

# Tech Brief

A NATIONAL DRINKING WATER CLEARINGHOUSE FACT SHEET



## Ion Exchange and Demineralization

### Summary

Ion exchange and membrane processes are becoming used extensively in water and wastewater treatment. Ion exchange is primarily used for the removal of hardness ions, such as magnesium and calcium, and for water demineralization. Reverse osmosis (RO) and electro dialysis, both membrane processes, remove dissolved solids from water using membranes.

### Ion Exchange and Demineralization Are Becoming Widely Used

**Ion exchange** units can be used to remove any charged (ionic) substance from water, but are usually used to remove hardness and nitrate from groundwater.

Water is pretreated to reduce the suspended solids and total dissolved solids (TDS) load to the ion-exchange unit. Methods of pretreatment include:

- filtration,
- coagulation and filtration,
- cold lime with or without soda ash,
- hot lime with or without soda ash,
- evaporation or distillation,
- electro dialysis,
- RO,
- continuous deionization,
- ultrafiltration,
- degasification, or
- combinations of the above.

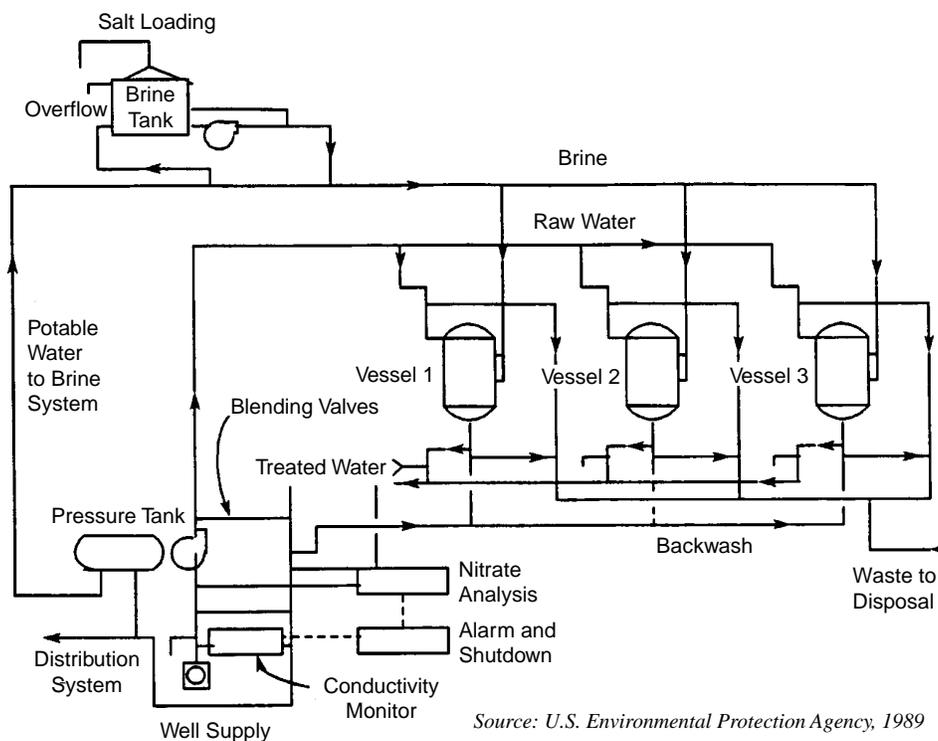
(Source: Owens, 1995)

**RO** systems are compact, simple to operate, and require minimal labor, making them suitable for small systems. They are also suitable for

systems where there is a high degree of seasonal fluctuation in water demand.

**Electrodialysis** is a process that also uses membranes. However, in electro dialysis, direct electrical current is used to attract ions to one side of the treatment chamber. Electro dialysis systems include a source of pressurized water, a direct current power supply, and a pair of selective membranes.

Figure 1. Ion exchange treatment system



Source: U.S. Environmental Protection Agency, 1989



# Ion Exchange/Demineralization Systems:

## Ion exchange

Ion exchange effectively removes more than 90 percent of barium, cadmium, chromium (III), silver, radium, nitrites, selenium, arsenic (V), chromium (VI), and nitrate. Ion exchange is usually the best choice for small systems that need to remove radionuclides.

### ADVANTAGES

- Ion exchange process, like reverse osmosis, can be used with fluctuating flow rates.
- Effluent contamination is virtually impossible.
- Large variety of specific resins are available from suppliers. Each resin is effective in removing specific contaminants.

### LIMITATIONS

- Ion exchange waste is highly concentrated and requires careful disposal.
- Potential for unacceptable levels (peaks) of contamination in effluent.
- Usually not feasible with high levels of TDS.
- Pretreatment required for most surface waters.
- Ion exchange units also are sensitive to the presence of competing ions. For example, influent with high levels of hardness will compete with other cations (positive ions) for space on the exchange medium, and the exchange medium must be regenerated more frequently.

### PROCESS

Inorganics removal is accomplished through adsorption of contaminant ions onto a resin exchange medium. As the name implies, one ion is substituted for another on the charged surface of the medium, which is usually a synthetic plastic resin. This resin surface is designed as either cationic or anionic (negatively charged). The exchange medium is saturated with the exchangeable ion before treatment operations.

During ion exchange, the contaminant ions replace the regenerant ions because they are preferred by the exchange medium. When there are no ions left to replace the contaminant ions, the medium is regenerated with a suitable solution, which resaturates the medium with the appropriate ions. Because of the required "down time," the shortest economical regeneration cycles are once per day.

The resin exchange capacity is expressed in terms of weight per unit volume of the resin. The calculation of the breakthrough time for an ion exchange unit requires knowledge of the resin exchange capacity, the influent

contaminant concentration, and the desired effluent quality.

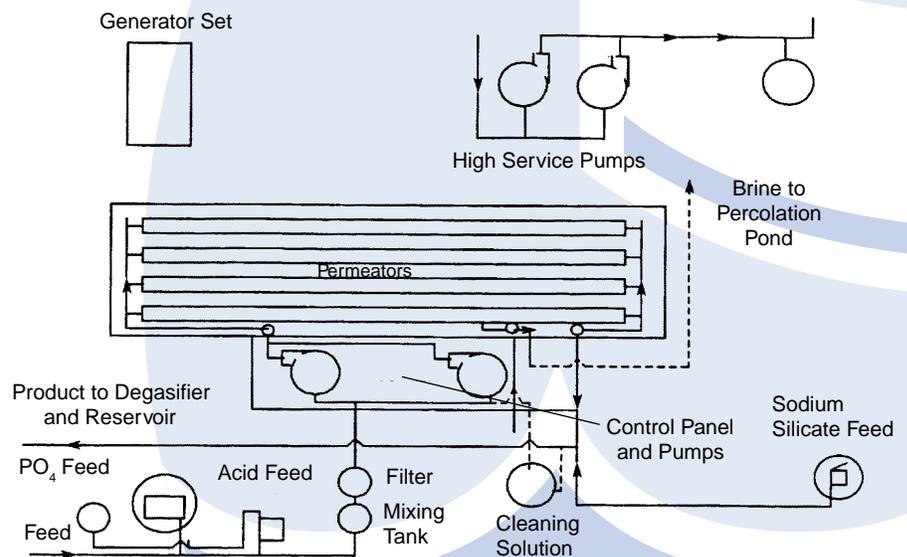
### EQUIPMENT

Typical ion exchange units consist of prefiltration, ion exchange, disinfection, storage, and distribution elements. (See figure 1 on page 1.)

### CHEMICALS

Sodium chloride is often used to regenerate the exchange medium in ion exchangers because of the low cost of the chemical. However, this can result in a high sodium residual in the finished water, which may be unacceptable for individuals with salt restricted diets. This problem can be avoided by using other regenerant materials, such as potassium chloride.

Figure 2. Schematic of a reverse osmosis system



## Reverse osmosis (RO)

RO can effectively remove nearly all inorganic contaminants from water. It removes more than 70 percent of arsenic (III), arsenic (IV), barium, cadmium, chromium (III), chromium (VI), fluoride, lead, mercury, nitrite, selenium (IV), selenium (VI), and silver. 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.

### ADVANTAGES

- Removes nearly all contaminant ions and most dissolved non-ions.
- Relatively insensitive to flow and TDS level, and thus suitable for small systems with a high degree of seasonal fluctuation in water demand.

- RO operates immediately, without any minimum break-in period.
- Low effluent concentration possible.
- Bacteria and particles are also removed.
- Operational simplicity and automation allow for less operator attention and make RO suitable for small system applications.

**LIMITATIONS**

- High capital and operating costs.
- Managing the wastewater (brine solution) is a potential problem.
- High level of pretreatment is required in some cases.
- Membranes are prone to fouling.

**PROCESS**

RO removes contaminants from water using a semipermeable membrane that permits only water, and not dissolved ions (such as sodium and chloride), to pass through its pores. Contaminated water is subject to a high pressure that forces pure water through the membrane, leaving contaminants behind in a brine solution. Membranes are available with a variety of pore sizes and characteristics.

**EQUIPMENT**

Typical RO units include raw water pumps, pretreatment, membranes, disinfection, storage, and distribution elements. (See figure 2 on page 2.) These units are able to process virtually any desired quantity or quality of water by configuring units sequentially to reprocess waste brine from the earlier stages of the process. The principal design considerations for reverse osmosis units are:

- operating pressure,
- membrane type and pore size,
- pretreatment requirements, and
- product conversion rate (the ratio of the influent recovered as waste brine water to the finished water).

**Electrodialysis**

Electrodialysis is very effective in removing fluoride and nitrate, and can also remove barium, cadmium, and selenium. (See figure 3 below.)

**ADVANTAGES**

- All contaminant ions and most dissolved non-ions are removed.
- Relatively insensitive to flow and TDS level.
- Low effluent concentration possible.

**LIMITATIONS**

- High capital and operating costs.
- High level of pretreatment required.
- Reject stream is 20–90 percent of feed flow.
- Electrodes require replacement.

**PROCESS**

The membranes adjacent to the influent stream are charged either positively or negatively, and this charge attracts counter-ions toward the membrane. The membranes are designed to allow either positively or negatively charged ions to pass through the membrane, thus ions move from the product water stream through a membrane to the two reject water streams. (See figure 4 on page 4.)

**EQUIPMENT**

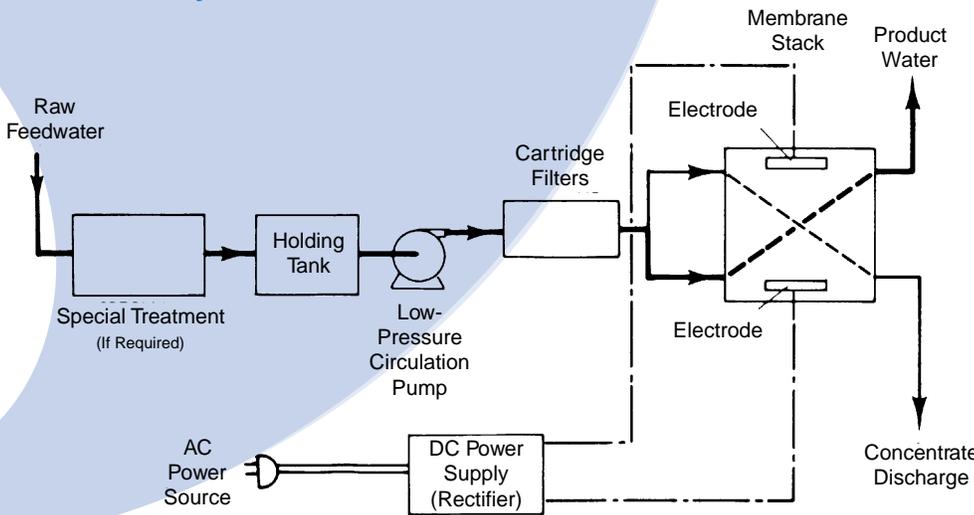
The three essential elements of the system are (1) a source of pressurized water, (2) a direct current power supply, and (3) a pair of selective membranes. The average ion removal varies from 25 to 60 percent per stage. Multistage units can increase the efficiency of removal. Many membrane pairs are “stacked” in the treatment vessel.

**CHEMICALS**

Fouling of membranes may limit the amount of water treated. Fouling is caused when membrane pores are clogged by salt precipitation or by physical obstruction of suspended particulates.

Particulates, suspended in water, can be removed in pretreatment but salts that exceed their solubility product at the membrane surface must be controlled chemically by pH reduction (to reduce carbonate concentration) or chelation of metal ions (by use of phosphate, for example). A reversal of the charge on the membranes, a process called electrodialysis reversal (EDR), helps to flush the attached ions from the membrane surface, thus extending the time between cleanings.

**Figure 3. Basic components of an electrodialysis unit**



Source: U.S. Agency for International Development, 1980

**Where can I find more information?**

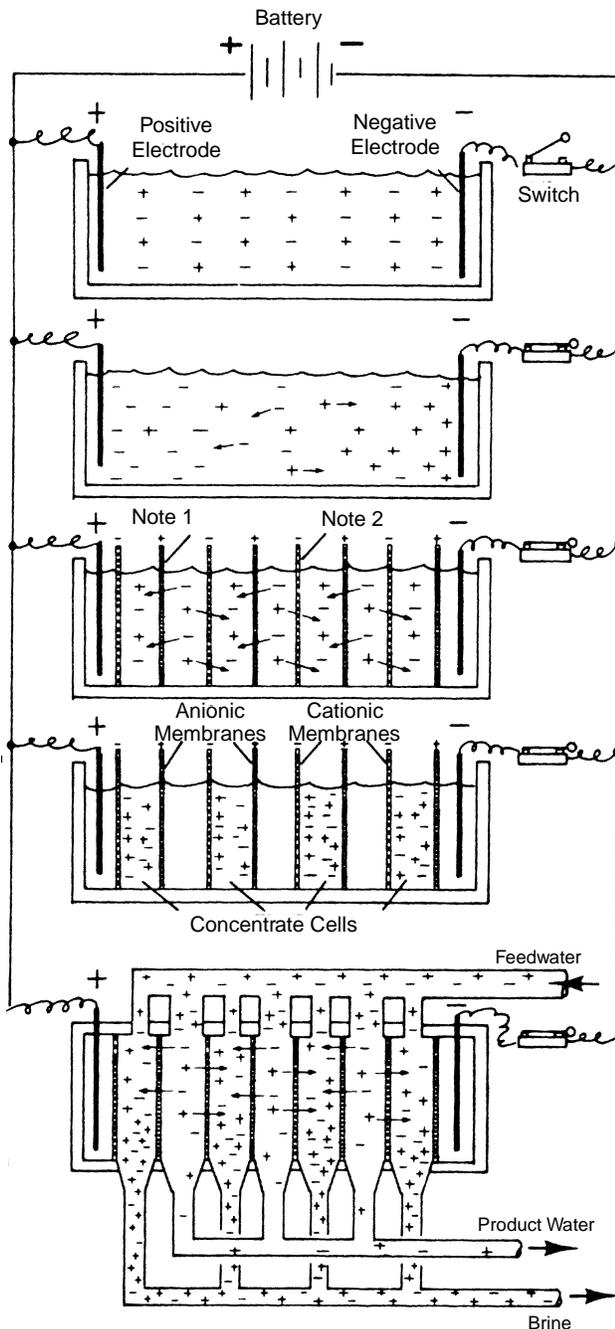
Information on ion exchange/demineralization was primarily obtained from two sources: Environmental Pollution Control Alternatives: Drinking Water Treatment for Small Communities, EPA/625/5-90/025; and Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities, EPA/625/4-89/023. Both may be ordered free from the U.S. Environmental Protection Agency Office of Research and Development at (513) 569-7562.

These publications also may be ordered from the National Drinking Water Clearinghouse (NDWC); however, copying costs apply. The first

book, item #DWBKGN09, an 82-page publication, costs \$11.82; and the second, item #DWBKDM04, a 209-page book, costs \$30.05. Shipping and handling charges also apply.

For further information or to order copies of "Tech Brief: Ion Exchange and Demineralization," item #DWBLPE56, "Tech Brief: Filtration," item #DWBLPE50, "Tech Brief: Disinfection," item #DWBLPE47, or "Tech Brief: Corrosion Control," item #DWBLPE52 call the NDWC at (800) 624-8301 or (304) 293-4191. These fact sheets are available at no cost, except for shipping and handling charges.

**Figure 4. Movement of ions in the electro dialysis process**



Many of the substances which make up the total dissolved solids (TDS) in brackish water are strong electrolytes. When dissolved in water they ionize; that is, the compounds dissociate into ions which carry an electric charge. Typical of the ions in brackish water are  $\text{Cl}^{-1}$ ,  $\text{Na}^{+1}$ ,  $\text{HCO}_3^{-1}$ ,  $\text{Mg}^{+2}$ ,  $\text{SO}_4^{-2}$ , and  $\text{Ca}^{+2}$ . These ions tend to attract the dipolar water molecules and to be diffused in times, fairly evenly throughout a solution.

If two electrodes are placed in a solution of ions and energized by a battery or other direct current source, the current is carried through the solution by the charged particles and the ions tend to migrate to the electrode of the opposite charge.

If alternately fixed charged membranes (which are selectively permeable to ions of the opposite charge) are placed in the path of the migrating ions, the ions will be trapped between the alternate cells formed.

Note 1: A positively fixed charge (anionic) membrane will allow negative ions to pass, but will repel positive ions.

Note 2: A negatively fixed charge (cationic) membrane will allow positive ions to pass, but will repel negative ions.

If this continued, almost all the ions would become trapped in the alternate cells (concentrate cells). The other cells, which lack ions, would have a lower level of dissolved constituents and would have a high resistance to current flows.

The phenomenon illustrated above is used in electro dialysis to remove ions from incoming saline water on a continuous basis. Feedwater enters both the concentrate and product cells. Up to about half of the ions in the product cells migrate and are trapped in the concentrate cells. Two streams emerge from the device: One of concentrated brine and the other with a much lower concentration of TDS (product water).

Source: U.S. Agency for International Development, 1980