Chapter 2

Overview of Desalination Technologies

GENERAL PROCESS DESCRIPTIONS

There are five basic techniques that can be used to remove salt and other dissolved solids from water: distillation, reverse osmosis (RO), electrodialysis (ED), ion exchange (IX), and freeze desalination. Distillation and freezing involve removing pure water, in the form of water vapor or ice, from a salty brine. RO and ED use membranes to separate dissolved salts and minerals from water. IX involves an exchange of dissolved mineral ions in the water for other, more desirable dissolved ions as the water passes through chemical "resins. The relative percentages of different types of desalination plants worldwide is shown in table 1.

In addition to removing salts and other dissolved solids from water, some of these desalination techniques also remove suspended material, organic matter, and bacteria and viruses; however, they will not produce water where there is none. These techniques were originally developed for treating large quantities of water (i. e., hundreds or thousands of gpd) at a central location, but some have been adapted recently for small scale use in the home. These desalination processes are described briefly below and in more detail in appendix A.

Distillation

Salt- and mineral-free water can be separated from seawater by vaporizing some of the water from the salt solution and then condensing this water vapor on a cooler surface. This is the same phenomenon that occurs when water vapor (or steam) inside a warm house condenses on a cold window pane, or when water vapor condenses to form rain or snow. This separation process is called distillation.

The vaporization of water molecules can be accelerated by heating the brine to its boiling point and/or reducing the vapor pressure over the brine. To maximize the efficiency of the distillation process, the heat given up during condensation is used to heat the incoming feed water, or to reheat the unvaporized brine. Because distillation involves vaporizing water from the salt y feed water, the energy required for distillation, as well as its costs, do not increase appreciably with increasing salinity of the feed water. Depending on the plant design, distilled water produced from seawater normally has salt concentrations of 5 to 50 ppm. Between 25 and 65 percent of the feed water is recovered by most distillation plants.

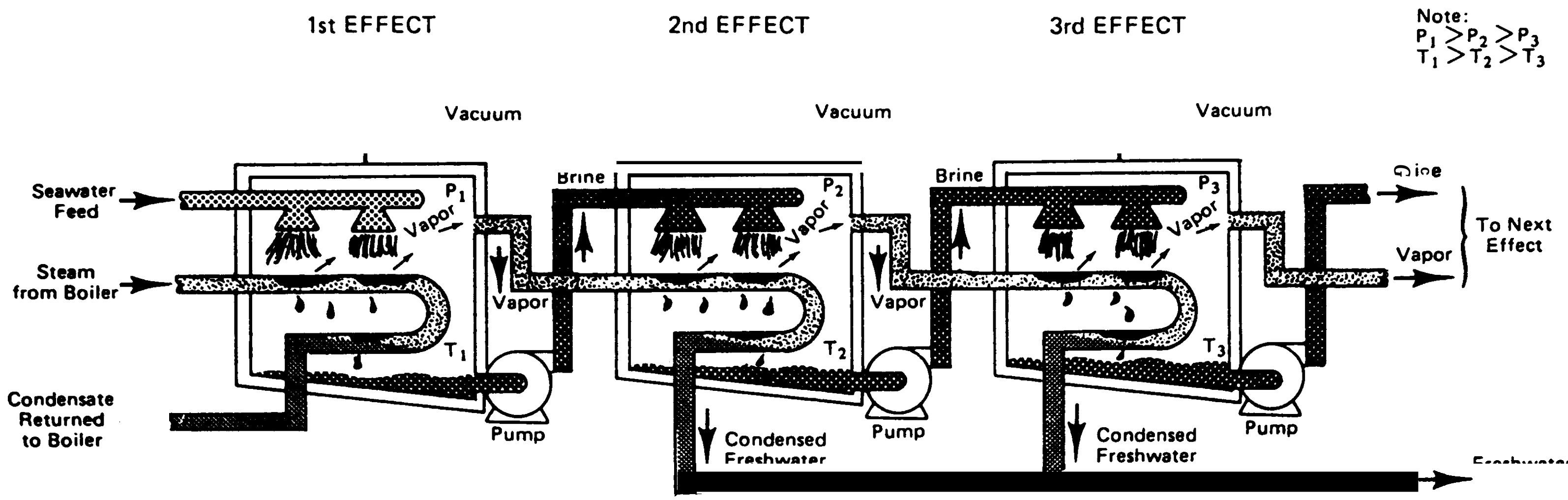
Four major processes are now used to distill water on a commercial or semi-commercial scale. Both "multiple-effect' (ME) (figure 1) evaporation and "multi-stage flash' (MSF) (figure 2) distillation involve boiling the brine in adjacent chambers at successively lower vapor pressures without adding heat. With "vapor compression" (VC) (figure 3) the water vapor from salty feed water is collected and compressed thereby condensing the vapor. "Solar" distillation typically occurs inside a glass

Table I.—Relative Distribution of Different Types of Desalination Plants Worldwide

Process	Number of plants	Percent of total	Capacity (mgd)	Percent of total
Distillation				
MSF	532	15.1	1,955	64.5
ME	329	9.3	145	4.8
Vc	275	7.8	66	2.2
Membrane				
RO	1,742	49.4	709	23.4
ED	564	16.0	139	4.6
Other	85	2.4	18	0.6
Total	3,527	100.0	3,032	100.1

SOURCE: International Desalination Associate's desalination plant inventory, 1987.

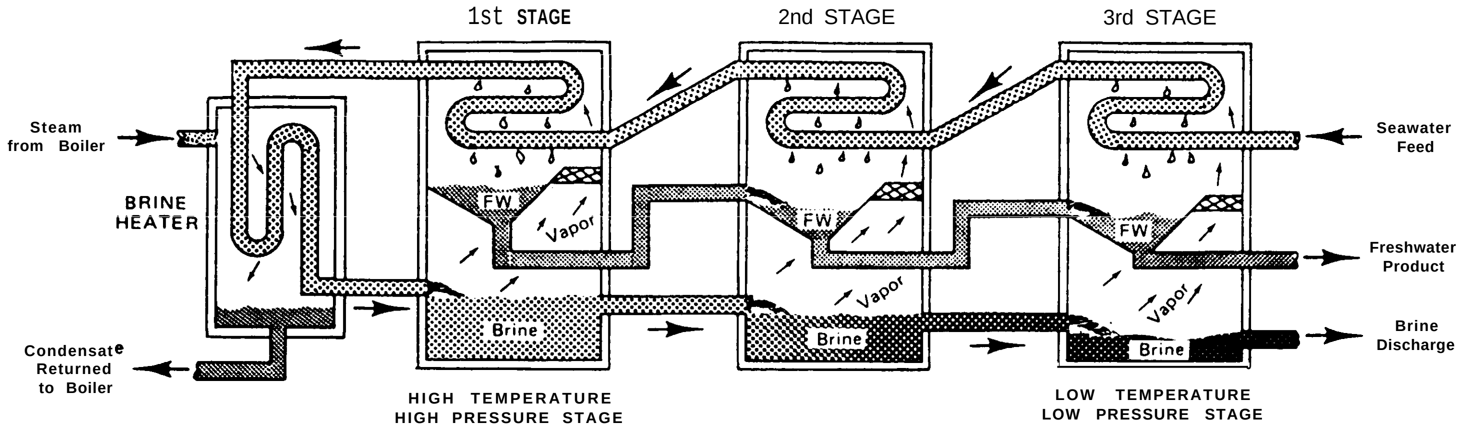
Figure 1.—Conceptual Diagram of a Horizontal-Tube Multiple-Effect (HTME) Distillation Plant



Notes: 1. This drawing is greatly simplified.
2. A final condenser such as shown on Figure 3-10 is necessary for operation.

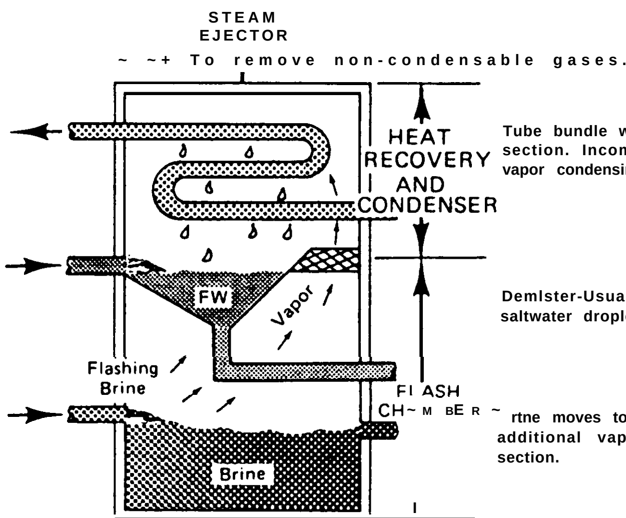
SOURCE: O.K. Buros, et al. "The USAID Desalination Manual," U.S. Agency for International Development, Washington, DC, prepared by CH2M Hill International Corp., August 1980.

Figure 2.—Conceptual Diagram of the Multistage Flash (MSF) Process



Note. For simplicity, no heat rejection section is shown In this diagram–see Figure 315.

FW = Freshwater



The seawater feed Increases in temperature as it moves toward the brtne heater where sufficient additional heat is added to permtt it to flash boil iri the first stage.

The freshwater produced by condensation in each stage IS flashed In subsequent stages to recover add!tlonal heat.

Brtne flashes when introduced into the stage wh!ch has a reduced pressure, permitting rapid bolll ng to occur Immedl - ately.

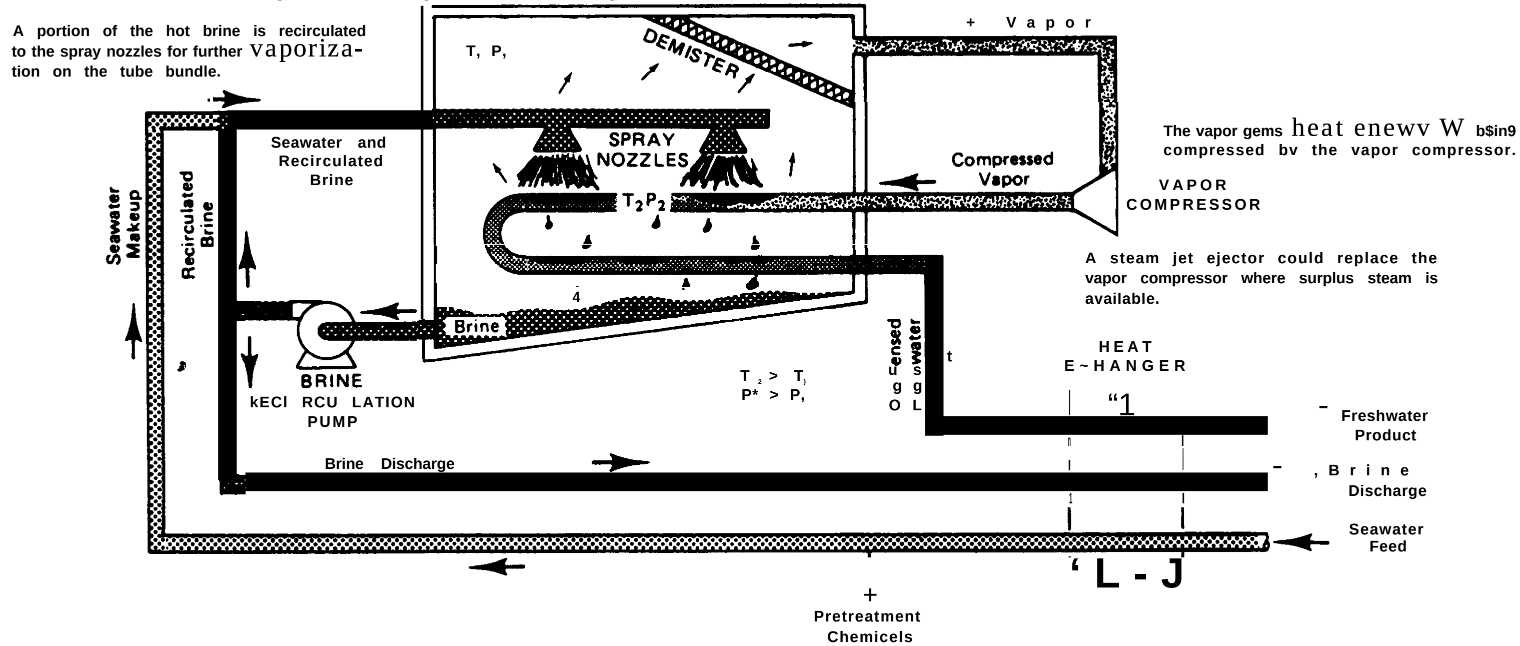
Tube bundle which serves as a heat recovery and condenser section. Incoming seawater inside the tubes is heated by vapor condensing on the outside of the tubes.

Demlster-Usually screening or wire mesh which removes saltwater droplets entrapped in the vapor.

rtne moves to the next stage to be flashed again to produce additional vapor and transfer heat to the heat-recovery section.

SOURCE: O.K. Buros, et al., “The IJSAID Desalination Manual,” U.S. Agency for International Development, Washington, DC, prepared by CH2M Hill International Corp., August 1980.

Figure 3.—Simplified Flow Diagram for a Spray-Film VaporOCompression Process



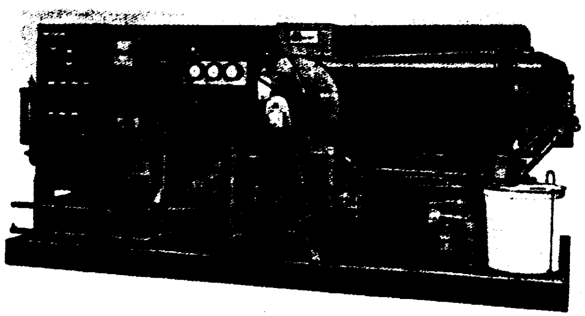


Photo Courtesy of Aqua-Chem, Inc.

This tvpe of electric-driven sprav film vapor compression unit is used for facilities such as hotels, industrial plants, and power stations. It is generallv available in capacities from 2,500 to 30,000 gpd [9.5 to 114 m^3/d]

SOURCE: O.K. Buros, et al., "The USAID Desalination Manual," U.S. Agency for International Development, Washington, DC, prepared by CH2M Hill International Corp., August 19S0.

enclosure, similar to a greenhouse, where water vapor rising from sun-heated brine condenses on the cooler inside surface of the glass. The droplets of distilled water that run down the glass are then collected in troughs along the lower edges of the glass (figure 4).

Reverse Osmosis

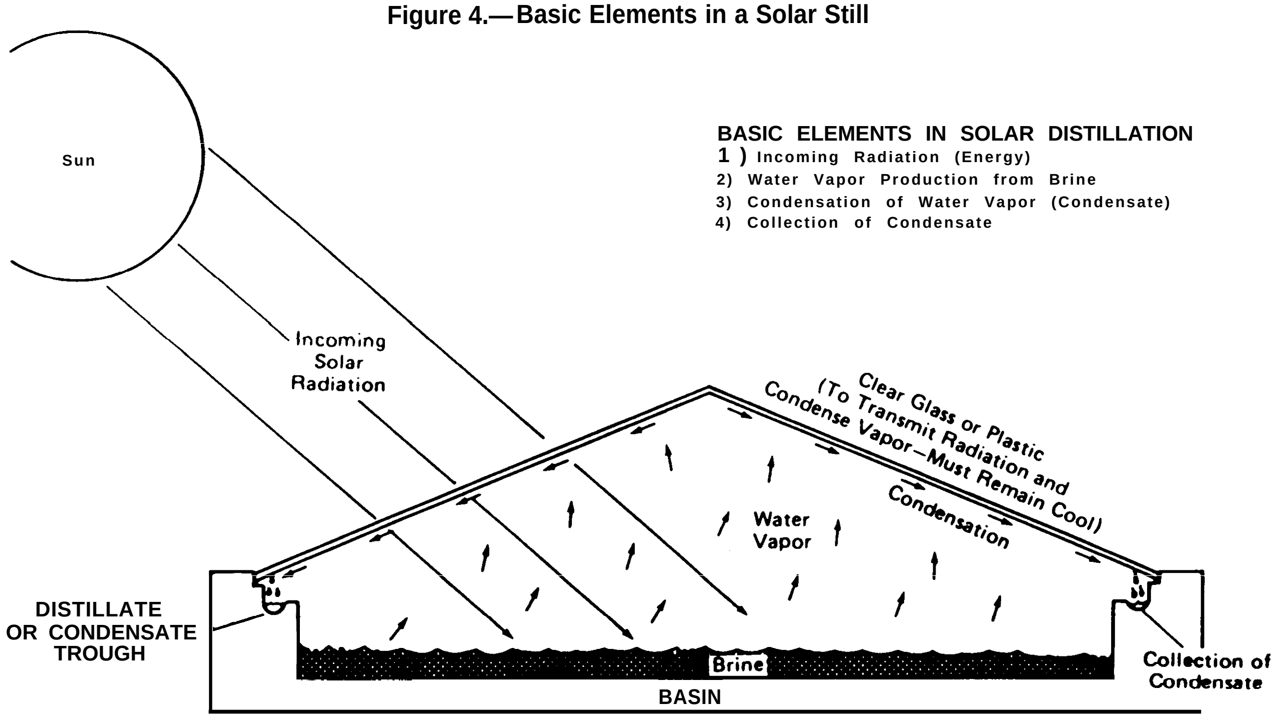
With RO, salty water on one side of a semi-permeable membrane is typically subjected to pressures of 200 to 500 lb/sq in. for brackish water, and 800 to 1,200 lb/sq in. for seawater. "Pure" water will diffuse through the membrane leaving behind a more salty concentrate containing most of the dissolved organic and inorganic contaminants (figure 5). Brackish water RO plants typically recover 50 to 80 percent of the feed water, with 90 to 98 percent salt rejection. For seawater, recovery rates vary from 20 to 40 percent, with 90 to 98 percent salt rejection.

RO membranes are manufactured commonly in the form of hollow, hair-like fibers; or several alternating layers of flat-sheet membranes and open "spacer" fabric which is rolled into a spiral configuration (figure 6). Membrane selection depends largely on feed water characteristics and membrane costs.

Electrodialysis (ED)

With this technique, brackish water is pumped at low pressures between several hundred flat, parallel, ion-permeable membranes that are assembled in a stack. Membranes that allow cations to pass through them are alternated with anion-permeable membranes. A direct electrical current is established across the stack by electrodes positioned at both ends of the stack. This electric current "pulls' the ions through the membranes and concentrates them between each alternate pair of membranes. Partially

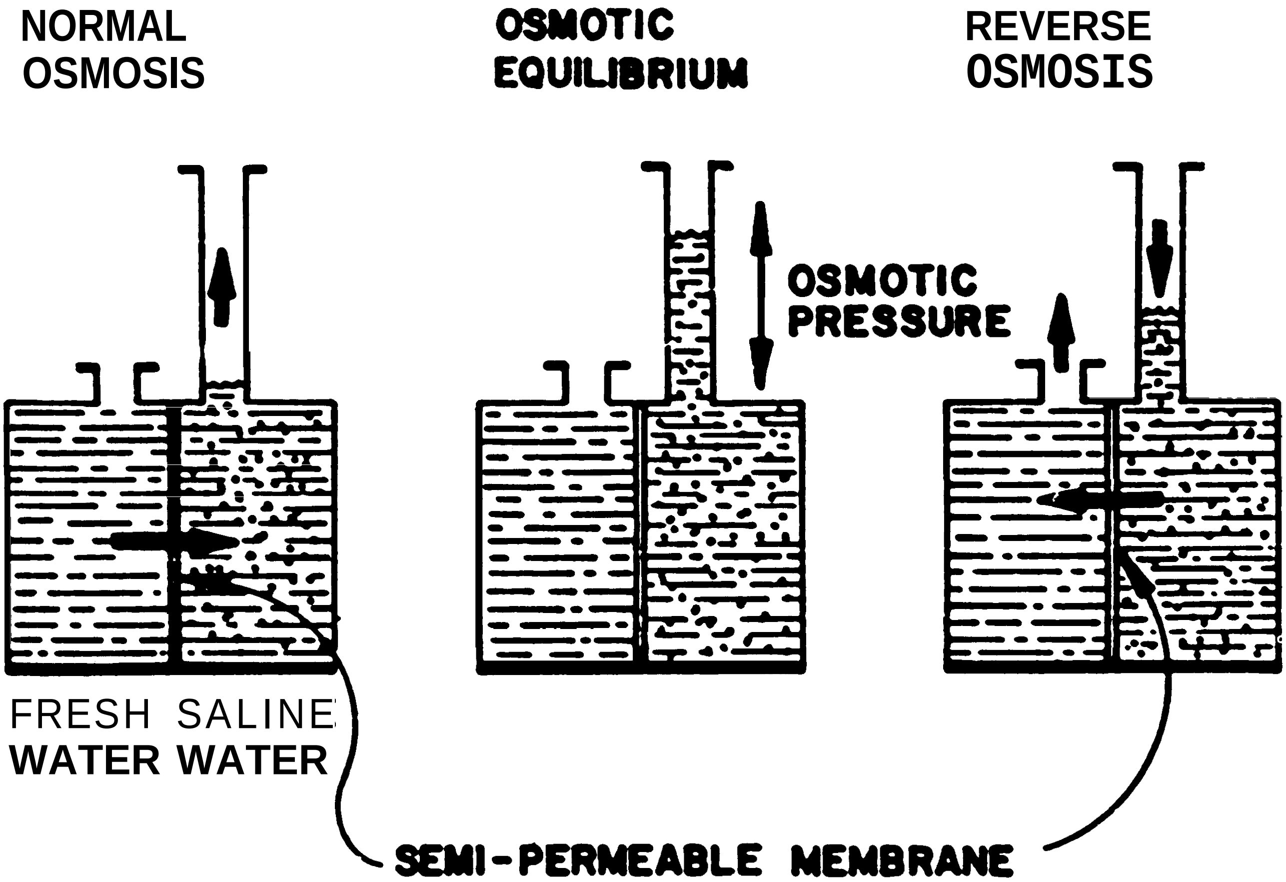
Figure 4.—Basic Elements in a Solar Still



The inside of the basin is usually black to efficiently absorb radiation and insulated on the bottom to retain heat.

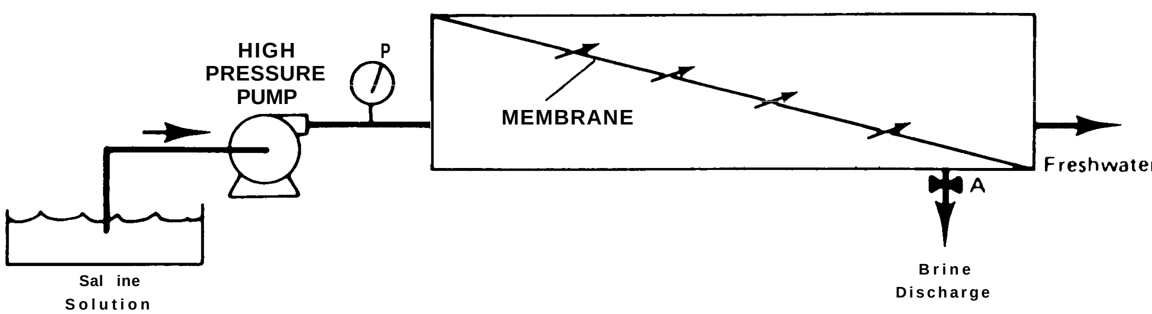
SOURCE: O.K. Buros, et al., "The USAID Desalination Manual," U.S. Agency for International Development, Washington, DC, prepared by CH2M Hill International Corp., August 1980.

Figure 5A.—Principles of Reverse Osmosis



SOURCE: S.L. Scheffer, H.D. Holloway, and E.F. Miller (R.M. Parsons Co.), "The Economics of Desalting Brackish Waters for Regional, Municipal and Industrial Water Supply in West Texas," Off Ice of Saline Water, R&D Progress Report 337, 1967.

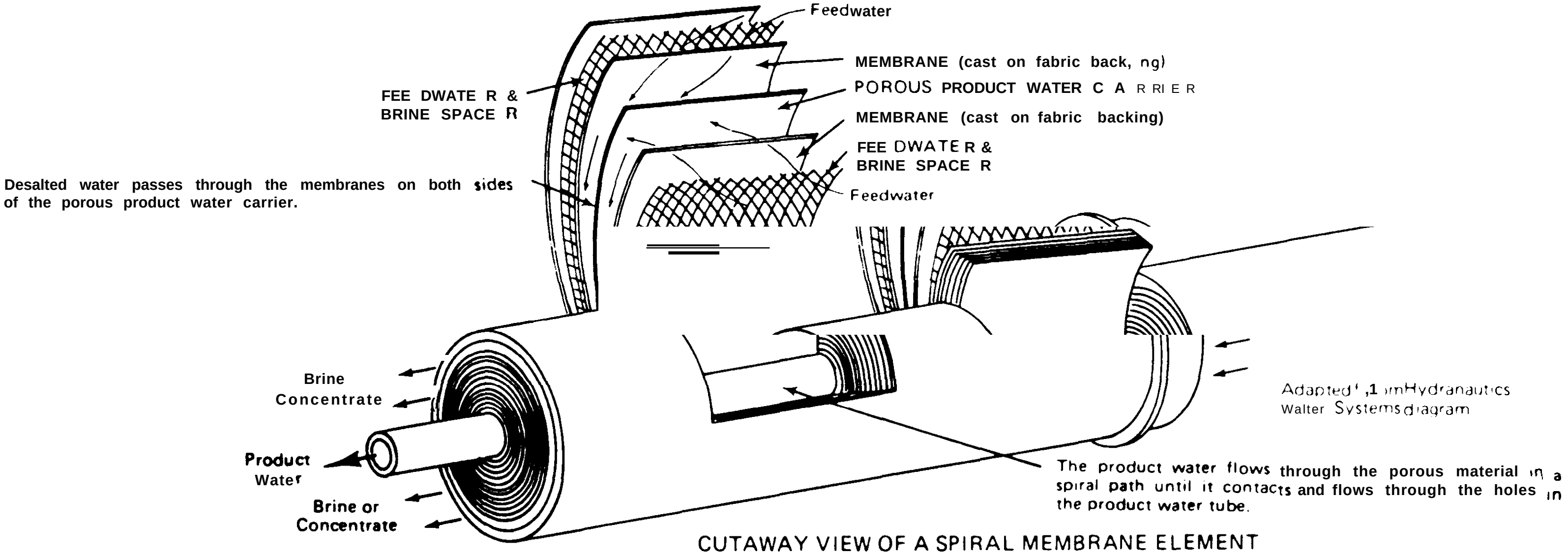
Figure 5B.—Elements of a Reverse Osmosis System



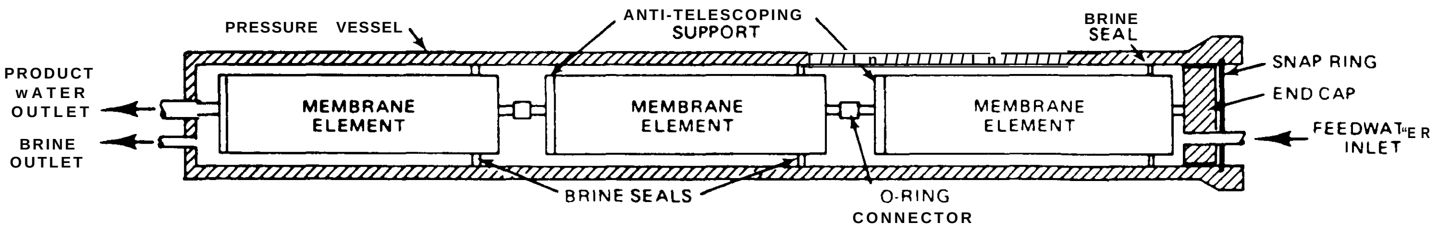
A membrane assembly is generally symbolized as a rectangular box with a diagonal line across it representing the membrane.

SOURCE: O.K. Buros, et al., "The USAID Desailnatlon Manual," U.S. Agency for International Development, Washington, DC, prepared by CH2M Hill International Corp., August 19S0.

Figure 6.—Spiral Membrane-Cut-Away View With Elements in a Pressure Vessel



CUTAWAY VIEW OF A SPIRAL MEMBRANE ELEMENT



CROSS SECTION OF PRESSURE VESSEL WITH 3-MEMBRANE ELEMENT

SOURCE: O.K. Buros, et al., "The USAID Desalination Manual," U.S. Agency for International Development, Washington, DC, prepared by CH2M Hill International Corp., August 1980.

desalted water is left between each adjacent set of membrane pairs (figure 7).

Scaling or fouling of the membranes is prevented in most ED units by operationally reversing the direction of the electrical current around the stacks at 15- to 30-minute intervals. This reverses the flow of ions through the membranes, so that the spaces collecting salty concentrate begin collecting less salty product water. Alternating valves in the water collection system automatically direct the flow in the appropriate direction. Typical freshwater recovery rates for ED (reversal) range from 80 to 90 percent of the feedwater volume (65).

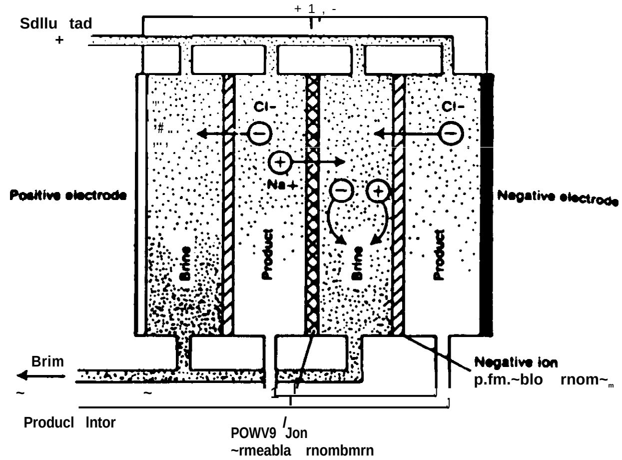
Ion Exchange (IX)

In this process undesirable ions in the feed water are exchanged for desirable ions as the water passes through granular chemicals, called ion exchange resins. For example, cation exchange resins are typically used in homes and municipal water treatment plants to remove calcium and magnesium ions in "hard' water, and by industries in the production of ultra-pure water. The higher the concentration of dissolved solids in the feed water, the more often the resins will need to be replaced or regenerated. With rising costs for resins and for disposing of regeneration solutions, IX is now competitive with RO and ED only in treating relatively dilute solutions containing a few hundred ppm of dissolved solids.

Freeze Desalination

When saltwater freezes, the ice crystallizes from pure water leaving the dissolved salt and other minerals in pockets of higher salinity brine. In fact,

Figure 7.–Electrodialysis (ED)



SOURCE: O.K. Buros, et al., "The USAID Deaallnation Manual," U.S. Agency for International Development, Washington, DC, prepared by CH2M Hiii International Corp., August 1980.

freeze desalination has the potential to concentrate a wider variety of waste streams to higher concentrations with less energy than any distillation process (55). Traditional freezing processes involve five steps:

1. precooking of the feed water,
2. crystallization of ice into a slush,
3. separation of ice from the brine,
4. washing the ice, and
5. melting the ice.

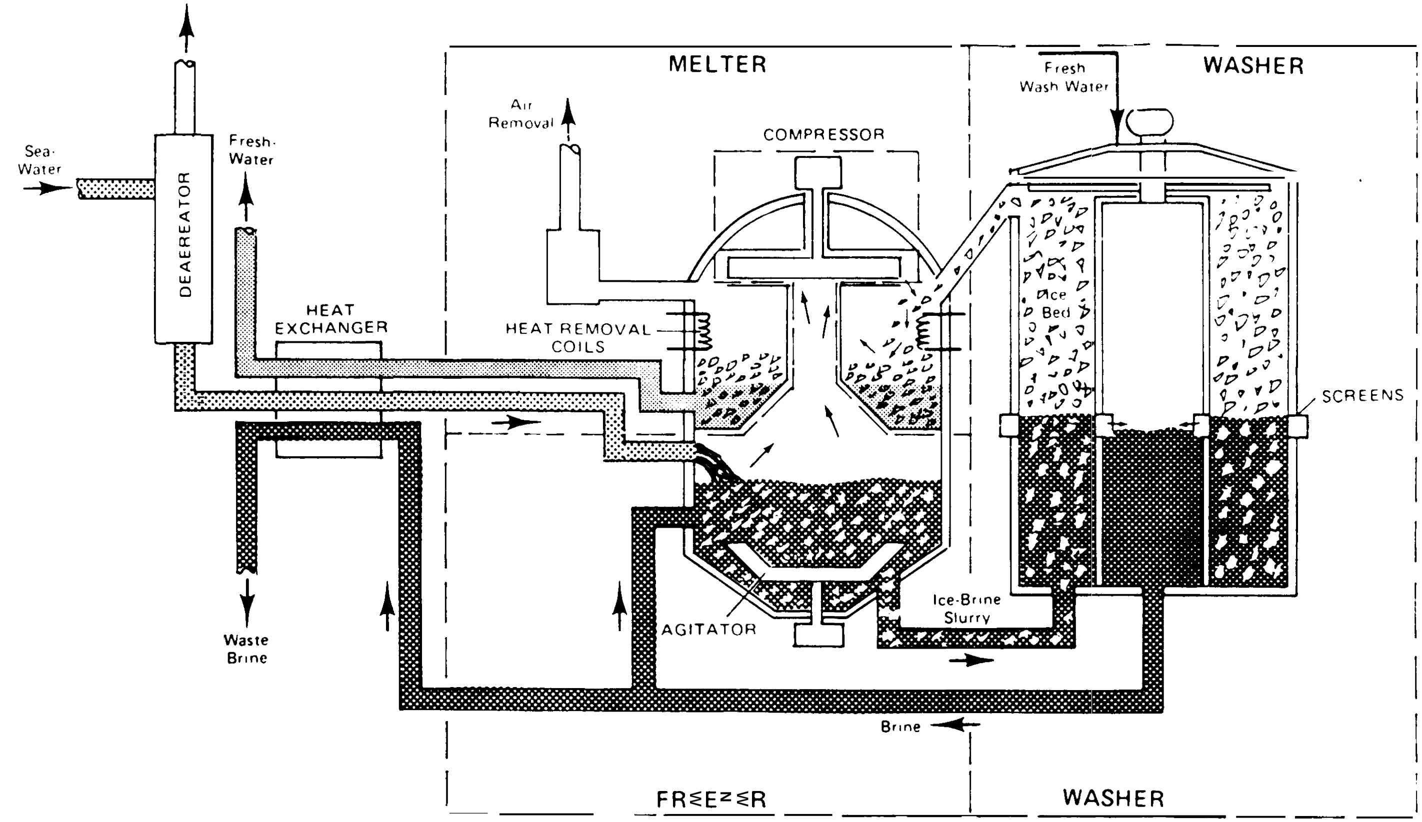
New research efforts are attempting to reduce the number of steps, especially the need to wash the ice crystals. Although small scale commercialization of freezing was attempted in the late 1960s, there were still significant operational problems. Only a few isolated commercial freezing plants now exist (figure 8).

PRETREATMENT OF INCOMING FEED WATER

The efficiency of desalination equipment can be significantly reduced due to fouling of membrane surfaces with solids (e. g., colloidal material, dissolved organics, bacteria, etc.) and/or the formation of scale (due to the precipitation of dissolved minerals). Consequently, the water fed to desalination units usually requires some type of pretreatment. The level of pretreatment required depends on the desalination process used, and feed water quality.

Pretreatment may include coagulation and settling; filtration; treatment with activated carbon to remove organics; disinfection to kill microorganisms; dechlorination (when chlorine and chlorine sensitive membranes are used); and the addition of acid, polyphosphates, or polymer-based additives to inhibit scaling (67,91). Generally speaking, these are all standard, water treatment techniques. Pretreatment costs may account for 3 percent to 30 percent of the total cost of desalination.

Figure 8. Schematic Diagram of a Freezing Desalination Plant Using the Vacuum-Freezing Vapor-Compression (VFVC) Process



NOTES: 1. The combined freezer (crystallizer) and melter in one vessel is a unit called a hydroconvert.
2. The compressor utilizes thin flexible metal blades. It is built specifically for the high-volume low-pressure conditions in the VFVC process.

SOURCE: O.K. Buros, et al., "The USAID Desalination Manual," U.S. Agency for International Washington, DC, prepared by CH2M Hill International Corp., August 980.

POST TREATMENT OF PRODUCT WATER

Depending on the quality of the product water and its intended use, some post treatment of the product water may be required. For example, distillation and ion exchange can produce water with such a low mineral content that the water may corrode metal pipes. Post treatment processes include carbon dioxide removal, pH adjustment, chemical addition, and disinfection. In some cases desalted water may be blended with water supplies from other sources to improve taste, to extend supplies of desalted water, and to improve the quality of other water (91).

SELECTING THE MOST APPROPRIATE DESALINATION TECHNOLOGY

Selec ion of the most appropriate technology depends on many site-specific factors including the concentration of organic and inorganic material in the incoming feed water (table 2), the desired quality of the treated water, the level of pretreatment that may be required prior to desalination, the availability of energy and chemicals to treat the water, and the ease with which waste concentrates can be disposed (91). In fact, both RO and ED membranes can be tailor-made based on the feed water composition. Many other factors that must also be considered include availability of construction and operating personnel, waste concentrate disposal, environmental considerations, maintenance requirements, and cost. An engineering study of site-specific conditions within the context of a long-term water resources development plan is usually required prior to selecting a specific process for desalinating or demineralizing large quantities of water.

Table 2.—Desalination Techniques

	Typical applications			
	Brackish water			
Technique	0-3,000 ppm	3,000-10,000 ppm	Seawater 35,000 ppm	Higher salinity brines
Distillation		s	P	P
Electrodialysis	b		t	P
Reverse osmosis	P	;	P	s
Ion exchange	P			

KEY: P - Primary application
s - Secondary application
t = Technically possible, but not economic

SOURCE: Office of Technology Assessment, 19S7.