WaterSense at Work

Laboratory and Medical Equipment

7.1 Water Purification

Best Management Practices for Commercial and Institutional Facilities

EPA WaterSense

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WaterSense® is a voluntary partnership program sponsored by the U.S. Environmental Protection Agency (EPA) that seeks to protect the nation's water supply by transforming the market for water-efficient products, services, and practices.

WaterSense at Work is a compilation of water efficiency best management practices intended to help commercial and institutional facility owners and managers from multiple sectors understand and better manage their water use. It provides guidance to help establish an effective facility water management program and identify projects and practices that can reduce facility water use.

An overview of the sections in *WaterSense at Work* is below. This document, covering water efficiency for water purification systems, is part of **Section 7: Laboratory and Medical Equipment**. The complete list of best management practices is available at www.epa.gov/watersense/best-management-practices. WaterSense has also developed worksheets to assist with water management planning and case studies that highlight successful water efficiency efforts of building owners and facility managers throughout the country, available at www.epa.gov/watersense/commercial-buildings.

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This document is one section from *WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities* (EPA-832-F-23-003). Other sections can be downloaded from www.epa.gov/watersense/best-management-practices. Sections will be reviewed and periodically updated to reflect new information. The work was supported under contract 68HERC20D0026 with Eastern Research Group, Inc. (ERG).

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 processes. 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.

Water purification system in a laboratory

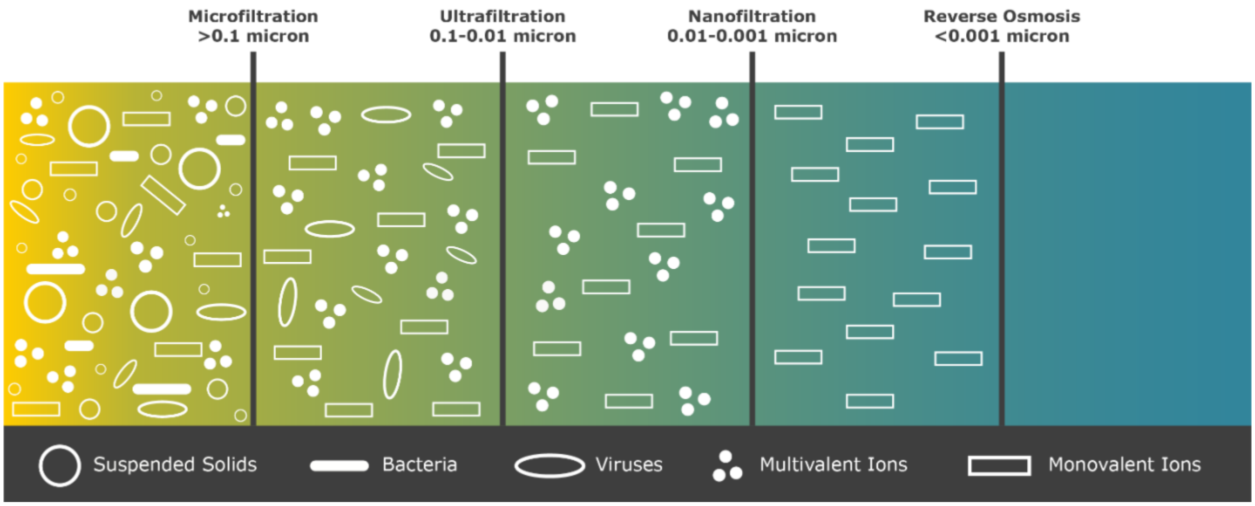
The various water purity levels (i.e., types or grades) required depend on the specific applications or end uses at the facility. There are several technical standards for water quality that facilities can use to help determine the appropriate water purity level needed for an application, including the ASTM International D1193 *Standard Specification for Reagent Water* and the International Organization for Standardization (ISO) 3696 *Water for Analytical Laboratory Use—Specification and Test Methods*. Once researchers determine the water purity level needed, lab managers can choose one or more water purification technologies that will achieve that water quality grade.

There are a number of water purification technologies that can be considered. These include: sediment and microporous filtration; carbon filtration; reverse osmosis and other membrane processes; water softening; deionization; and distillation. 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 impurities or contaminants can be tolerated. Typically, as finer particles are removed, the purification process becomes more water- and energy-intensive and potentially more expensive to operate. 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. Further, facility managers should work with researchers to evaluate what grade of water is needed to support the majority of their operations, and design centralized treatment systems to supply that grade. If higher-purity water is needed for certain applications, polishers or point-of-use treatment equipment can be used as necessary.[1]

Sediment and Microporous Filtration

Sediment and microporous filtration (e.g., microfiltration, ultrafiltration) physically remove suspended solid contaminants greater than the filter's rated pore size by capturing them on the surface of the media. Microporous filtration typically occurs at low pressures and does not remove any dissolved solids. As shown in Figure 1, microfiltration can remove particles down to 0.1 micron in size, and ultrafiltration can remove particles down to 0.01 micron.[2] After a period of use, filters will require backwashing with water to remove contaminants trapped on the media surface. To reduce water use from filtration processes, facilities can use pressure sensors to determine when the pressure drop in the filter is significant enough to require backwashing and conduct backwashing as infrequently as possible.[3] Some filtration processes include single-use cartridge filters that don't require backwashing, but they have to be disposed of when the filter is changed.

Figure 1. Water Contaminants Removed by Different Levels of Filtration and Membrane Processes



Carbon Filtration

Carbon filtration uses adsorption to remove chlorine and dissolved organics as water passes through the filter. Carbon filters can use either disposable cartridges or packed

[1] National Institutes of Health (NIH). March 2013. *Laboratory Water, Its Importance and Application*. Page 13. https://orf.od.nih.gov/TechnicalResources/Documents/DTR%20White%20Papers/Laboratory%20Water-Its%20Importance%20and%20Application-March-2013_508.pdf.

[2] International Institute for Sustainable Laboratories (I2SL) and U.S. Environmental Protection Agency (EPA). May 2022. *Best Practices Guide: Water Efficiency in Laboratories*. Page 8. www.epa.gov/system/files/documents/2022-06/ws-I2SL-Laboratory-Water-Efficiency-Guide.pdf.

[3] *Ibid*.

columns. Disposable cartridges are disposed of once the adsorptive capacity is exhausted. Alternatively, packed columns can be removed and regenerated off-site. Water use is required to regenerate the columns; however, when regeneration occurs off-site (which is typical), this would not impact facility water use. Although facility water use won't be impacted by off-site regeneration, facilities are still encouraged to regenerate packed columns only when necessary.

Reverse Osmosis and Other Membrane Processes

Membrane processes use a semi-permeable membrane layer to remove impurities at a smaller level than microporous filtration. As illustrated in Figure 1 on page 2, nanofiltration can remove particles down to 0.001 micron in size, and reverse osmosis can remove particles even less than 0.0001 micron.[4] Reverse osmosis membranes are able to reject bacteria, pyrogens, and organic and inorganic solids. Because reverse osmosis is capable of removing the smallest particles, it is used most often by laboratory and medical facilities requiring very pure water, and it is the most water-intensive membrane process.

Laboratory 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 removes a large portion of contaminants but recovers only a portion of the incoming water. Reverse osmosis systems produce two streams of water: the purified water (i.e., permeate) and the concentrated reject water, which contains a high level of dissolved minerals and is typically sent to the sanitary sewer. The percent recovery (also known as the recovery rating), defined as the ratio of 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 recoveries of 50 to 75 percent.[5,6] Thus, the systems reject 25 to 50 percent of water entering the system. Reverse osmosis systems can be optimized to increase percent recovery and reduce water use by pretreating incoming feed water to remove suspended and dissolved solids using other water purification technologies; using advanced membrane technologies (e.g., membranes with larger

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[4] *Ibid.*
[5] Hoffman, H.W. (Bill), et. al. May 2018. *Best Management Practices for Commercial and Institutional Water Users*. Prepared for the Texas Water Development Board. Page 44. www.twdb.texas.gov/conservation/BMPs/CI/index.asp.
[6] I2SL and EPA, *op. cit.,* Page 9.

surface area and/or higher permeability); and optimizing system flow configurations to use multiple stages of membranes or recycling a portion of the concentrated reject water. Fully optimized systems can achieve recoveries greater than 90 percent.[7]

Water Softening

Water softening is used to remove hardness minerals, such as calcium and magnesium, from water. Facilities often use water softeners to generate boiler feed water or pretreat water before it goes through other water purification technologies. 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. Regeneration typically happens onsite and, therefore, impacts a facility's overall water use.

It is also important to consider how much water is used during regeneration and the water softener's salt efficiency. Efficient water softeners can use 4 gallons (15 liters) of water or less per 1,000 grains of hardness removed and can achieve at least 3,500 grains of hardness per pound of salt.[8]

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[7] U.S. Department of Energy (DOE), Federal Energy Management Program (FEMP). August 2013. *Reverse Osmosis Optimization*. Pages 4-11. www.energy.gov/femp/articles/reverse-osmosis-optimization.

[8] ASHRAE and ICC. 2020. ANSI/ASHRAE/ICC/USGBC/IES Standard 189.1-2020. *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. Page 33. www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards.

Deionization

Deionization resin tanks

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, bacteria, or viruses, but because the process is relatively fast, it is commonly used in laboratory applications requiring a low level of water purification. Similar to activated carbon filters, deionization resins must be regenerated periodically to ensure effectiveness, and regeneration often occurs off site. Water use is required to regenerate the resin; however, when regeneration is done off-site (which is typical), no water is used at the facility level. Facilities are still encouraged to send resins for regeneration only when necessary.

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. Smaller units are often more water-efficient since they can have no discharge, whereas larger systems typically reject 15 to 25 percent of water entering the system to prevent scale buildup.[9] If once-through cooling water is used in the condenser, a substantial amount of water can be used during the distillation process. Replacing distillation equipment that uses single-pass cooling with air-cooled models and using a central chilled or condenser water loop to provide cooling are more water-efficient options. In general, it is best to avoid simple distillation and use other methods of water purification, as it can be energy-, time-, labor-, and cost-intensive.[10,11]

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.

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[9] East Bay Municipal Utility District (EBMUD). 2008. *WaterSmart Guidebook—A Water-Use Efficiency Plan Review Guide for New Businesses.* Page TREAT4. www.ebmud.com/water/conservation-and-rebates/commercial/watersmart-guidebook.

[10] ASHRAE and ICC, *op. cit.*, Page 31.

[11] NIH, *op. cit.* Page 9.

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. Chemical disinfection can use additional water if chemicals are added in liquid or slurry form.[12]

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 reverse osmosis systems, if water meters are installed on the incoming feed water and permeate water lines, read the meters regularly to ensure the system is achieving its intended percent recovery rate. In addition, ensure a continuous commissioning process is in place to ensure the system is functioning optimally.[13]
- For water softeners, work with a plumbing professional or the product manufacturer to account for and program regeneration based on the incoming water hardness and/or flow through the system. Monitor and adjust settings periodically.
- 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. Facilities are encouraged to regenerate only as needed.
- For distillation systems, periodically clean the boiling chamber to remove accumulated minerals. This will ensure efficient operation of the system.

Retrofit Options

Facilities might choose to install multiple water purification systems in sequence to increase the effectiveness and efficiency of the water purification process. For example, 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.

[12] EBMUD, *op. cit*.
[13] DOE, FEMP, *op. cit.* Pages 18-19.

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

For carbon filtration, deionization, or water softening processes, consider installing water meters and/or conductivity meters so regeneration can be based on the volume of water treated or conductivity instead of a set schedule.

For reverse osmosis systems, consider installing water meters on the incoming feed water and permeate water lines and reading them regularly to ensure the system is achieving its intended recovery rate. Consider retrofitting reverse osmosis systems to optimize the configuration by adding pretreatment, multiple stages, or reject water recycling systems.

Consider reusing water purification system reject water as an alternative onsite water source where appropriate and feasible. See *WaterSense at Work Section 8: Onsite Alternative Water Sources* at www.epa.gov/watersense/best-management-practices 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 long, inoperable periods. Consider using point-of-use treatment systems where highly purified water use is limited.

Example point-of-use treatment unit that provides purified water at the laboratory work station

Select water purification systems that require the least amount of backwashing or regeneration or that are designed to optimize water efficiency. For specific systems, consider the following:

- For filtration processes, ensure the system has a pressure gauge to determine when to initiate a backwash phase.

- For membrane processes such as reverse osmosis, choose a system with a high recovery rate for its size and that can achieve a minimum recovery rate of 50 percent.[14] Design your system with an optimized configuration that may include feed water pretreatment, advanced membrane technologies, and multiple stages and/or concentrated reject water recycling.[15] If not recycled within the system, consider whether the reject water could be used in the facility. See *WaterSense at Work Section 8: Onsite Alternative Water Sources* at www.epa.gov/watersense/best-management-practices for more information.
- For water softeners, select 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. Look for systems that use 4 gallons (15 liters) of water or less per 1,000 grains of hardness removed. For salt efficiency, look for systems that can achieve at least 3,500 grains of hardness per pound of salt.[16]
- For carbon filtration and deionization systems, select systems that regenerate based on the volume of water treated or conductivity.
- Facilities should avoid simple distillation systems for water purification.[17] If distillation systems are necessary, choose units that use air-cooled coils rather than water-cooled coils and that recover at least 85 percent of the feed water.[18]

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.

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 water. Systems with higher recovery rates are considered more efficient because they are able to produce more purified water from the same amount of feed.

[14] Hoffman, H.W. (Bill), et. al., *op. cit.*
[15] DOE, FEMP, *op. cit.* Pages vi-19.
[16] ASHRAE and ICC, *op. cit.* Page 33.
[17] ASHRAE and ICC, *op. cit.* Page 31.
[18] Hoffman, H.W. (Bill), et. al., *op. cit.* Page 41.

Recovery rates can vary widely depending upon the type of membrane, quality of incoming water, system configuration, and system operation. Large reverse osmosis systems typically have a recovery rate between 50 to 75 percent. When a reverse osmosis system is optimized, however, recovery rates can exceed 90 percent.[19] For example, the Sandia National Laboratories in Albuquerque, New Mexico, installed a high-efficiency reverse osmosis system with pretreatment before the membranes. The facility was able to achieve a 95 percent recovery rate, rejecting only 5 percent of the water entering the system.[20]

For water softeners, water use is dependent on the frequency and efficiency of regeneration. Demand-initiated water softeners initiate regeneration based on the incoming water's hardness, the volume of water softened, or treated water conductivity rather than a set schedule. Beyond how regeneration is initiated, water consumption during regeneration can vary. Systems can use 4 gallons (15 liters) of water or less per 1,000 grains of hardness removed.[21]

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.

Additional Resources

ASHRAE and the International Code Council (ICC). 2020. ANSI/ASHRAE/ICC/USGBC/IES Standard 189.1-2020. *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. Pages 30-33. www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards.

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Hoffman, H.W. (Bill), et. al. May 2018. *Best Management Practices for Commercial and Institutional Water Users*. Prepared for the Texas Water Development Board. Pages 38-44. www.twdb.texas.gov/conservation/BMPs/CI/index.asp.

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[19] DOE, FEMP, *op. cit.* Page 5.
[20] DOE, FEMP. August 2009. *Microelectronics Plant Water Efficiency Improvements at Sandia National Laboratories*. Page 2. www.nrel.gov/docs/fy09osti/46334.pdf.
[21] ASHRAE and ICC, *op. cit.* Page 33.

International Institute for Sustainable Laboratories (I2SL) and U.S. Environmental Protection Agency (EPA). May 2022. *Best Practices Guide: Water Efficiency in Laboratories*. www.epa.gov/system/files/documents/2022-06/ws-I2SL-Laboratory-Water-Efficiency-Guide.pdf.

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U.S. Department of Energy (DOE), Federal Energy Management Program (FEMP). August 2013. *Reverse Osmosis Optimization*. www.energy.gov/femp/articles/reverse-osmosis-optimization.

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