reflected by the particles. Turbidity is commonly used as an indicator for the general condition of the water.

The suspended or colloidal particles, commonly referred to as total suspended solids (TSS), are all the extremely small suspended solids in water which will not settle out by gravity. TSS is measured on a sample of water (which has been settled) and are those particles which will not pass through a very fine filter (usually 0.45 micron). The filter is pre-weighed prior to passing of the water, and post-weighed. The difference in the two weights is the TSS concentration (in mg/L).

B. Source in Nature: Turbidity in surface water is comprised of several naturally occurring or introduced organic matter and inorganic minerals, including clays, silts, industrial wastes, sewage, algae, and plankton. Turbidity increases during spring runoff and seasonal precipitation events as a result of increased overland flow and erosion. Turbidity is carried in both gentle and fast currents. Groundwater is usually less susceptible to turbidity because of the natural filtering capabilities of the earth layers it passes through. Turbidity in a water distribution system can result from a watermain break, watermain construction, or excessive flowrates which may disrupt pipe sedimentation.

C. SDWA Limits: For systems required to use the treatment technique (TT), the MCL is <5.0 NTU at all times; <0.5 NTU in 95% of all samples using conventional and direct filtration; and <1.0 NTU in 95% of all samples using diatomaceous earth, slow sand, and all other filtration techniques.. EPA requires daily monitoring for turbidity.

D. Health Effects of Contamination: Turbidity may be harmless, but may be an indicator of harmful water constituents, is aesthetically unpleasant, and is likely to cause color, odor, and taste problems. The major concern with turbidity is that it interferes with the disinfection process. Turbidity can harbor or carry pathogens, and can interfere with disinfection by taking up or using the disinfectant intended for the pathogens in the water. The pathogens which are not killed can result in several waterborne diseases. Depending on the type and concentration of inorganics present, health effects may or may not be a concern.

2. REMOVAL TECHNIQUES

A. USEPA BAT: For community surface and groundwater (under the direct influence of surface water) systems TT is required. In this case, the accepted treatment technique is the use of the conventional treatment processes of chemical addition, coagulation and flocculation, clarification, and dual media filtration. Benefits: proven; reliable. Limitations: initial investment.

B. Alternative Methods of Treatment: Direct filtration may be substituted for the complete treatment where the utility has demonstrated, through adequate pilot-plant studies, that the water will consistently meet the USEPA MCL Such pilot-plant studies should be conducted during all seasons of the year in order to study the various water conditions and achieve a complete range of raw water qualities.

C. Safety and Health Requirements for Treatment Processes: General industry safety, health, and self protection practices for process equipment should be followed, including proper use of chemicals and tools. When dealing with waterborne diseases, take precautions to prevent infection through open cuts/wounds, or illnesses from ingestion. Wear PPE and wash hands thoroughly.

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. TT:

Process - For community surface and groundwater (under the direct influence of surface water) systems, conventional treatment techniques, including chemical coagulation and flocculation, final settling or clarification, and dual media filtration ensure protection of both surface and groundwaters. These TTs work to remove TSS and turbidity prior to disinfection. Processes and dosages may vary by site, so actual process and dosage selection depends on careful review of overall raw water quality and characteristics. 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). Costs presented below include alum (230 ppm) as the coagulant, rapid mix for 30 seconds, and flocculation for 30 minutes. Final settling or clarification consists of settling of the floc matter. Filtration consists of final removal by filtering of all floc; suspended; and, based on filtration method/size, most dissolved solids, including pathogens. These TTs result in lowering overall TSS/TDS and turbidity, which in turn allows greater disinfection contact time on any remaining pathogens.

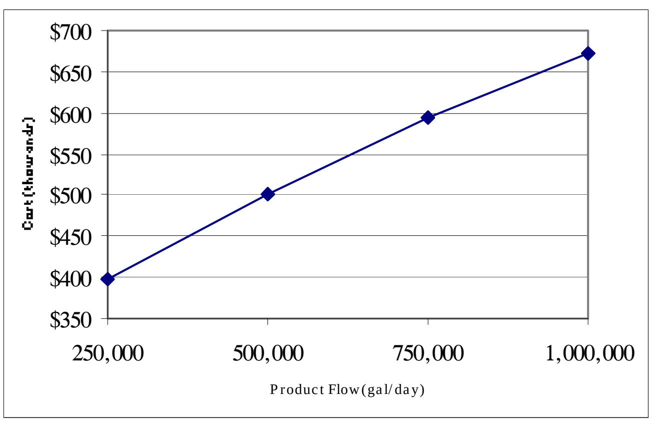
Maintenance - Proper monitoring, operation, and maintenance procedures, especially of the final filter, are essential to ensure the reliability of TT processes. Recycled filter backwash may concentrate pathogens and result in a significant source of increased turbidity and pathogen infestation. As a result, a period of filter-to-waste flow may be required after post-backwash cleaning periods. Because turbidity removal can parallel pathogen removal, finished water turbidity monitoring (<0.5 NTU) is required for indicating the degree of pathogen removal. Depending on filtration process, recharging or clean installation of media is required.

Waste Disposal - Pretreatment waste streams and spent filter material require approved disposal.

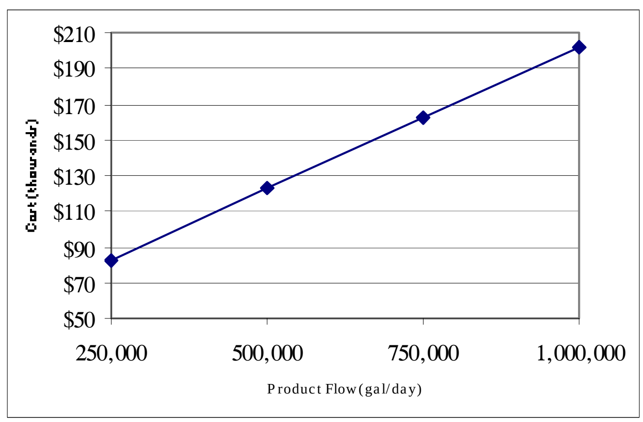
Advantages -
- Well established and reliable.
- Low operator requirements.

Disadvantages -
- Costly initial investment.

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.

ZINC

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: Zinc (Zn), atomic number: 30, atomic weight: 65.38, a bluish-white, lustrous metal extracted from certain ores. Oxidation state is +2. Used to form numerous alloys with other metals and as a galvanizing agent.

B. Source in Nature: Zn is found in natural deposits in the environment. Zn is added to livestock and poultry feed to promote weight gain and control disease and is delivered to the soil as waste, where it can be distributed to surface water. Zn is found in paints and dyes and may also come from industrial/mining contamination. Zn can be found in water distribution systems as a result of leaching of brass and galvanized iron pipes and fittings. Excessive Zn in water supply systems can result in corrosion of plumbing materials.

C. SDWA Limits: SMCL for Zn is 5.0 mg/L.

D. Health Effects of Contamination: Zn, in small amounts, is an essential and beneficial element in human and animal metabolism. As a nutrient, Zn can be obtained from eating a balanced diet or taken as an additional supplement. Excessive Zn can give drinking water an undesirable, metallic taste and may cause water to appear milky. Upon boiling, water may appear to have a greasy surface scum. At concentrations of 40 mg/L or greater and with prolonged consumption, Zn poisoning is possible. Although Zn is not considered to be toxic, it may act as a gastrointestinal irritant.

E. Effects on Aquatic Life: Zn, in concentrations as low as 0.05 mg/L, may become toxic to fish and invertebrates resulting in reduced breeding and/or death of aquatic life.

2. REMOVAL TECHNIQUES

A. USEPA BAT: As a secondary drinking water contaminant, BATs are not assigned.

B. Alternative Methods of Treatment: The treatment method used to remove Zn will be a function of the treated water requirements and flowrates. The most common methods of treatment to remove Zn include distillation, ion exchange, reverse osmosis, and lime softening. For individual well systems, distillation or IX may be the best selections. For municipal water systems, IX or RO may be the best selections. Lime softening is used when Zn concentrations must be reduced to 0.05 mg/L or below to meet the aquatic standard.

- Distillation heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Zn remains in the boiler section. Generally, distillation for Zn removal is considered a POU process. Benefits: kills bacteria and viruses; well established. Limitations: high energy requirements; postfiltration may be required.
- IX for soluble Zn uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Zn in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.
- RO for soluble Zn uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Zn), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.
- Lime softening for soluble Zn uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Zn. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Zn compounds may be formed at low carbonate levels requiring coagulation and flocculation.

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.

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Water Treatment Engineering and Research Group, D-8230
PO Box 25007, Denver CO 80225 (303) 445-2260
Revision Date: 9/21/01

3A. Distillation:

Process - Distillation is a physical separation process where contaminants are separated from water through evaporation (or vaporization), cooling, and condensation. POU distillation units, or stills, generally consist of a boiling chamber, where the water enters, is heated, and vaporized as steam; condensing coils or chamber, where the water is cooled and converted back to liquid; and a storage tank for purified water or distillate. Heating water to form steam requires energy.

Pretreatment - Usually installed as a POU system. No pretreatment needed.

Maintenance - Unevaporated contaminants remaining in the boiling chamber need to be regularly flushed out. Ca and Mg precipitates or scale may collect at the bottom of the boiling chamber. This scale eventually needs to be removed, usually by hand scrubbing or by an application of strong (acetic) acid solution. Frequency of maintenance depends on the water quality.

Waste Disposal - Flushed waste streams, solid waste, and cleaning acids all require approved disposal.

Advantages -

- Kills bacteria and viruses
- Other heavy metals are also precipitated.
- Proven and reliable.
- Unit size can vary.
- No pretreatment requirements.

Disadvantages -

- Minute amounts of minerals, dissolved gases, and some organic contaminants can be carried with the steam into the distillate.
- Produces water with a flat taste as a result of removal of minerals.
- May require postfiltration; produces very soft water that can be corrosive to metal pipes.
- Slow process.
- Consumes enormous amounts of energy for heating and cooling requirements.

Costs - The cost of POU distillation equipment is based on the water production rate (usually in GPD) and energy rating (usually 115- to 120-volt for smaller (3-4 GPD) units, or 220- or 240- volt for larger (8-12 GPD) units). Generally, POU unit equipment costs range from $300 - $1200. The energy costs associated with operation of distillation units are extremely unit and site specific. Generally, POU unit energy costs can be calculated as follows: wattage of unit x cost of energy/Kw-hr x Kw/1000w x 24 hr/day = cost to operate unit.
For these reasons generic costs curves at higher flowrates are not provided.

3B. 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 Zn, 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 Zn 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 Zn compounds with positively charged ions. Many different types of IX resins can be used to reduce dissolved Zn concentrations. These include Na cation resins and zeolites containing alkali or alkaline earth metals. The use of IX to reduce concentrations of Zn will be dependant on the specific chemical characteristics of the raw water.

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.

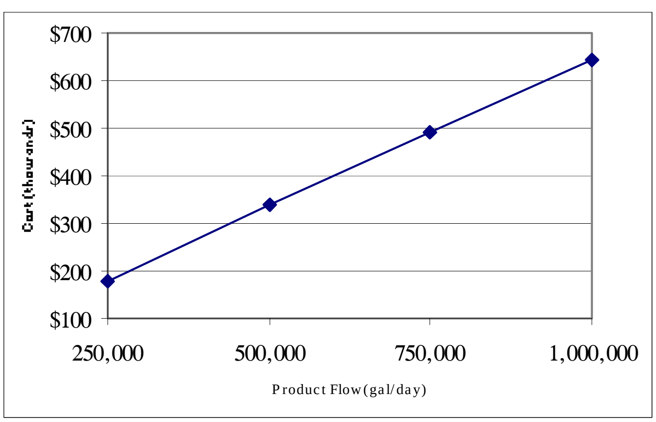
Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Zn concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated Zn 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.

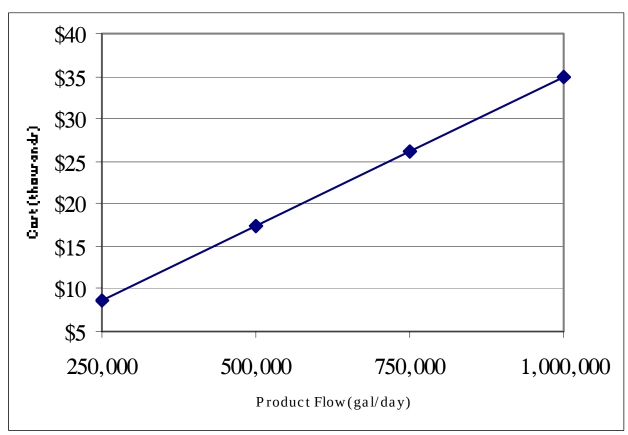
Advantages -
- Ease of operation; highly reliable.
- Lower initial cost; resins will not wear out with regular regeneration.
- Effective; widely used.
- Suitable for small and large installations.
- Variety of specific resins are available for removing specific contaminants.

Disadvantages -
- Requires salt storage.
- Usually not feasible with high levels of TDS.
- Resins are sensitive to the presence of competing ions.

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. 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 CO_3^{-2} hardness and reduce the solubility of Zn. Heavy metals, like Zn, precipitate as $Zn(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Zn, 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.

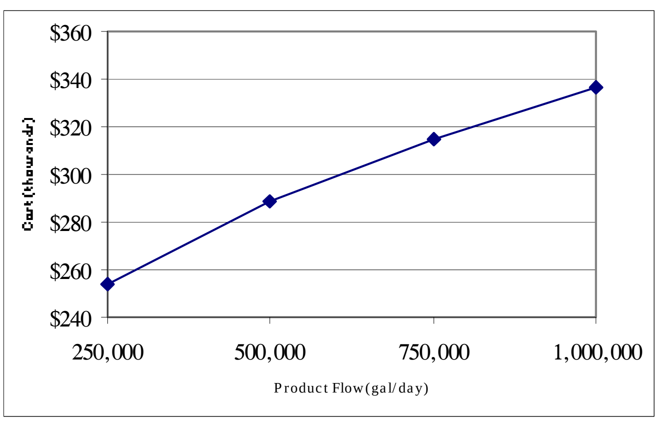
Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which 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 Zn sludge: incineration, landfill, and ocean disposal.

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

Disadvantages -
- Excessive insoluble Zn may be formed requiring coagulation and filtration.
- Operator care required with chemical handling.
- Produces high sludge volume.

BAT Equipment Cost*



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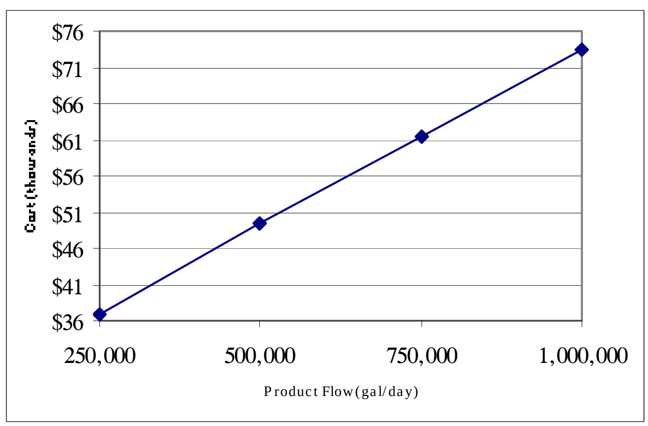

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3D. Reverse Osmosis:

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.

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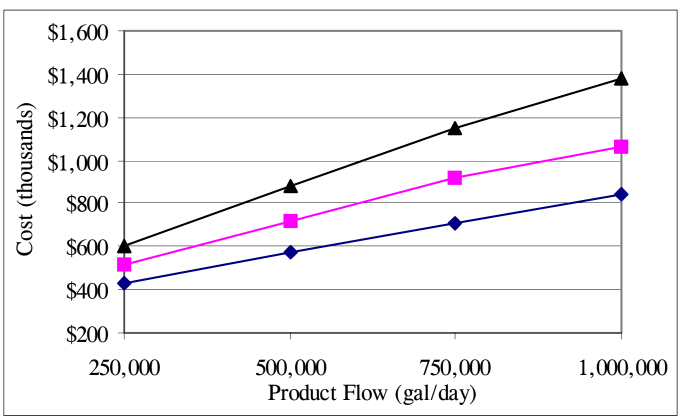
Maintenance - Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly flushed through the system at high volume/low pressure 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.
- Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

BAT Equipment Cost*



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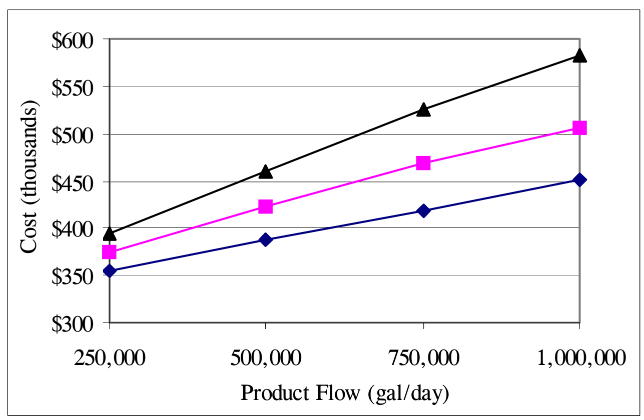

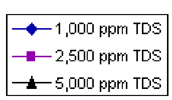

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