Tech Brief

N A T I O N A L   D R I N K I N G   W A T E R   C L E A R I N G H O U S E

Treatment Technologies for Small Drinking Water Systems

To ease many of the demands placed on small systems, the 1996 Safe Drinking Water Act amendments require the U.S. Environmental Protection Agency (EPA) to evaluate affordable technologies and address existing and future regulations, which establish a maximum contaminant level or treatment technique.

The following tables are taken from three EPA guidance documents: EPA-815-R-98-001, *Small System Compliance Technology List for the Surface Water Treatment Rule and Total Coliform Rule*; EPA-815-R-98-002, *Small System Compliance Technology List for the Non-Microbial Contaminants Regulated Before 1996*; and EPA-815-R-98-003, *Variance Technology Findings for Contaminants Regulated Before 1996*.

For information about the availability of these guidance and supporting documents, please contact the Safe Drinking Water Hotline: phone (800) 426-4791, fax (703) 285-1101, or e-mail *hotline-sdwa@epamail.epa.gov*.

Surface Water Treatment Rule Compliance Technologies for Disinfection

Unit technology	Limitations (see footnotes)	Operator skill level required	Raw water quality range and considerations[1]	Removals: Log *Giardia* & Log Virus w/CT's indicated in ()[1]
Free Chlorine	(a, b)	Basic	Better with high quality. High iron or manganese may require sequestration or physical removal.	3 log (104) & 4 log (6).
Ozone	(c, d)	Intermediate	Better with high quality. High iron or manganese may require sequestration or physical removal.	3 log (1.43) & 4 log (1.0).
Chloramines	(e)	Intermediate	Better with high quality. Ammonia dose should be tempered by natural ammonia levels in water.	3 log (1850) & 4 log (1491).
Chlorine Dioxide	(f)	Intermediate	Better with high quality.	3 log (23) & 4 log (25).
Onsite Oxidant Generation	(g)	Basic	Better with high quality.	Research pending on CTvalues. Use free chlorine.
Ultraviolet (UV) Radiation	(h)	Basic	Relatively clean source water required. Iron, natural organic matter and turbidity affect UV dose.	1 log *Giardia* (80-120) & 4 log viruses (90-140) mWsec/cm2 doses in parentheses [2].

1 CT(Concentration x Time), in mg-min/L, based upon 1989 Surface Water Treatment Rule Guidance Manual. Temp. 10 C, mid-pH range, unless otherwise indicated.

2 UV dose is product of mW/cm2 (intensity) x sec (time); bases of viral inactivation ranges are rotavirus and MS–2 tests.

Limitations Footnotes

a. Providing adequate CT(time/storage) may be a problem for some supplies.
b. Chlorine gas requires special caution in handling and storage, and operator training.
c. Ozone leaks represent hazard: air monitoring required.
d. Ozone used as primary disinfectant (i.e., no residual protection).
e. Long CT. Requires care in monitoring of ratio of added chlorine to ammonia.
f. Chlorine dioxide requires special storage and handling precautions.
g. Oxidants other than chlorine not detected in solution by significant research effort. CTshould be based on free chlorine until new research determines appropriate CTvalues for electrolyzed salt brine.
h. No disinfectant residual protection for distributed water.

Surface Water Treatment Rule Compliance Technology for Filtration

Unit technology	Limitations (see footnotes)	Operator skill level required	Raw water quality range and considerations[1]	Removals: Log *Giardia* & Log Virus
Conventional Filtration (includes dual-stage and dissolved air flotation)	(a)	Advanced	Wide range of water quality. Dissolved air flotation is more applicable for removing particulate matter that doesn't readily settle: algae, high color, low turbidity—up to 30-50 nephelometric turbidity units (NTU) and low-density turbidity.	2-3 log *Giardia* & 1 log viruses.
Direct Filtration (includes in-line filtration)	(a)	Advanced	High quality. Suggested limits: average turbidity 10 NTU; maximum turbidity 20 NTU; 40 color units; algae on a case-by-case basis.[1]	0.5 log *Giardia* & 1–2 log viruses (1.5—2 log *Giardia* w/coagulation).
Slow Sand Filtration	(b)	Basic	Very high quality or pretreatment. Pretreatment required if raw water is high in turbidity, color, and/or algae.	4 log *Giardia* & 1–6 log viruses.
Diatomaceous Earth Filtration	(c)	Intermediate	Very high quality or pretreatment. Pretreatment required if raw water is high in turbidity, color, and/or algae.	Very effective for *Giardia*; low bacteria and virus removal.
Reverse Osmosis	(d, e, f)	Advanced	Requires prefiltrations for surface water—may include removal of turbidity, iron, and/or manganese. Hardness and dissolved solids may also affect performance.	Very effective (cyst and viruses).
Nanofiltration	(e)	Intermediate	Very high quality of pretreatment. See reverse osmosis pretreatment.	Very effective (cyst and viruses).
Ultrafiltration	(g)	Basic	High quality or pretreatment.	Very effective *Giardia*,>5—6.
Microfiltration	(g)	Basic	High quality or pretreatment required.	Very effective *Giardia*,>5—6 log; Partial removal viruses.
Bag Filtration	(g, h, i)	Basic	Very high quality or pretreatment required, due to low particulate loading capacity. Pretreatment if high turbidity or algae.	Variable *Giardia* removals & disinfection required for virus credit.
Cartridge Filtration	(g, h, i)	Basic	Very high quality or pretreatment required, due to low particulate loading capacity. Pretreatment if high turbidity or algae.	Variable *Giardia* removals & disinfection required for virus credit.
Backwashable Depth Filtration	(g, h, i)	Basic	Very high quality or pretreatment required, due to low particulate loading capacity. Pretreatment if high turbidity or algae.	Variable *Giardia* removals & disinfection required for virus credit.

1 National Research Council (NRC), Committee on Small Water Supply Systems. "Safe Water From Every Tap: Improving Water Service to Small Communities." National Academy Press, Washington, D.C. 1997.

2 Adham, S.S., Jacangelo, J.G., and Laine, J.M. "Characteristics and Costs of MF and UF Plants." *Journal American Water Works Association*, May 1996.

Limitations Footnotes

a. Involves coagulation. Coagulation chemistry requires advanced operator skill and extensive monitoring. A system needs to have direct full-time access or full-time remote access to a skilled operator to use this technology properly.
b. Water service interruptions can occur during the periodic filter-to-waste cycle, which can last from six hours to two weeks.
c. Filter cake should be discarded if filtration is interrupted. For this reason, intermittent use is not practical. Recycling the filtered water can remove this potential problem.
d. Blending (combining treated water with untreated raw water) cannot be practiced at risk of increasing microbial concentration in finished water.
e. Post-disinfection recommended as a safety measure and for residual maintenance.
f. Post-treatment corrosion control will be needed prior to distribution.
g. Disinfection required for viral inactivation.
h. Site-specific pilot testing prior to installation likely to be needed to ensure adequate performance.
i. Technologies may be more applicable to system serving fewer than 3,300 people.

Compliance Technology For The Total Coliform Rule

40 CFR 141.63(d)–Best technologies or other means to comply (Complexity level indicated)	Comments/Water quality concerns
Protecting wells from contamination, i.e., placement and construction of well(s) (Basic).	Ten State Standards and other standards (AWWA A100–90) apply; interfacing with other programs essential (e.g., source water protection program).
Maintenance of a disinfection residual for distribution system protection (Intermediate).	Source water constituents may affect disinfection: iron, manganese, organics, ammonia, and other factors may affect dosage and water quality .T otal Coliform Rule (TCR) remains unspecific on type/amount of disinfectant, as each type differs in concentration, time, temperature, pH, interaction with other constituents, etc.
Proper maintenance of distribution system: pipe repair/replacement, main flushing programs, storage/reservoir and operation and maintenance (O&M) programs (including cross-connection control/backflow prevention), and maintenance of positive pressure throughout (Intermediate).	O&M programs particularly important for smaller systems needing to maintain water purity. States may vary on distribution protection measures. See also EP A's Cross-Connection Control Manual (#EPA 570/9-89-077).
Filtration and/or disinfection of surface water or other groundwater under direct influence; or disinfection of groundwater (Basic thru Advanced).	Same issues as cited above under maintaining disinfection residual; pretreatment requirements affect complexity of operation. Refer to Surface Water Treatment Rule Compliance Technology List; and other regulations under development.
Groundwaters: Compliance with State Wellhead Protection Program (Intermediate).	EPA/State Wellhead Protection Program implementation (per §1428 SDWA): may be used to assess vulnerability to contamination, and in determination of sampling and sanitary survey frequencies.

Technologies for Inorganic Contaminants

Unit Technology	Limitations (see footnotes)	Operator skill level required	Raw water quality range
1.Activated Alumina	(a)	Advanced	Groundwaters, competing anion concentrations will affect run length.
2.Ion Exchange (IO)		Intermediate	Groundwaters with low total dissolved solids, competing ion concentrations will affect run length.
3.Lime Softening	(b)	Advanced	Hard ground and surface waters.
4.Coagulation/Filtration	(c)	Advanced	Can treat wide range of water quality.
5.Reverse Osmosis (RO)	(d)	Advanced	Surface water usually require prefiltration.
6.Alkaline Chlorination	(e)	Basic	All groundwaters.
7.Ozone Oxidation		Intermediate	All groundwaters.
8.Direct Filtration		Advanced	Needs high raw water quality.
9.Diatomaceous earth filtration		Intermediate	Needs very high raw water quality.
10.Granular Activated Carbon		Basic	Surface waters may require prefiltration.
11.Electrodialysis Reversal		Advanced	Requires prefiltration for surface water.
12.Point of Use (POU)-IO	(f)	Basic	Same as Technology #2.
13.POU-RO	(f)	Basic	Same as Technology #5.
14.Calcium Carbonate Precipitation	(g)	Basic	Waters with high levels of alkalinity and calcium.
15.pH and alkalinity adjustment (chemical feed)	(g)	Basic	All ranges.
16.pH and alkalinity adjustment (limestone contactor)	(h)	Basic	Waters that are low in iron and turbidity. Raw water should be soft and slightly acidic.
17.Inhibitors		Basic	All ranges.
18.Aeration	(i)	Basic	Waters with moderate to high carbon dioxide content.

Limitations Footnotes

a. Chemicals required during regeneration and pH adjustments may be difficult for small systems to handle.
b. Softening chemistry may be too complex for small systems.
c. It may not be advisable to install coagulation/filtration solely for inorganics removal.
d. If all of the influent water is treated, post-treatment corrosion control will be necessary.
e. pH must exceed pH 8.5 to ensure complete oxidation without build-up of cyanogen chloride.
f. When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance.
g. Some chemical feeds require high degree of operator attention to avoid plugging.
h. This technology is recommended primarily for the smallest size category.
i. Any of the first five aeration technologies listed for volatile organic contaminants can be used.

Technologies for Volatile Organic Contaminants

Unit technology	Limitations (see footnotes)	Operator skill level required	Raw water quality range[1]
1. Packed Tower Aeration (PTA)	(a)	Intermediate	All groundwaters.
2. Diffused Aeration	(a, b)	Basic	All groundwaters.
3. Multi-Stage Bubble Aerators	(a, c)	Basic	All groundwaters.
4. Tray Aeration	(a, d)	Basic	All groundwaters.
5. Shallow Tray Aeration	(a, e)	Basic	All groundwaters.
6. Spray Aeration	(a, f)	Basic	All groundwaters.
7. Mechanical Aeration	(a, g)	Basic	All groundwaters.
8. Granular Activated Carbon (GAC)	(h)	Basic	All groundwaters.

1 National Research Council (NRC). "Safe Water from Every Tap: Improving Water Service to Small Communities." National Academy Press. Washington, DC. 1997.

Limitations Footnotes

a. Pretreatment for the removal of microorganisms, iron, manganese, and excessive particulate matter may be needed. Post-treatment disinfection may have to be used.
b . May not be as efficient as other aeration methods because it does not provide for convective movement of the water thus limiting air-water contact. It is generally used only to adapt exisiting plant equipment.
c. These units are highly efficient; however, the efficiency depends upon the air-to-water ratio.
d. Costs may increase if a forced draft is used. Slime and algae growth can be a problem but can be controlled with chemicals such as copper sulfate or chlorine.
e. These units require high air-to-water ratios (100-900 m3/m3).
f. For use only when low removal levels are needed to reach a maximum contaminant level (MCL) because these systems may not be as energy efficient as other aeration methods because of the contacting system.
g. For use only when low removal levels are needed to reach an MCLbecause these systems may not be as energy efficient as other aeration methods because of the contacting system. The units often require large basins, long residence times, and high energy inputs, which may increase costs.
h. See the Synthetic Organic Compounds (SOC) compliance technology table for limitation regarding these technologies.

Have you read all of our fact sheets?

"Tech Briefs," drinking water treatment fact sheets have been a regular feature in National Drinking Water Clearinghouse (NDWC) newsletter *On Tap* for more than three years. NDWC Technical Assistance Specialist Mohamed Lahlou, Ph.D., researches, compiles information, and writes these very popular items.

- Tech Brief: Disinfection, item #DWBLPE47;
- Tech Brief: Filtration, item #DWBLPE50;
- Tech Brief: Corrosion Control, item #DWBLPE52;
- Tech Brief: Ion Exchange and Demineralization, item #DWBLPE56;
- Tech Brief: Organics Removal, item #DWBLPE59;
- Tech Brief: Package Plants, item #DWBLPE63;
- Tech Brief: Water Treatment Plant Residuals Management, item #DWBLPE65;
- Tech Brief: Lime Softening, item #DWBLPE67;
- Tech Brief: Iron and Manganese Removal, item #DWBLPE70;
- Water Conservation Measures Fact Sheet, item #DWBLPE74;
- Tech Brief: Membrane Filtration, item #DWBLPE81; and
- Tech Brief: Treatment Technologies for Small Drinking Water Systems.

Additional copies of fact sheets are free; however, postal charges may be added. To order, call the NDWC at (800) 624-8301 or (304) 293-4191. You may also order online at *ndwc_orders@estd.wvu.edu*, or download fact sheets from our Web site at http://www.ndwc.wvu.edu.

For further information, comments about this fact sheet, or to suggest topics, call Lahlou at one of the above numbers or contact him via e-mail at *mlahlou2@wvu.edu*.

Technologies for Synthetic Organic Compounds

Unit technology	Limitations (see footnotes)	Operator skill level required[1]	Raw water quality range and considerations[1]
1. Granular Actived Carbon (GAC)		Basic	Surface water may require prefiltration.
2. Point of Use GAC	(a)	Basic	Surface water may require prefiltration.
3. Powdered Activated Carbon	(b)	Intermediate	All waters.
4. Chlorination	(c)	Basic	Better with high quality waters.
5. Ozonation	(c)	Basic	Better with high quality waters.
6. Packed Tower Aeration (PTA)	(d)	Intermediate	All groundwaters.
7. Diffused Aeration	(d, e)	Basic	All groundwaters.
8. Multi-Stage Bubble Aerators	(d, f)	Basic	All groundwaters.
9. Tray Aeration	(d, g)	Basic	All groundwaters.
10. Shallow Tray Aeration	(d, f)	Basic	All groundwaters.

1 National Research Council (NRC). "Safe Water from Every Tap: Improving Water Service to Small Communities." National Academy Press. Washington, DC. 1997.

Limitations Footnotes

a. When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance.
b. Most applicable to small systems that already have a process train including basins mixing, precipitation or sedimentation, and filtration. Site specific design should be based on studies conducted on the system's particular water.
c. See the Surface Water Treatment Rule compliance technology tables for limitations associated with this technology.
d. Pretreatment for the removal of microorganisms, iron, manganese, and excessive particulate matter may be needed. Post-treatment disinfection may have to be used.
e. May not be as efficient as other aeration methods because it does not provide for convective movement of the water thus limiting air-water contact. It is generally used only to adapt existing plant equipment.
f. These units are highly efficient; however, the efficiency depends upon the air-to-water ratio.
g. Forces may increase if a forced draft is used.

Technologies for Radionuclides

Unit technology	Limitations (see footnotes)	Operator skill level required[1]	Raw water quality range and considerations[1]
1. Ion Exchange (IO)	(a)	Intermediate	All groundwaters.
2. Point of Use (POU) IO	(b)	Basic	All groundwaters.
3. Reverse Osmosis (RO)	(c)	Advanced	Surface waters, usually require prefiltration.
4. POU RO	(b)	Basic	Surface waters, usually require prefiltration.
5. Lime Softening	(d)	Advanced	All waters.
6. Green Sand Filtration	(e)	Basic	
7. Co-precipitation with Barium Sulfate	(f)	Intermediate to Advanced	Groundwaters with suitable water quality.
8. Electrodialysis/Electrodialysis Reversal		Basic to Intermediate	All groundwaters.
9. Pre-formed Hydrous Manganese Oxide Filtration	(g)	Intermediate	All groundwaters.

1 National Research Council (NRC). "Safe Water from Every Tap: Improving Water Service to Small Communities." National Academy Press. Washington, DC. 1997.

Limitations Footnotes

a. The regeneration solution contains high concentrations of the contaminant ions. Disposal options should be carefully considered before choosing this technology.
b. When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance.
c. Reject water disposal options should be carefully considered before choosing this technology. See other RO limitations described in the Surface Water Treatment Rule Compliance Technologies Table.
d. The combination of variable source water quality and the complexity of the chemistry involved in lime softening may make this technology too complex for small surface water systems.
e. Removal efficiencies can vary depending on water quality.
f. This technology may be very limited in application to small systems. Since the process requires static mixing, detention basins, and filtration; it is most applicable to systems with sufficiently high sulfate levels that already have a suitable filtration treatment train in place.
g. This technology is most applicable to small systems that already have filtration in place.

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Treatment Technologies for Small Drinking Water Systems

Introduction

Small systems still face difficulties in meeting the requirements of the Safe Drinking Water Act (SDWA) because many technologies available to large systems may be too expensive or complicated for small systems to consider. Furthermore, trained operators and maintenance personnel may not always be available or affordable, leading to standards violations.

Overview of Some Treatment Technologies Used by Small Systems

When the SDWA was reauthorized in 1996, it addressed small system drinking water concerns and required the U.S. Environmental Protection Agency (EPA) to assess treatment technologies relevant to small systems serving fewer than 10,000 people. With this requirement, the SDWA also identified two classes of technologies:

¥ compliance technologiesÑwhich refer to affordable technologies or other treatment techniques (TT) that comply with the maximum contaminant level (MCL) and to technologies that satisfy a TT requirement. Options include package plants or modular systems, and point-of-entry (POE) or point-of-use (POU) treatment; and

¥ variance technologiesÑwhich refer to technologies that must reduce contaminants to levels that protect public health. These technologies may not achieve compliance with the MCL or TT requirement, but must achieve the maximum reduction or inactivation efficiency affordable to a system, considering its size and the quality of the source water.

With small systemsÕ needs in mind, the National Research Council (NRC) recently published the results of a studyÑ Safe Water From Every Tap: Improving Water Service to Small Communities Ñ which found that continuous technical and financial assistance is still needed to help more than 54,000 small systems comply with changing regulations. In addition, the NRC study discussed some water treatment technologies that small systems may use to provide safe drinking water to their customers. These treatment technologies are also explained separately through Tech Briefs, four-page water treatment fact sheets, offered by the National Drinking Water Clearinghouse (NDWC). These fact sheets are available online at http://www.ndwc.wvu.edu or by calling (800) 624-8301.

1. Disinfection

The Surface Water Treatment Rule (SWTR) requires public water systems to disinfect water obtained from surface water supplies or groundwater sources under the influence of surface water. Primary methods of disinfection are chlorine gas, chloramines, ozone, ultraviolet light, chlorine dioxide, and hypochlorite.

Chlorine (gas)

Chlorine gas removes almost all microbial pathogens and is appropriate as both a primary and secondary disinfectant. Chlorine is a dangerous gas that is lethal at concentrations as low as 0.1 percent air by volume. Adequate mixing and contact time must be provided after injection to ensure complete disinfection of pathogens.

Hypochlorites

Sodium hypochlorite is available as a solution in concentrations of five to 15 percent chlorine, but is more expensive than chlorine gas. Sodium hypochlorite is easier to handle than gaseous chlorine or calcium hypochlorite, but it is very corrosive and must be kept away from equipment that can be damaged by corrosion.

Calcium hypochlorite is a solid white substance, which is 65 percent available chlorine and dissolves easily in water. It is a corrosive material with a strong odor that must be kept away from organic materials, such as wood, cloth, and petroleum products because of the dangers of fire or explosion. Calcium hypochlorite readily absorbs moisture, forming chlorine gas so shipping containers must be emptied completely or carefully resealed.

Chloramines

Chloramines are formed when water containing ammonia is chlorinated or when ammonia is added to water containing chlorine. An effective bactericide that produces fewer disinfection byproducts, chloramine is generated onsite. It is a weak disinfectant and is much less effective against viruses or protozoa than free chlorine. Chloramine is appropriate for use as a secondary disinfectant to prevent bacterial regrowth in a distribution system. Nitrogen trichloride appears to be the only detrimental reaction. Adequate contact and mixing time must be provided.

Ozonation

Ozone is a powerful oxidizing and disinfecting agent formed by passing dry air through a system of high voltage electrodes. Requiring shorter contact time and a smaller dosage than chlorine, ozone is widely used as a primary disinfectant. Ozone does not directly produce halogenated organic materials unless a bromide ion is present. A secondary disinfectant, usually chlorine, is required because ozone does not maintain an adequate residual in water. The capital costs of ozonation systems may be high and operation and maintenance are relatively complex.

Ultraviolet Light

Ultraviolet (UV) radiation, which is generated by a special lamp, penetrates the cell wall of an organism, rendering it unable to reproduce. UV radiation effectively destroys bacteria and viruses. As with ozone, a secondary disinfectant must be used to prevent regrowth of microorganisms. UV radiation:

¥ is readily available,
¥ produces no known toxic residuals,
¥ requires short contact times, and
¥ is easy to operate and maintain.

Conventional UV radiation may not inactivate Giardia lamblia or Cryptosporidium cysts in a cost-effective way, and should be used only by groundwater systems not directly influenced by surface water and where there is virtually no risk of protozoan cyst contamination. UV radiation is unsuitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter. However, microorganisms can be killed without generating byproducts of chemical oxidation or halogenation.

Chlorine Dioxide

Chlorine dioxide, although a powerful oxidant, may be more difficult to handle than other forms of chlorine. Chlorine dioxide requires trained staff to manage its use and is so reactive that it may not provide a residual disinfectant in the distribution system. Photochemical decomposition of chlorine dioxide in reservoirs may increase chlorate concentrations, and other factors, including the generation process used and water pH, can affect chlorate and chlorite levels.

2. Filtration

Federal and state laws require all surface water systems and systems under the influence of surface water to filter their water. Filtration methods include slow and rapid sand filtration, diatomaceous earth filtration, direct filtration, membrane filtration, and cartridge filtration.

Slow Sand Filtration

The filter consists of a bed of fine sand approximately three to four feet deep supported by a one-foot layer of gravel and an underdrain system. It is a low-cost, simple to operate, reliable technology, and it is able to achieve greater than 99.9 percent Giardia cyst removal. Slow sand filtration is not suitable for water with high turbidity. The filter surface requires maintenance. Extensive land is required due to low-flow operation. Biological processes and chemical/physical processes common to various types of filters occur on the surface of the filter bed. Slow sand filters do not require coagulation/flocculation and may not require sedimentation.

Diatomaceous Earth Filtration

Diatomaceous earth (DE) filtration, also known as precoat or diatomite filtration, relies on a layer of diatomaceous earth approximately 1/8-inch thick placed on a septum or filter element. Septums may be placed in pressure vessels or operated under a vacuum in open vessels. The filters are simple to operate and effective in removing cysts, algae, and asbestos. They have been chosen for projects with limited initial capital, and for emergency or standby capacity to service large seasonal increases in demand. This filter is most suitable for water with low bacterial counts and low turbidity. Coagulant and filter aids are required for effective virus removal. Since chemical coagulation is not required, small water systems have used DE filtration for many years.

Direct Filtration

Direct filtration systems are similar to conventional systems, but omit sedimentation. Effective direct filtration performance ranges from 90 to 99 percent for virus removal and from 10 to 99.99 percent for Giardia removal. Coagulation must be included for Giardia removal. Direct filtration is often used with steel pressure vessels to maintain the pressure in a water line to avoid repumping after filtration. Direct filtration is only applicable for systems with high quality and seasonally consistent influent supplies. Direct filtration requires advanced operator skill and has frequent monitoring requirements.

Membrane Filtration

More stringent water quality regulations and inadequate water resources are making membrane technology increasingly popular as an alternative treatment technology for drinking water. Capital, operation, and maintenance costs continue to decline, making membrane processes more viable.

Nanofiltration (NF) : This membrane process employs pressures between 75 to 150 pounds per square inch (psi) for operation. While it provides removal of ions contributing to hardness (i.e., calcium and magnesium), the technology is also very effective for removing color and disinfection byproducts precursors.

Ultrafiltration (UF) : Operational pressures range from 10 to 100 psi, depending upon the application. UF may be employed for removal of some organic materials from freshwater and may be used for liquid/solid separation.

Microfiltration (MF) : A major difference between MF and UF is membrane pore size. The primary applications for this membrane process are particulate and microbial removal.

Bag Filtration

Bag filtration systems are based on physical screening processes. If the pore size of the bag filter is small enough, parasite removal will occur. Unless the quality of the raw water precludes the need for pretreatment, EPA recommends pretreatment of the raw water using sand or multimedia filters, followed by preliminary bag or cartridge filtration, and the use of micron filters as final filters to increase particulate removal efficiencies and to extend the life of the filter.

Cartridge Filtration

Cartridge filters are an emerging technology suitable for removing microbes and turbidity. These filters are easy to operate and maintain, making them suitable for treating low-turbidity influent. They can become fouled relatively quickly and must be replaced with new units. Although these filter systems are operationally simple, they are not automated and can require relatively large operating budgets. A disinfectant is recommended to prevent surface-fouling microbial growth on the cartridge filters and to reduce microbial passthrough.

Backwashable Depth Filtration

Backwashable depth filters operate in part like cartridge filters. This method filters uncoagulated water and is designed to be backwashed when terminal head loss is attained or turbidity breakthrough occurs.

3. Corrosion Control

Corrosion in a system can be reduced by adjusting pH and alkalinity, softening the water, and changing the level of dissolved oxygen. Any corrosion adjustment program should include monitoring as water characteristics change over time.

pH Adjustment: Operators can promote the formation of a protective calcium carbonate coating (scale) in water lines by adjusting pH, alkalinity, and calcium levels.

Lime Softening: Lime softening affects leadÕs solubility by changing the waterÕs pH and carbonate levels. Hydroxide ions are then present, and they decrease metal solubility by promoting the formation of solids that protect the surface of the pipe.

Dissolved Oxygen Levels: The presence of excessive dissolved oxygen increases waterÕs corrosive activity. However, removing oxygen from water is not practical because of the expense. The following strategies may be used to minimize the presence of oxygen:

¥ exclude the aeration process in groundwater treatment,
¥ increase lime softening,
¥ extend the detention periods for treated water in reservoirs, or
¥ use the correct size water pumps in the treatment plant to minimize the introduction of air during pumping.

4. Ion Exchange and Demineralization

Ion exchange and membrane processes are becoming used extensively in water and wastewater treatment. Ion exchange is primarily used to remove of hardness ions, such as magnesium and calcium, and for water demineralization. Reverse osmosis and electrodialysis, both membrane processes, remove dissolved solids from water using membranes.

Ion Exchange (IO)

IO units can be used to remove any charged (ionic) substance from water, but are usually used to remove hardness and nitrate from groundwater. Ion exchange effectively removes more than 90 percent of barium, cadmium, chromium, silver, radium, nitrites, selenium, arsenic, and nitrate. Ion exchange is usually the best choice for removing radionuclides.

Reverse Osmosis (RO)

RO systems are compact, simple to operate, and require minimal labor, making them suitable for small systems where there is a high degree of seasonal fluctuation in water demand. RO can effectively remove nearly all inorganic contaminants from water. Properly operated units will attain 96 percent removal rates. RO can also effectively remove radium, natural organic substances, pesticides, and microbiological contaminants. RO is particularly effective when used in series. Water passing through multiple units can achieve near zero effluent contaminant concentrations.

Electrodialysis

Electrodialysis is very effective in removing fluoride and nitrate and can also remove barium, cadmium, and selenium.

Some of the advantages are:

¥ all contaminant ions and most dissolved non-ions are removed,
¥ it is relatively insensitive to flow and total dissolved solids (TDS) level, and
¥ it may have low effluent concentration.

Some of the limitations are:

¥ high capital and operating costs,
¥ high level of pretreatment required,
¥ reject stream is 20 to 90 percent of feed flow, and
¥ electrodes require replacement.

Activated Alumina

Activated Alumina (AA) is a physical and chemical process in which ions in the feed water are sorbed to an oxidized AA surface. AA is used in packed beds to remove contaminants such as fluoride, arsenic, selenium, silica, and natural organic matter

5. Organic Removal

The technologies most suitable for organic contaminant removal in drinking water systems are granular activated carbon (GAC) and aeration. GAC has been designated by the EPA as the best available technology (BAT) for synthetic organic chemical removal.

Granular Activated Carbon

Several operational and maintenance factors affect the performance of GAC. Contaminants in the water can occupy GAC adsorption sites, whether they are targeted for removal or not. Also, adsorbed contaminants can be replaced by other contaminants with which GAC has a greater affinity. Therefore, the presence of other contaminants might interfere with the removal of the contaminants of concern.

After a period of months or years, depending on the concentration of contaminants, the surface of the pores in the GAC can no longer adsorb contaminants. The carbon must then be replaced.

Aeration

Aeration, also known as air stripping, mixes air with water to volatilize contaminants (turn them to vapor), which are either released directly to the atmosphere or treated and released. Aeration is used to remove volatile organic chemicals (VOC) and can also remove radon. A small system might be able to use a simple aerator constructed from relatively common materials instead of a specially designed aerator system. Aerators include:

¥ a system that cascades the water or passes it through a slotted container,
¥ a system that runs water over a corrugated surface, or
¥ an airlift pump that introduces oxygen as water is drawn from a well.

Other Aeration Types

Packed Column Aeration (PCA): PCA or packed tower aeration (PTA) is a waterfall aeration process that drops water over a medium within a tower to mix the water with air. The medium is designed to break the water into tiny droplets and to maximize its contact with air bubbles for removal of the contaminant. Air is also blown in from underneath the medium to enhance this process. Packed columns usually operate automatically and need only daily visits to ensure that the equipment is running satisfactorily. Maintenance requirements include servicing pump and blower motors and replacing air filters on the blower.

Diffused Aeration: In a diffused aeration system, a diffuser bubbles air through a contact chamber for aeration. The diffuser is usually located near the bottom of the chamber where pressurized air is introduced. The main advantage of diffused aeration systems is that they can be created from existing structures, such as storage tanks. However, these systems are less effective than PCA and usually are employed only in systems with adaptable existing structures.

Multiple Tray Aeration: Multiple tray aeration directs water through a series of trays made of slats, perforations, or wire mesh. A blower introduces air from underneath the trays. Multiple tray aeration units have less surface area than PCA units and can experience clogging from iron and manganese, biological growth, and corrosion problems. Multiple tray aeration units are readily available from package plant manufacturers.

Shallow Tray Aeration (STA): STAs involve the use of shallow trays and are more efficient than multiple tray aerators. STAs increase the available area of mass transfer; thereby increasing the removal efficiency of most VOCs. However, because of the high air-to-water ratio, greater energy costs may be incurred.

Spray Aeration: Spray aeration is an accepted technology in which the contaminated water is sprayed through nozzles. The small droplets produced expose a large interfacial surface area through which VOCs can migrate from a liquid (water) phase to the gaseous (air) phase. Spray aerators have been used to effectively treat VOCs, but are not energy efficient and need a large operational area.

Mechanical Aeration: Mechanical aeration uses mechanical stirring mechanisms to mix air with the water. These systems can effectively remove VOCs. Mechanical aeration units need large amounts of space because they demand long detention times for effective treatment. As a result, they often require open-air designs, which can freeze in cold climates. However, mechanical aeration systems are easy to operate and are less susceptible to clogging from biological growth than PCA systems.

6. Lime Softening

Lime softening is best suited to groundwater sources, which have relatively stable water quality. The combination of variable source water quality and the complexity of the chemistry of lime softening may make it too complicated for small systems that use surface water sources. Lime softening is unlikely to be suitable for treating groundwater in systems serving 500 or fewer people unless those systems have access to a trained operator who can monitor the treatment process. Either hydrated lime or quicklime may be used in the softening process. The choice depends upon economic factors, such as the relative cost per ton of the two materials as well as the size and equipment of the softening plant.

What are other softening alternatives?

The selection of lime, lime-soda ash, or caustic soda softening is based on cost, TDS criteria, sludge production, carbonate and noncarbonate hardness, and chemical stability. Water containing little or no noncarbonate hardness can be softened with lime alone. Caustic soda softening increases the TDS of treated water, while lime and lime-soda ash softening often decrease TDS. Caustic soda softening produces less sludge than lime and lime-soda ash softening. Caustic soda does not deteriorate during storage, while hydrated lime may absorb carbon dioxide and water during storage, and quicklime may slake in storage causing feeding problems. The final selection is generally based on cost, water quality, and owner and operator preference.

For More Information

Small drinking water systems are more likely to violate SDWA regulations because when MCLs were set, they were based upon systems serving larger metropolitan areas. Thus, small systems must explore innovative technologies that they can afford. The NDWCÕs RESULTS (Registry of Equipment Suppliers of Treatment Technologies for Small Systems) database houses information related to small drinking water systems. The clearinghouse gathered this information from system operators, drinking water state offices, vendors, and others.

Database searches are available from the NDWC through combinations of site location, vendor name, type of technology, type of contaminant, and system sizeÑand they include contact names and telephone numbers. Consulting engineers, local officials, private owners, and regulators may use RESULTS to understand new technologies that are affordable, appropriate, and reliable. Information in RESULTS may be obtained three ways: access the database through the NDWCÕs Web site located at http://www.ndwc.wvu.edu, call the NDWC at (800) 624-8301 or (304) 293-4191 and ask a technical assistant to perform a search for you; or order a copy of the RESULTS diskette, available in DOS or Macintosh versions, from the NDWC for a small fee.

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* NDWC RESULTS Database: Small Water Systems Technologies report and Tech Briefs are available online at http://www.ndwc.wvu.edu or by calling (800) 624-8301 or (304) 293-4191.