

Drinking Water Treatment: Reverse Osmosis

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Homeowners can find out more about reverse osmosis in this guide, which discusses the principles and process of RO treatment for household drinking water.

Contaminants removed from water by reverse osmosis

Reverse osmosis (RO) membrane filters frequently are used to reduce the levels of total dissolved solids and suspended particles within water. Some contaminants treated effectively by RO membrane filters are listed in *Table I*. This table is not an exhaustive list of contaminants that RO may remove, but rather lists those for which RO can be a practical treatment method for treating household drinking water.

Table I. Contaminants removed by household reverse osmosis units.

Ions and Metals	Arsenic, Aluminum, Barium, Cadmium, Calcium, Chloride, Chromium, Copper, Fluoride, Iron, Lead, Magnesium, Manganese, Mercury, Nitrate, Potassium, Radium, Selenium, Silver, Sodium, Sulfate, Zinc
Particles	Asbestos, Protozoan cysts, Cryptosporidium
Pesticides	Endrin, Heptachlor, Lindane, Pentachlorophenol

Reverse osmosis can remove microorganisms. However, it is not recommended for that use (i.e., only coliform-free water should be fed to the system) because membrane deterioration can occur due to the bacteria, and contamination may occur through pinhole leaks.

Contaminants not removed from water by reverse osmosis

Contaminants not removed from water by RO filters include dissolved gases such as hydrogen sulfide, a common nuisance contaminant with characteristic rotten egg odor, which passes through the RO membrane. Some pesticides, solvents and volatile organic chemicals (VOCs) are not removed by RO. Refer to Extension Circular EC703, *Drinking Water Treatment: An Overview* for a discussion of possible water quality problems and appropriate treatments for these contaminants. The RO membrane's efficiency in reducing the

amount of contaminant in the water depends on the contaminant concentration, chemical properties of the contaminant, the membrane type and condition, and operating conditions. Refer to the section in this guide on the RO process for explanation of these factors.

No one piece of treatment equipment manages all contaminants. All treatment methods have limitations and often situations require a combination of treatment processes to effectively treat the water. Activated Carbon (AC) filtration and/or sediment filtration is commonly used in conjunction with RO filters. Sediment filters help remove silt particles that may foul the RO membrane. AC filters remove chlorine and certain pesticides and organic solvents that the RO membrane is not as effective in removing (see *Table II*). The section in this guide on equipment discusses this concept.

Table II. Contaminants removed by activated carbon filter commonly included in a household reverse osmosis system.

Ions and Metals	Chlorine, Radon
Organic Chemicals	Benzen ¹ , Carbon tetrachloride, Dichlorobenzene, Toluene, Trichloroethylene, Total Trihalomethanes (THMs)
Pesticides	1,2,4-trichlorobenzene, 2,4-D, Atrazine

Water testing

Regardless of the water treatment system being considered, the water should first be tested to determine which contaminants are present. Public water systems are routinely tested for contaminants. Water utilities are required to publish Consumer Confidence Reports (CCRs), which inform consumers on the source of the water, contaminants present, potential health effects of those contaminants, and methods of treatment used by the utility. Depending on the population served by the utility, CCRs may be mailed, posted in newspapers or posted on the Internet. Copies of the CCR can be obtained from the local water utility. Public supplies must conform to federal standards established by the Safe Drinking Water Act. If contaminants exceed the Maximum Contaminant Level (MCL), the water must be treated to correct the problem and/or another source of water suitable for drinking must be provided.

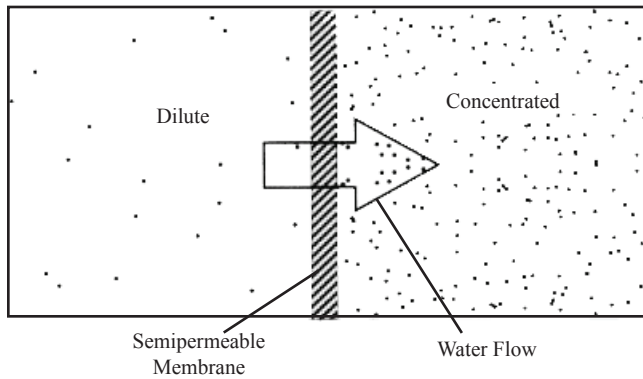


Figure 1. In *osmosis*, water moves across the membrane from the dilute to the concentrated solution. From "Water Treatment Notes: Reverse Osmosis Treatment of Drinking Water," Cornell Cooperative Extension, New York State College of Human Ecology.

In contrast, monitoring private water systems is the consumer's responsibility. Therefore, contamination is more likely to go undetected in a private water supply. Knowledge of what contaminants may be present in the water should guide the testing, since it is not economically feasible to test for all possible contaminants.

It is essential to know what contaminants are present, their quantities, and reasons for removal (i.e., health risks, tastes or odors, etc.) prior to selecting treatment methods or equipment. Refer to NebGuide G907 *Drinking Water: Testing for Quality* for testing information.

Treatment principles

RO is based on the principle of *osmosis*. In osmosis, a membrane separates two solutions containing different amounts of dissolved chemicals. The membrane allows some compounds like water to pass through it, but does not allow larger compounds through (i.e., a semipermeable membrane). Pressure differences cause pure water to pass through the membrane from the dilute to the more concentrated solution. The pressure is called osmotic pressure and this process is osmosis. The natural tendency is for water to move through the membrane from the dilute to the concentrated solution until chemicals reach equal concentrations on both sides of the membrane. *Figure 1* shows the natural osmotic process.

In reverse osmosis, pressure is applied to the concentrated side of the membrane (the contaminated side). This forces the osmotic process into reverse so that, with adequate applied pressure, pure water is forced from the concentrated (contaminated) side to the dilute (treated) side. Treated water is collected in a storage container. The rejected contaminants on the concentrated side of the membrane are washed away as wastewater. *Figure 2* shows the reverse osmosis process.

The amount of treated water that an RO membrane typically used in the home can produce, per day, is in the range of 10 to 35 gallons per day. The amount of treated water produced depends on several factors, including membrane type and condition, operating conditions (such as flow control and pressure) and feed water quality (i.e., contaminant concentration, temperature and pH).

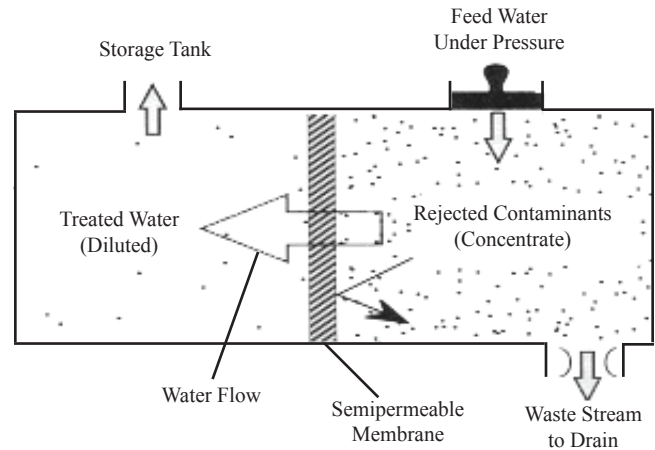


Figure 2. In *reverse osmosis*, pressure is applied to the concentrated solution reversing the natural direction of flow, forcing water across the membrane from the concentrated solution into the more dilute solution. From "Water Treatment Notes: Reverse Osmosis Treatment of Drinking Water," Cornell Cooperative Extension, New York State College of Human Ecology.

Two measures of performance of an RO membrane are recovery rate and rejection rate. Recovery rate refers to the fact that only part of the water that flows into an RO system comes out as treated water. Part of the water fed into the system is used as wastewater to wash away the rejected contaminants. The recovery rate is therefore a measure of efficiency calculated as:

$$\% \text{ Recovery} = (\text{Volume of treated water produced} / \text{Total volume of feed water}) \times 100$$

The use of large quantities of water to produce little treated water may be avoided by properly designed RO systems. Most household RO systems are designed with a 20 percent - 30 percent recovery rate.

This means that a system with 100 gallons/day of untreated water fed to it and a 20 percent recovery rate would yield 20 gallons/day of treated water and dispose of 80 gallons/day in the waste stream. Proper adjustment of the flow regulator on the side of the waste stream is important. If the flow of wastewater is slow, more time is available for water to pass through the membrane, so the recovery rate is higher. However, RO membranes are readily fouled if concentrated contaminants are not washed away soon enough. Conversely, if the waste flow rate is too fast, the recovery rate is low and excessive water flows down the drain.

Closely related to flow rate, water pressure is another key factor in RO systems. The incoming feed line pressure must be adequate to overcome the osmotic pressure and any backpressure generated from the storage tank "down-line" from the membrane. Auxiliary pumps can be added to increase incoming water pressure as necessary. Generally, the higher the pressure difference across the membrane the better the rejection of contaminants and recovery rate. Also, some RO systems have shut off valves to stop flow whenever storage tank pressure is too high for efficient recovery or if the storage tank is full.

Temperature and pH of the feed water are also factors in performance. There is a 1 to 2 percent decrease in treated

water produced for every degree below the standard 77°F. Well water at 45°F (a typical temperature for Nebraska groundwater) would produce about half the amount of treated water that would be produced at 77°F. Also, slightly acidic feed water may prolong the life of the membrane and help decrease scale buildup in the system.

The rejection rate is the percentage of contaminant that is not allowed to move through the membrane. A rejection rate is calculated for each contaminant separately, as well as for Total Dissolved Solids (TDS). For contaminants that cause health concerns, the rejection rate needs to be high enough to reduce the contaminant to a safe level. The quality of the incoming water, or feed water, is crucial here. For example, if the water supply contains nitrate at 40 mg/L, an RO membrane with 85 percent rejection would reject $40 \times 0.85 = 34$ mg/L nitrate, leaving 6 mg/L in the treated water.

However, if the water supply contains 80 mg/L nitrate, an 85 percent rejection rate would reduce the nitrate concentration to 12 mg/L in the treated water. This nitrate level, even after RO treatment, is above the maximum contaminant level (MCL) of 10 mg/L nitrate set by the EPA.

Equipment

Treatment systems can be classified as either Point-of-Use (POU) or Point-of-Entry (POE). POU devices treat water at the point it is used, such as the faucet. Most RO systems are POU systems placed under the sink or on the countertop. A separate faucet is generally installed at the sink to allow the option of using treated water only for drinking and cooking. Water treated by RO can be more corrosive than untreated water so special plumbing, in addition to the faucet, is installed with RO systems.

POE devices treat water as it enters the household so all water used within the house is treated. POE reverse osmosis units are more costly to purchase, install and operate than POU systems.

Although the RO process is simple, the complete system is often complex. Typical RO systems consist of a pretreatment filter, the RO membrane, flow regulator, post-treatment filter, storage tank and dispensing faucet as shown in *Figure 3*. AC or sediment filters before the RO membrane and AC filters after the RO membrane are commonly used. Pre-filters help extend the life of the system by removing silt and other large particles and/or chlorine that may be harmful to the RO membrane. If the feed water is not chlorinated, AC filters should not be used for pre-filtration because they can encourage microbial growth on the membrane surface. In this case, only a sediment pre-filter is recommended. AC post-filters can also remove certain pesticides and organic solvents that the RO membrane does not remove. The AC treatment process is also improved since the RO membrane removes compounds that may hinder adsorption by the carbon.

Membrane selection is an important aspect of RO treatment that can significantly affect performance. The most common membrane materials are polyamide thin-film composites (TFC) or cellulose-type membranes. Both are synthetic fibers. The membrane can be spiral wound (like a rolled-up newspaper), or individual hollow fibers can be bundled together. This

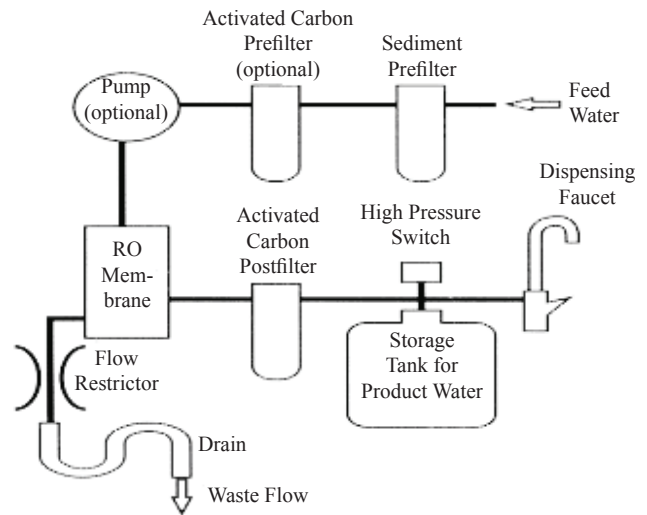


Figure 3. A schematic of a typical RO system. From “*Water Treatment Notes: Reverse Osmosis Treatment of Drinking Water*,” Cornell Cooperative Extension, New York State College of Human Ecology.

provides a very large surface area for water treatment within a compact tube element.

TFC membranes are more costly, but have greater strength and durability than cellulose-types. They have higher total dissolved solids rejection rates, are more resistant to microbial attack and are more tolerant of high pH. Cellulose type membranes are less costly and can tolerate chlorine, which is commonly used for disinfection of drinking water. TFC membranes deteriorate in chlorinated water. If the feed water is chlorinated and a TFC membrane is used, an AC prefilter is needed to remove chlorine from the water.

Another type of membrane is a sulfonated polysulfone (SPS) membrane. SPS membranes are tolerant of chlorine and can withstand higher pH levels, but are more costly than cellulose-types and less effective than TFC membranes. SPS membranes can be used in RO systems when the water is soft and pH is high.

The storage tank generally has a capacity of 2 to 5 gallons. It is pressurized to provide adequate flow when the tap is open. Post-filters can be used for removing any taste and odor compounds or residual organics not removed by the RO process. If an AC filter is used for pre-filtration, post-filtration can be eliminated.

Monitoring gauges and lights are also becoming increasingly common. Shut-off valves are important to stop water flow when the storage tank is full, so excess water is not wasted. Since RO treatment uses significant amounts of water, consideration must be given to the adequacy of the household septic system. The wastewater, carrying rejected contaminants, typically is connected to a household drain and this wastewater increases the load on the septic system.

As with any drinking water treatment system, regular maintenance is important to extend the life of the system and to help ensure peak performance. Pre-filters and post-filters require regular replacement. The length of time before prefilter replacement depends upon water volume, quality and contaminant concentration. Post-filter replacement also depends on contaminant concentration, as well as membrane rejection

percentages and AC removal efficiency. Manufacturers and dealers can assist in determining replacement intervals.

Microorganisms (alive or dead) can clog RO membranes. This is called bio-fouling. Disinfect RO systems regularly with products provided by the manufacturer. Clogged RO membranes can decrease water flow in the system and cause poor performance. If membrane fouling is detected early, it is possible to clean and regenerate the membrane; the method depends on the type of membrane and fouling. Completely clogged or torn membranes require replacement. However, damaged RO membranes are not easily detected. Periodically test water to determine if the membrane is intact and functioning properly. Many systems are equipped with a monitor that indicates high total dissolved solids content or inadequate TDS rejection, one indicator of improper functioning. For relatively hard water, pretreatment of the water by a softener can increase the life of the membrane.

Selection Requirements

Federal, state or local laws do not regulate home RO drinking water treatment systems. The industry is self-regulated. The National Sanitation Foundation and the Water Quality Association evaluate performance, construction, advertising, and operation manual information. The NSF program establishes performance standards that must be met for endorsement and certification. The WQA program uses the same NSF standards and provides equivalent American National Standards Institute (ANSI) accredited product certifications. WQA-certified products carry the Water Quality Association Gold Seal. Though these certifications and validations should not be the only criteria for choosing an RO system, they are helpful to ensure effectiveness of the system.

Other important guidelines for consumers purchasing drinking water treatment equipment are discussed in NebGuide G1488 *Drinking Water Treatment: What You Need to Know When Selecting Water Treatment Equipment*. The NebGuide drinking water treatment series focuses on contaminants most likely to be encountered in Nebraska drinking water supplies. It is possible that some water supplies may contain contaminants not addressed here, such as cryptosporidium, giardia, hexavalent chromium and others. Reverse osmosis systems may remove some of these contaminants as well.

Summary

Drinking water treatment using RO is one option for the homeowner to treat drinking water problems. RO is an effective method to reduce certain ions and metals, such as nitrate and arsenic. It is often used in combination with AC filtration. Selecting an RO system should be based on water analysis and assessment of the individual homeowner's needs and situation. Regular maintenance of the membrane and replacement of any filters/cartridges are critical factors in maintaining effectiveness and reducing bacterial contamination of the system. NSF and the WQA test and certify products and this certification and validation can help guide selection.

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