7.2 Water Purification

EPA WaterSense

Overview

Water purification systems are used in laboratory and medical applications requiring high-quality water that is free of minerals and organic contaminants. Generally, these systems purify water through physical or chemical means. Many water purification systems use additional water during a backwash phase to remove particle buildup on the purification media, or discharge a reject stream containing concentrated contaminants. Typically, as finer particles are removed, the purification process becomes more water- and energy-intensive. Therefore, it is important to evaluate the level of water quality required to ensure that the system does not deliver a higher level of purification than is needed. Systems that deliver a higher water quality than the facility needs will often be more expensive to operate than a more appropriate system and can result in wasted water and energy.

Water purification system in a laboratory

There are several technical standards for water quality that facilities can use to evaluate the appropriate water purification method, including ASTM International *ASTM D1193 Standard Specification for Reagent Water* and the International Organization for Standardization (ISO) *ISO 3696 Water for Analytical Laboratory Use—Specification and Test Methods*. These standards generally classify water quality into specific types based on the quality required.[3]

When determining the level of treatment needed to supply water of a specific quality, there are a number of water purification technologies used in lab and medical facilities that can be considered. These include: microporous filtration, carbon filtration, deionization, distillation, membrane processes, and water softening. Because no single water purification system is able to remove 100 percent of all contaminants, it is common for multiple water purification technologies to be installed in sequence where only a low level of contaminants can be tolerated.

Microporous Filtration

Microporous filtration physically removes solid contaminants by capturing them on the surface of the media. Microporous filtration typically occurs at low pressures and does not remove any dissolved solids.[4] After a period of use, filters will require backwashing with water to remove contaminants trapped on the media surface.

Carbon Filtration

Carbon filtration uses adsorption to attract particles as water passes through the filter. The adsorption process depends upon the physical characteristics of the activated carbon; the chemical compositions of the carbon and the contaminants;

[3] Millipore. Overview of Lab Water Grades. www.millipore.com/lab_water/clw4/tutorial&tabno=4.
[4] Messinger, Stephen. September 2006. "What Makes Water Taste Best?" *Water Conditioning & Purification Magazine*. www.wcponline.com/TOC.cfm?ISN=110.

the temperature and pH of the water; and the amount of time the contaminant is exposed to the activated carbon.[5] Carbon filters can use either disposable cartridges or packed columns. Disposable cartridges are disposed of once the adsorptive capacity is exhausted. Alternatively, packed columns can be removed and regenerated off site.[6] Water use is required to regenerate the columns; however, since regeneration is typically done off site, no water is used at the facility level.

Deionization

Deionization is a physical process similar to water softening that exchanges cations and anions present in the untreated water with hydrogen and hydroxide ions. Deionization is not effective at removing particulates, but because the process is relatively fast, it is commonly used in laboratory applications requiring a low level of water purification. Regeneration of deionization resins often occurs off site.[7] Water use is required to regenerate the resin; however, since the regeneration is done off site, no water is used at the facility level.

Distillation

Distillation functions by boiling water to form steam condensate using either an electric or gas still. Solid contaminants are left behind as the steam is generated, then the steam is condensed into a purified water stream. Distillers can use large volumes of water if once-through cooling water is used in the condenser, or if a reject stream is discharged from the boiler to prevent scale buildup. These systems typically reject 15 to 25 percent of water entering the system.[8]

Membrane Processes (Including Reverse Osmosis)

Membrane processes use a semi-permeable membrane layer to separate purified water from contaminants. Several types of membranes are used for water purification, including (from largest to smallest size of particles removed) microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. Because reverse osmosis is capable of removing the smallest particles, it is used most often by laboratory and medical facilities requiring very pure water.

Reverse osmosis system

Reverse osmosis units use pressure to reverse osmotic pressure and force water with a high solute concentration through a membrane filter to create purified (i.e., low solute) water. Reverse osmosis is

[5] University of Minnesota | Extension. 1992. Treatment Systems for Household Water Supplies: Activated Carbon Filtration (Clean Water Series). www.extension.umn.edu/distribution/naturalresources/DD5939.html.
[6] East Bay Municipal Utility District (EBMUD). 2008. *WaterSmart Guidebook—A Water-Use Efficiency Plan Review Guide for New Businesses*. Pages TREAT1-6. www.ebmud.com/for-customers/conservation-rebates-and-services/commercial/watersmart-guidebook.
[7] Water Online. Deionization. www.wateronline.com/product.mvc/Deionization-0001.
[8] EBMUD, *op. cit*.

able to remove a large portion of contaminants but recovers only a portion of the incoming water. The recovery rate, defined as the ratio of the purified water (i.e., permeate) to feed (i.e., incoming) water, is used to depict the efficiency of a reverse osmosis system. For commercial and institutional applications, reverse osmosis units typically have recovery rates of 50 to 75 percent.[9] Thus, the systems reject 25 to 50 percent of water entering the system.

Water Softening

Water softening is used to remove hardness minerals, such as calcium and magnesium, from water. Cation exchange water softeners are the most common type of water softening system, although other water purification technologies, such as reverse osmosis and distillation systems, can also soften water.

In a cation exchange water softener, hard water with positively charged calcium and magnesium ions passes through a mineral tank consisting of positively charged sodium ions attached to a bed of negatively charged resin beads. The calcium and magnesium ions are exchanged for the sodium ions on the resin beads, which causes the gradual depletion of available ion exchange sites. Eventually, the water softener must be regenerated to replenish the softening capacity. The regeneration process uses water to purge and rinse the system and replenish the sodium ion supply on the resin beads. As a result, the system generates sodium-rich wastewater that must be disposed.

The frequency of regeneration and the amount of water used by the water softening process is dictated by the hardness of the incoming water, the rate of water consumption, and the hardness removal capacity of the cation exchange water softener. The most efficient cation exchange water softeners are demand-initiated, which base the frequency of regeneration on the incoming water's hardness or the demand for softened water rather than a set regeneration schedule.

Other Technologies

Several less common technologies are also used to purify water. Chlorine compounds, ozone, or hydrogen peroxide can be used to chemically disinfect water. Ultraviolet light, heat, and extreme mechanical sheer can also be used to treat water with contaminants. These technologies might not require the backwash phase used by other water purification technologies, but they can require regular cleaning, which can be water-intensive.[10] Chemical disinfection can use additional water if chemicals are added in liquid or slurry form.

[9] U.S. Environmental Protection Agency (EPA) and U.S. Energy Department (DOE), Energy Efficiency & Renewable Energy (EERE), Federal Energy Management Program (FEMP). May 2005. *Laboratories for the 21st Century: Best Practices, Water Efficiency Guide for Laboratories*. Page 5. www1.eere.energy.gov/femp/program/labs21_bmp.html.

[10] EBMUD, *op. cit*.

Operation, Maintenance, and User Education

For optimal water purification system efficiency, consider the following operation, maintenance, and user education techniques:

- Use water purification only when necessary and match the process to the actual quality of water required.
- For filtration processes, base backwash phases upon the pressure differential across the filtration media. A pressure drop will indicate that the filter requires backwashing.
- For carbon filtration and deionization processes where regeneration occurs off site, work with maintenance professionals to determine an optimal schedule for removing and regenerating units. This can be determined based on incoming water characteristics and the amount and quality of purified water required daily. Deionization systems should require regeneration based on the volume of water treated or conductivity.
- For distillation systems, periodically clean the boiling chamber to remove accumulated minerals. This will ensure efficient operation of the system.
- For water softeners, work with a plumbing professional or the product manufacturer to account for and program regeneration based upon the incoming water hardness and/or flow through the system. Monitor and adjust settings periodically.

Retrofit Options

Facilities might choose to install multiple water purification systems in sequence to increase the effectiveness and efficiency of the water purification process. When one of the later phases of treatment uses a membrane, at a minimum, it might be necessary to install a pretreatment step to remove larger particles.

For filtration processes, consider installing pressure gauges, if not already installed. Pressure gauges can be used to determine when to initiate a backwash phase.

Consider reusing water purification system reject water as an alternative onsite water source where appropriate and feasible. See *Section 8: Onsite Alternative Water Sources* for more information.

Replacement Options

Prior to purchasing a new water purification system or replacing an old one, evaluate the incoming water supply and assess the quality and quantity requirements of the intended use for a period of time. This will help to determine the level of water purification needed and the sizing of the system. Choose the least intensive treatment needed to achieve the desired quality level and size the system correctly for the intended use. Oversized systems can waste water and energy and lead to degraded quality due to of long, inoperable periods.

7.2 Water Purification

Consider water purification systems that require the least amount of backwashing or regeneration. For membrane processes such as reverse osmosis, consider a system with a high recovery rate for its size. For deionization systems, consider systems that regenerate based on the volume of water treated or conductivity. For distillation systems, consider units that use air-cooled coils, rather than water-cooled coils and recover at least 85 percent of the feed water.[11] For water softeners, consider demand-initiated systems instead of systems with manual or auto-initiated regeneration. In addition, consider installing multiple smaller, more efficient cation exchange water softeners that can be alternated to minimize the frequency of regeneration and allow for a constant, uninterrupted supply of soft water.

Savings Potential

The water use of a water purification system is dependent upon the level of purification required, incoming water quality, volume of use, and purified water demand. Water use is also specific to the type of water purification system used.

Carbon filtration and deionization systems are typically regenerated off site. If regenerated off site, the water use of these systems will not directly affect the water use of the facility. However, minimizing the frequency of removal and regeneration will help to reduce the water use of these systems.

The water use of distillers is dependent upon the method of cooling and the amount of reject water used to clear the boiler of scale buildup. Water savings can be maximized if air-cooled coils are used rather than water-cooled coils. Additionally, systems that produce less reject water will consume less water overall.

For filtration processes, water use is determined by the water quality requirements and frequency of the backwash phase. Optimizing the frequency of the backwash phase by initiating backwash only when a pressure drop occurs across the filter media will ensure less water is used overall.

The water efficiency of a reverse osmosis process can be determined by the recovery rate, which is defined as the ratio of permeate to feed. Systems with higher recovery rates are considered more efficient, because they are able to produce more purified water from the same amount of feed.

Recovery rates can vary widely depending upon the type of membrane and quality of incoming water. Some less efficient reverse osmosis systems, for example, have a recovery rate of 33 to 50 percent.[12] The recovery rate can be maximized by increasing the number of stages of membrane pressure vessels, which allows for higher pressures to be achieved in order to more effectively overcome natural osmosis. A one-stage system can achieve a recovery rate of 50 percent, while two- and three-stage systems can achieve recovery rates of 75 percent and 90 percent, respectively.[13] For example, the Sandia National Laboratories in Albuquerque, New Mexico, installed a high-efficiency reverse osmosis system with pretreatment before the membranes.

[11] *Ibid*.
[12] Pagliaro, Tony. 1995. "Commercial/Industrial Reverse Osmosis Systems: General Design Considerations." *WaterReview*. Page 3. www.wqa.org/pdf/Technical/cirodes.pdf.
[13] *Ibid*. Page 2.

The facility was able to achieve a 95 percent recovery rate, rejecting only 5 percent of the water entering the system.[14]

Additional Resources

East Bay Municipal Utility District. 2008. *WaterSmart Guidebook—A Water-Use Efficiency Plan Review Guide for New Businesses*. Pages TREAT1-6. www.ebmud.com/for-customers/conservation-rebates-and-services/commercial/watersmart-guidebook.

EPA and DOE, Energy Efficiency & Renewable Energy, Federal Energy Management Program. May 2005. *Laboratories for the 21st Century: Best Practices, Water Efficiency Guide for Laboratories*. Page 5. www1.eere.energy.gov/femp/program/labs21_bmp.html.

Schultz Communications. July 1999. *A Water Conservation Guide for Commercial, Institutional and Industrial Users*. Prepared for the New Mexico Office of the State Engineer. www.ose.state.nm.us/wucp_ici.html.

[14] EPA and DOE, EERE, FEMP. August 2009. *Microelectronics Plant Water Efficiency Improvements at Sandia National Laboratories*. Page 2. www1.eere.energy.gov/femp/program/waterefficiency_csstudies.html.