An Introduction to Water Desalination

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1. SITE SELECTION

1.1 Site technical requirements. Site technical requirements are specific to each particular process. Generalized recommendations can be made regarding location, space, and access requirements. A typical desalination system flowsheet is shown in figure 1-1. A typical desalination system layout, using reverse osmosis as a sample process, is shown in figure 1-2.

1.1.1 Location. Desalination facilities will be located as close to the raw water source as possible in order to avoid excessive pipeline or pumping costs and to minimize operation and maintenance costs for pumping raw water (high saline content). Topography should be considered in the siting of a desalination facility, and gravity flow should be used where possible.

1.1.2 Space requirements. The space required for desalination facilities is determined by the process. Membrane desalination equipment needs less space than distillation/ condensation desalination equipment. In general, space requirements are less for the desalination equipment than for a conventional surface water treatment plant of the same capacity. An exception is solar desalination systems. These systems employ solar collectors that require an area several times greater than other types of desalination equipment in order to achieve equal capacity.

1.1.3 Access. Access to systems must be provided to permit routine maintenance, sludge and brine removal, and delivery of desalination equipment and supplies. The access requirements for desalination facilities are similar to those for conventional water treatment facilities.

1.2 Water storage and system modularization.

1.2.1 Equipment downtime. In all distillation/ condensation and many membrane desalination plants, storage will be determined by equipment downtime when equipment
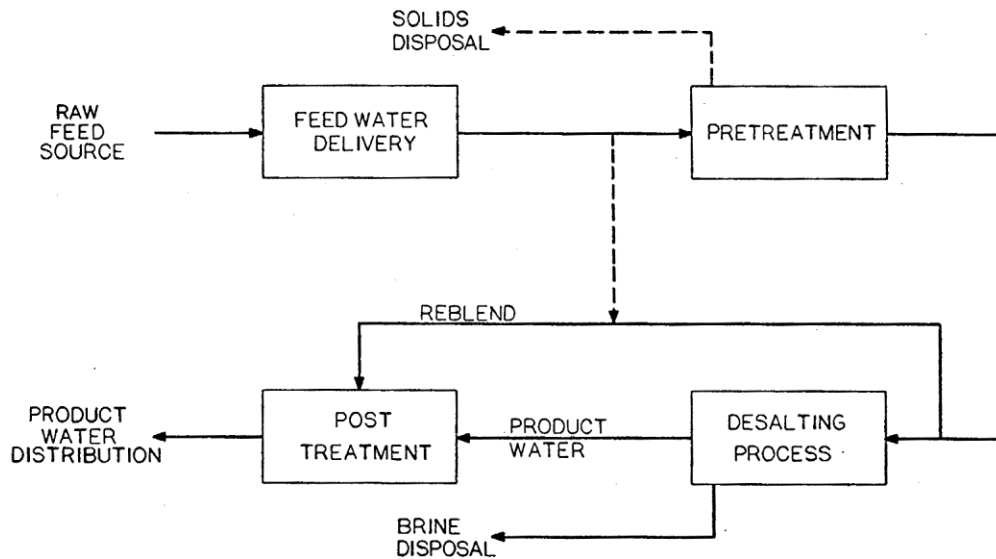
Figure 1-1
Typical desalination flow sheet

downtime is more than 1 day. To determine the necessary storage, establish the longest period of time that could be required for planned or unplanned maintenance. Calculate the storage by multiplying this time period by the water demand rate.

1.2.2 Peak daily demands. When maximum equipment downtime is less than 1 day, the peak daily demands may set a larger storage demand.

1.2.3 Fire water storage. On a facility served by a desalination system, fire water may be saline water or potable water depending on economic analysis. Dual water distribution system will be required if saline water is used. Hence, part of the fire protection water can be either saline or potable water due to piping and pumping cost. Economic evaluation of various design alternatives is usually needed to assure the optimal design to be adopted.

1.2.4 System redundancy and modularization. One complete and functional desalination module in excess of that required to supply the design flow will be provided as redundant capacity, and all desalination systems will have a minimum of three independently functioning desalination modules where practicable.
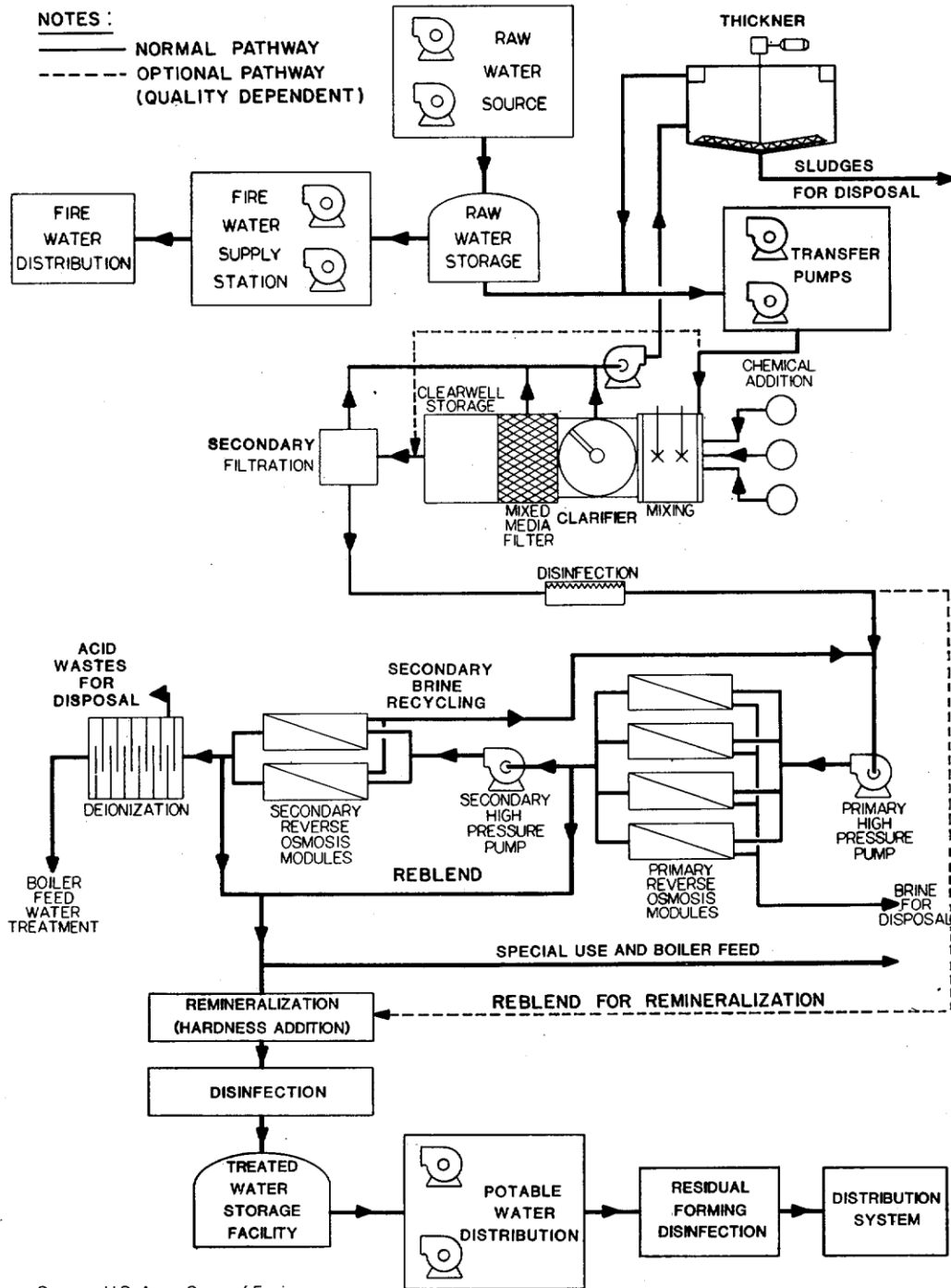
Figure 1-2

Typical reverse osmosis desalination system

2. WATER SOURCE SELECTION

2.1 General. The selection of a water supply will be based on available quantity, quality, and cost of development. Investigate usable fresh surface water and groundwater thoroughly, prior to consideration of sources requiring desalination. When fresh water sources do not exist, consider saline water sources. The most commonly used parameter to differentiate between saline water qualities is total dissolved solids (TDS). The total dissolved solids is defined as the sum of the dissolved organic materials and the inorganic salts. Fresh waters contain less than 1,000 milligrams per liter of total dissolved solids. Brackish water contains 1,000-20,000 milligrams per liter of total dissolved solids. Sea water usually contains at least 20,000 milligrams per liter of total dissolved solids. Quantities of potable water needed will be determined by an analysis of the site.

2.2 Quality. The quality will be determined by the planned use. Physical, chemical, and bacteriological testing of source waters are required to determine the level of treatment to supply the necessary water quality. When the quantity withdrawn exceeds the recharge rate, quality inherently decreases; therefore, this must be considered during design.

2.2.1 Physical characteristics. The physical characteristics of the raw water source that must be evaluated are total suspended solids (TSS), temperature, turbidity and silt density index (SDI).

2.2.1.1 Total suspended solids. The total suspended solids level of raw water sources must be evaluated to determine the level of pretreatment processes required. Raw water having low total suspended solids levels generally requires less pretreatment. The source with the lowest total suspended solids is preferred.

2.2.1.2 Temperature. The temperature of the raw water source must be matched to the specific desalination process. In extreme cases, the water temperature may control the desalination process selection. A climatological survey must be made prior to finalization of process selection to determine the seasonal maximum and minimum water temperatures of the proposed water sources.

3. GENERAL PROCESS SELECTION.

In selecting a potable water production system, it is important to estimate costs of various options. The conventional unit of comparison is cost in dollars per 1,000 gallons of product water. Water quality and energy sources will be estimated from simple site reconnaissance. For example, a sea coast site where the water source temperature exceeds 95 degrees Fahrenheit indicates a high-salinity high-temperature combination favoring distillation/condensation processes. Reverse osmosis requires a feed water temperature below 95 degrees Fahrenheit. If local well testing indicates salinity between 500 and 3,000 milligrams per liter and electricity is inexpensive, electrodialysis reversal or highflux reverse osmosis is indicated.

3.1 Desalination requirements. The design of a desalination system requires a clear understanding of the following: the quantity of product water desired; the quality of the desired product; and the quality of the feed water source. This discussion addresses the production of potable water containing less than 500 milligrams per liter of total dissolved solids. Laundries, boilers, dining halls, and hospitals may require water purer than 500 milligrams per liter of total dissolved solids. Potable water from the desalination system may be further treated to meet these requirements.

3.2 Saline feed water quantity. The production of potable water from saline water usually requires a significantly larger quantity of saline feed water than the quantity of potable water produced. When desalination is necessary to produce potable water, the process splits the feed water into two streams. One stream is the product water; the other stream is the brine that contains most of the salts originally in the feed water. In waters that need very little desalination, high-rate reverse osmosis may only reject 5 percent of the feed stream as brine. In reverse osmosis of sea water, more than 70 percent of the intake water may be rejected as brine. Multiply the required product quantity by the reciprocal of the product water recovery fraction to find the quantity of saline water that must be processed to yield the desired quantity of product water. In equation form it can be expressed as:

water demand / % recovery of product water = saline feed water flow

In some cases, the limited quantity of an available saline water may require a decision to adopt a more expensive desalination process with a higher water recovery rate. However, it may require choosing a different and more saline feed water with a greater availability.

3.3 Blending of waters. Blending a high concentration stream with a low concentration stream wastes the osmotic pressure energy between the two streams. Therefore, it is best to match the design of the desalination system to the product quality desired. When a desalination process cannot be economically matched to the desired product quality, then a process that yields water with a very low dissolved material content must be used. To conserve capital and equipment costs and meet the desired water demand, the high purity product water can be blended with the pretreated saline feed water to produce the required product quantity and quality. When only two streams are blended, the equation below can be used to show the flow of concentrated water that when blended with a dilute flow will result in the desired product concentration:

$$[(P - H)(D)]/(C-P) = F$$

Where:

        P = Desired product water concentration

        H = High purity water concentration

        D = Flow of the high purity water

        C = Concentration in the impure concentrated stream

        F = Flow rate of the concentrated stream

The same blend equations will apply to blending for remineralization, which is a more common procedure.

3.2 PROCESS LIMITATIONS.   The various desalination processes presently available have limitations that must be considered prior to selecting a desalination process for a particular site. These limitations apply only to the desalination processes themselves; pretreatment can be and is often used to bring a saline feed water within limits so that a desalination process

can be used. The raw feed water chemistry for all desalination systems must be evaluated thoroughly for constituents that may precipitate in the desalination system.

3.2.1 High-temperature distillation. High-temperature distillation is limited by the saturation of alkaline earth metal salts, such as $CaSO_4$, $BaSO_4$, $SrSO_4$, $CaCO_3$, $BaCO_3$, and $SrCO_3$. Carbonate salt scaling can be controlled by acid addition. The recovery of water from a high-temperature distillation plant is usually limited by calcium sulfate solubility. When the concentration of the sulfate and the limiting alkaline earth metal is one-third of the saturated condition at ambient temperature, distillation design must include pretreatment to reduce or inhibit the scaling ions. High-temperature distillation is also limited to oil and grease levels below 1 milligram per liter. All other limitations on the high-temperature distillation process are equipment specific and require individual evaluation.

3.2.2 Low-temperature and mechanical distillation. Low-temperature and mechanical distillation systems are limited to operation below saturation of alkaline earth sulfates and carbonates. The lower operating temperature permits economical operation on waters that are at or below half saturation at ambient temperature. Oil and grease are limited to less than 1 milligram per liter. Any other limitations are equipment specific.

3.2.3 Reverse osmosis. The most severe limitation on reverse osmosis is the maximum limit of 50,000 milligrams per liter of total dissolved solids in the feed water. Another limitation is that there must be no iron in the feed water. This limitation is so rigid that only stainless steel and non-ferric materials will be used downstream of the iron removal. The solubility of alkaline earth sulfates and carbonates limits reverse osmosis treatment. Any water containing less than 4,000 milligrams per liter of total dissolved solids that would be saturated with an alkaline earth sulfate when the concentration is multiplied by 1.5 should not be considered for reverse osmosis desalination. Reverse osmosis is limited to waters that do not have silica saturation in the reject brine. Silica chemistry is extremely complex. When the molybdenum reactive silica concentration exceeds 30 milligrams per liter as SiO_2 or the pH exceeds 8.3 in the brine stream, an environmental chemist or engineer should be consulted. Reverse osmosis is also limited to the treatment of waters with less than 1 milligram per liter of oil and grease.

3.2.3.1 Cellulose acetate membranes. Cellulose acetate membranes are usually limited to pH levels between 4.0 and 7.5. Cellulose acetate membranes require some form of continuous disinfection with the feed water to prevent microbial degradation of the membranes and can tolerate up to 1 milligram per liter of free chlorine. Therefore, cellulose acetate membranes are usually disinfected by maintaining 0.2 to 0.9 milligrams per liter of free chlorine in the feed water. Cellulose acetate membranes cannot be used on waters where the temperature exceeds 88 degrees Fahrenheit. Cellulose acetate membranes should not be used at pressures greater than the manufacturer's recommended pressure, since they are prone to membrane degradation by pressure compaction.

3.2.3.2 Polyaromatic amide membranes. Brackish water polyaromatic amide membranes are generally limited to operation in feed waters between pH 4 and pH 11. Polyaromatic amide membranes are less pH tolerant and should not be used outside of the range pH 5 to pH 9. All polyaromatic amide membranes are limited to use on feed streams that are free of residual chlorine. If chlorination is necessary or desirable as a pretreatment option, complete dechlorination must be effected. Polyaromatic amide membranes are tolerant of water temperatures up to 95 degrees Fahrenheit. While polyaromatic amide membranes are not as quickly or completely compacted as are cellulose acetate membranes, manufacturer's recommended pressures must be followed to prevent mechanical damage to membrane modules.

3.2.4 Electrodialysis reversal. While electrodialysis reversal has been used to treat water as saline as sea water, 4,000 milligrams per liter of total dissolved solids is considered to be an upper limit for economical operation. Some electrodialysis membranes can tolerate strong oxidants, like chlorine, but most cannot. The reversal of polarity used in electrodialysis reversal for removal of scale allows operation on water that is saturated with alkaline earth carbonates. Saturation with an alkaline sulfate with low carbonate alkalinity should be avoided.

3.3 Distillation/condensation energy. In distillation/condensation plants, energy is used in the form of steam and electricity. Steam is used to heat the saline water to increase its vapor pressure. Normally, electricity is used to run the compressor in vapor compression distillation.

If excess steam is available, its use as a power source should be
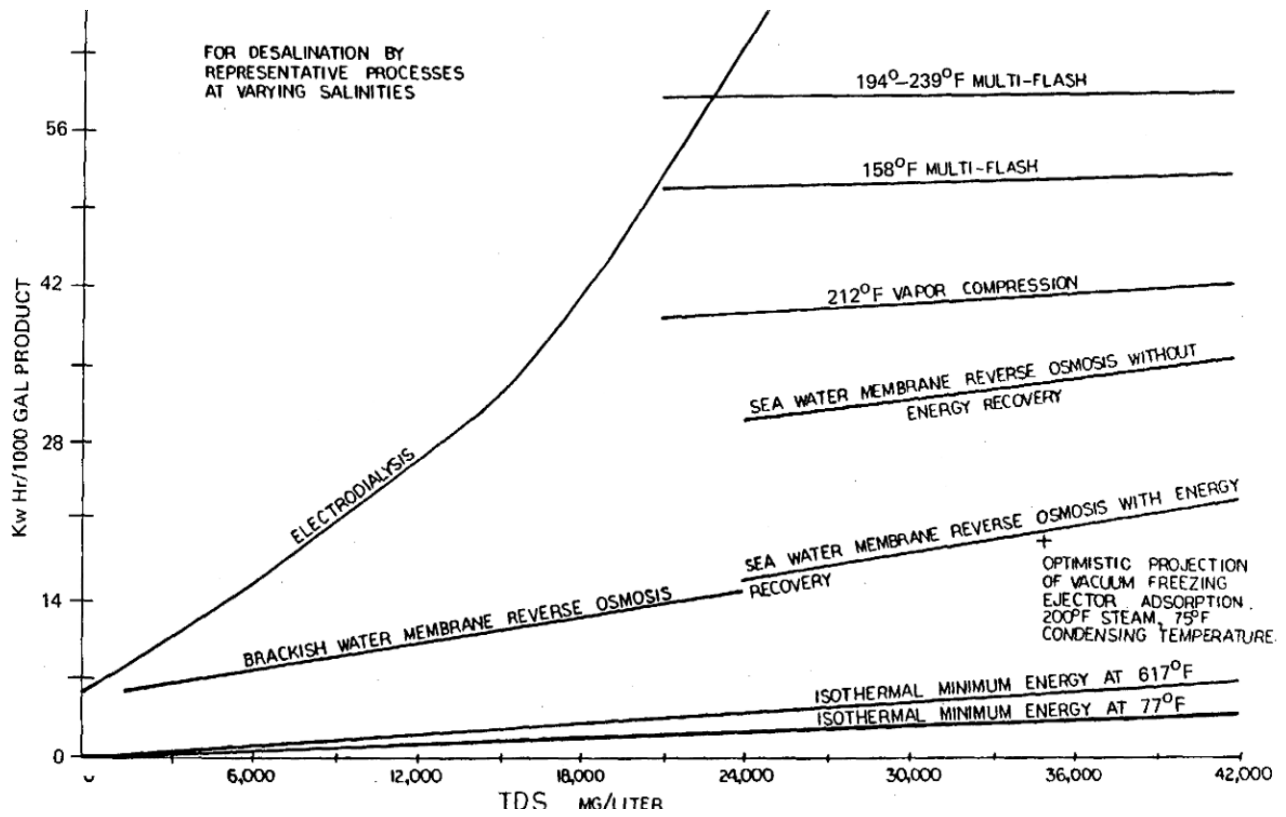

FOR DESALINATION BY REPRESENTATIVE PROCESSES AT VARYING SALINITIES

194°–239°F MULTI-FLASH

158°F MULTI-FLASH

212°F VAPOR COMPRESSION

SEA WATER MEMBRANE REVERSE OSMOSIS WITHOUT ENERGY RECOVERY

ELECTRODIALYSIS

SEA WATER MEMBRANE REVERSE OSMOSIS WITH ENERGY RECOVERY

OPTIMISTIC PROJECTION OF VACUUM FREEZING EJECTOR ADSORPTION 200°F STEAM, 75°F CONDENSING TEMPERATURE

BRACKISH WATER MEMBRANE REVERSE OSMOSIS

ISOTHERMAL MINIMUM ENERGY AT 617°F

ISOTHERMAL MINIMUM ENERGY AT 77°F

Kw Hr/1000 GAL PRODUCT

TDS MG/LITER

Figure 3-1

Energy Consumption

RULE	A	B	C	D	D	E
	If the freshest source of water is:	And if the desired output water will be:	And if electricity is to be generated:	And if the projected cost ratio of 264 deg F steam/electricity is:	Then investigate the cost of:	And have the following tests performed:
1	More salty than sea water	Potable water			Transportation of fresher water; distillation can be used but at great expense	Total Dissolved Solids (TDS)
2	Sea water	High-pressure boiler feed water	By steam turbine		Distillation followed by ion exchange	TDS, Ca, SO_4, CO_3, pH
3	Sea water	Potable water	By steam turbine	Greater than 10^7 BTU/kwh	Thermal distillation either with or without vapor compression	TDS, Ca, SO_4, CO_3, pH
4	Sea water	Potable water	By internal combustion engine		Vapor compression distillation and waste heat	TDS, bacterial count, turbidity
5	Sea water	Potable water	no	Less than 10^7 BTU/kwh	Reverse osmosis	TDS, Ca, SO_4, CO_3, pH, bacterial count, silt density index, turbidity, oil & grease
6	Brackish water	Potable water			Reverse osmosis	TDS, Ca, SO_4, CO_3, pH, bacterial count, silt density index, turbidity, oil & grease
7	Slightly saline brackish water	Potable water			Electrodialysis reversal	TDS, full ionic breakdown, bacterial count, turbidity

Table 3-1

Preliminary desalination process selection

investigated. The amount of electricity or mechanical work that steam will yield depends on its

temperature as well as the temperature to which it can be condensed. The energy consumption of both vapor compression and thermal distillation, as related to the total dissolved solids of feed water, is shown in figure 3-1.

3.4 Membrane energy. Historically, membrane desalination systems use less energy than other systems. Brackish water desalination should be accomplished by membrane separation processes because of the reduced energy requirement. The energy consumption of electrodialysis reversal can be made to follow reduced or variable salinity, while the energy consumption of reverse osmosis is set principally by membrane water flux. Again, the energy consumption of electrodialysis reversal and reverse osmosis as a function of the total dissolved solids content of the feed water is shown in figure 3-1. As membrane materials are developed, energy consumption may be reduced.

3.5 Waste disposal. Waste disposal may influence process selection. Since brine disposal costs can be an important part of process economics, brine disposal alternatives must be explored while water quality analyses are being performed.

3.6 Preliminary process selection. Use preliminary site information to eliminate certain desalination processes. A decision logic table for use with preliminary information is shown in table 3-1. Decisions based upon table 3-1 are to be considered preliminary only. Necessary water quality tests to further support the recommendations made in Column E of table 3-1 are in Column F.

3.7 Process selection. When initial site and raw water source selections have been made, use preliminary water quality information with table 3-1 to assist in a preliminary process selection. As more specific information is obtained from laboratory analyses of water quality, make an initial process selection using the second decision logic table, table 3-2. After a treatability investigation has been completed, select the final desalination process. The use of the decision logic table sequence will only provide generalized assistance in process selection; additional economic, engineering, and environmental studies may indicate that methods or combinations of methods must be used.

Rule	A	C	D	E	F
	If the feedwater TDS is (mg/liter):	And if the product of $(Ca)(SO_4)$ $moles^2/liter^2$ in the reject brine is:	And if the oil and grease in the raw feedwater is:	Then investigate the cost of:	And have the following pretreatment processes investigated for effectiveness:
1	Greater than 50,000			Transportation of fresher water. Distillation of this water is extremely expensive.	Precipitation of less soluble salts
2	Between 20,000 and 50,000	Considerably less than 2×10^{-4}	Greater than 10 mg/liter	Reverse osmosis or distillation and steam and electricity	Alum jar tests, pH adjustment, 10 micron or smaller filter plugging
3	Between 20,000 and 50,000		Less than 10 mg/liter	Reverse osmosis	Alum jar tests, 10 micron or smaller filter plugging, UV sterilization
4	Between 20,000 and 50,000		Less than 10 mg/liter	Spiral-wound membrane reverse osmosis	pH adjustment, UV sterilization, chlorine disinfection, chlorine residual
5	Between 20,000 and 50,000		Less than 10 mg/liter	Hollow fine-fiber membrane reverse osmosis	10 micron or smaller filter test; UV sterilization
6	Between 3,000 and 20,000	Considerably less than 2×10^{-4}	Greater than 10 mg/liter	Distillation	pH adjustment, alum jar test
7	Between 3,000 and 20,000		Less than 10 mg/liter	Reverse osmosis	pH adjustment, alum jar test, silt density index, UV sterilization
8	Between 500 and 4,000			Electrodialysis reversal	pH adjustment, alum jar test, 10 micron filter plugging, chlorine disinfection

Table 3-2

Selecting desalination processes after water quality data are obtained

4. DISTILLATION/CONDENSATION TECHNIQUES

4.1 General. Distillation/condensation is the most common desalination process. More than 70 percent of all desalination facilities in use today employ some variation of the distillation/condensation process.

4.2 High-temperature distillation. High temperature distillation facilities that operate at temperatures greater than 205 degrees Fahrenheit are the most prevalent desalination facilities in the world today. There are three methods of vaporization: submerged tube vaporization; flash vaporization; and thin-film vaporization. These methods are illustrated in figure 4-1. Submerged tube vaporization is the least efficient vaporization technique, but it allows for easy maintenance. This type of vaporization system is most often used in exhaust gas waste heat recovery distillation systems. The flash vaporization technique is presently the most common technique in existing distillation units. The impact of sprayed hot brine within the evaporator unit causes both erosion and corrosion of most metals. Using a thin-film spray vaporization process, the raw water is introduced at slightly less than atmospheric pressure through an orifice onto heat exchanger tubes for immediate vaporization. The corrosive environment is reduced from the flash vaporization system, but scaling can occur on the heat transfer surfaces. These vaporization techniques are used in the two major high-temperature distillation processes, multiple-effect (ME) evaporation, and multistage flash (MSF) evaporation.

4.2.1 Multiple-effect evaporation units. To maximize thermal energy efficiency within a distillation/condensation system, several units or effects are used. The heat from the condensation step of one effect is used to supply vaporization heat for the following effect. The next effect is a slightly lowered pressure and temperature. This gradual reduction by heat transfer results in a much greater yield of product water from a given quantity of thermal energy. A typical multiple-effect evaporation unit is shown in figure 4-2.
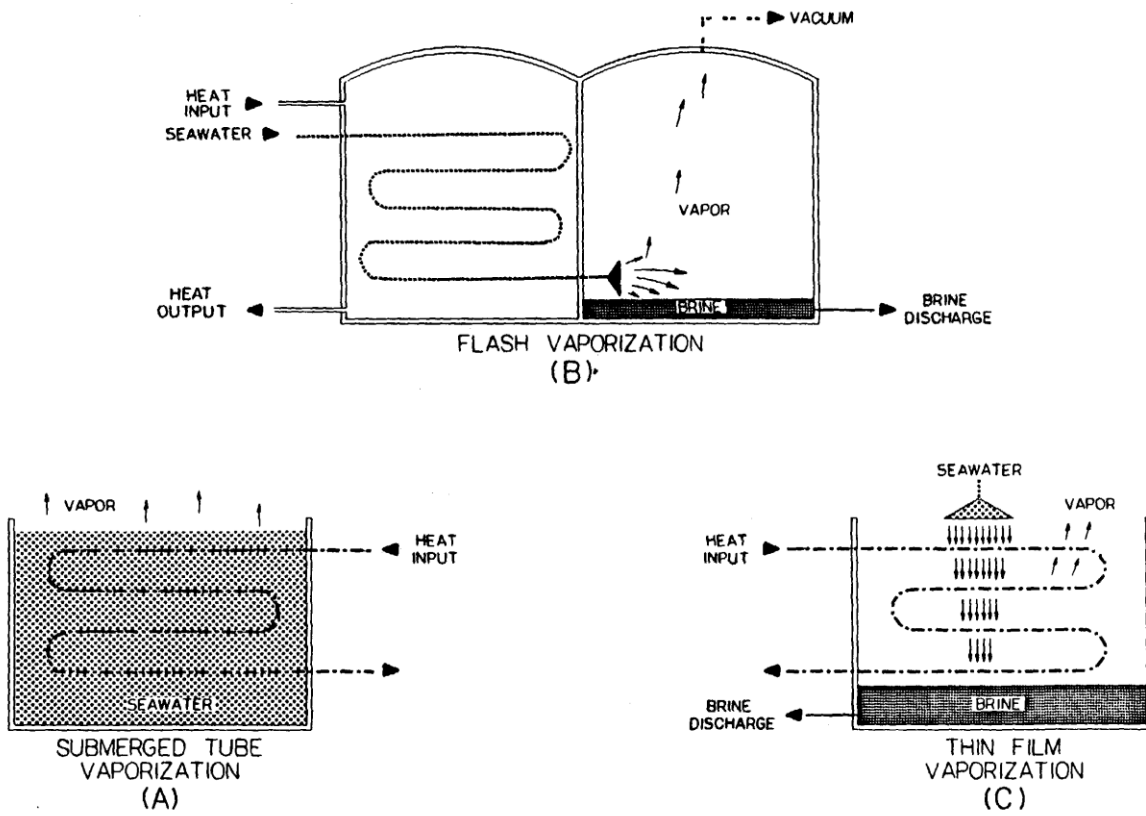
Figure 4-1

Three methods of vaporization

Figure 4-2

Multiple-effect vertical-tube evaporation process.

4.2.2 Multistage flash-evaporation units. Distillation technology was advanced through the development of multistage flash evaporation units. Stages of flash evaporation are operated using heat from an external source. Pressure is reduced gradually in each successive stage to continue flash operation at successively lower temperatures and pressures. Because scaling is not a serious problem, this design has become the most prevalent distillation process. A typical multistage flash-evaporation unit is shown in 4-3. Although internal scaling is not a great problem, corrosion of flash-evaporation units is of concern.

4.3 Low-temperature distillation. Distillation/ condensation facilities that operate at temperatures less than 205 degrees Fahrenheit are low-temperature units.

In situations where waste heat is plentiful, low temperature waste-heat-recovery evaporation units are used. A waste-heat-recovery unit is shown in 4-4. For onshore application, low-pressure waste steam from power generation facilities can provide the necessary thermal energy for desalination systems. The most recent developments in distillation/condensation technology involve the use of waste heat or low pressure steam with evaporation units and a mechanical vapor compression system. Multiple stages then derive the maximum vapor and product water production from the system.

4.4 Mechanical distillation. The use of mechanical methods for vapor production and heat transfer can result in a highly efficient desalination system. These systems operate at temperatures less than atmospheric boiling point and use a variety of methods to vaporize raw waters. These mechanical processes commonly use multiple effects to maximize the efficiency of the applied mechanical energy.

4.4.1 Vapor compression. The technique of vapor compression uses a mechanical energy source, such as an engine of electric motor, to power a compression turbine. This turbine draws vapor from the distillation vessel and compresses it, which raises the temperature of the exhaust vapor. The vapor is then passed over a heat exchanging condenser, where it returns to the liquid state as product water. The heat removed during condensation is returned to the raw water to assist in the production of more vapor. The more recent vapor compression multiple-effect units produce a concentrated brine byproduct that has had its excess heat reduced by the multiple effects.
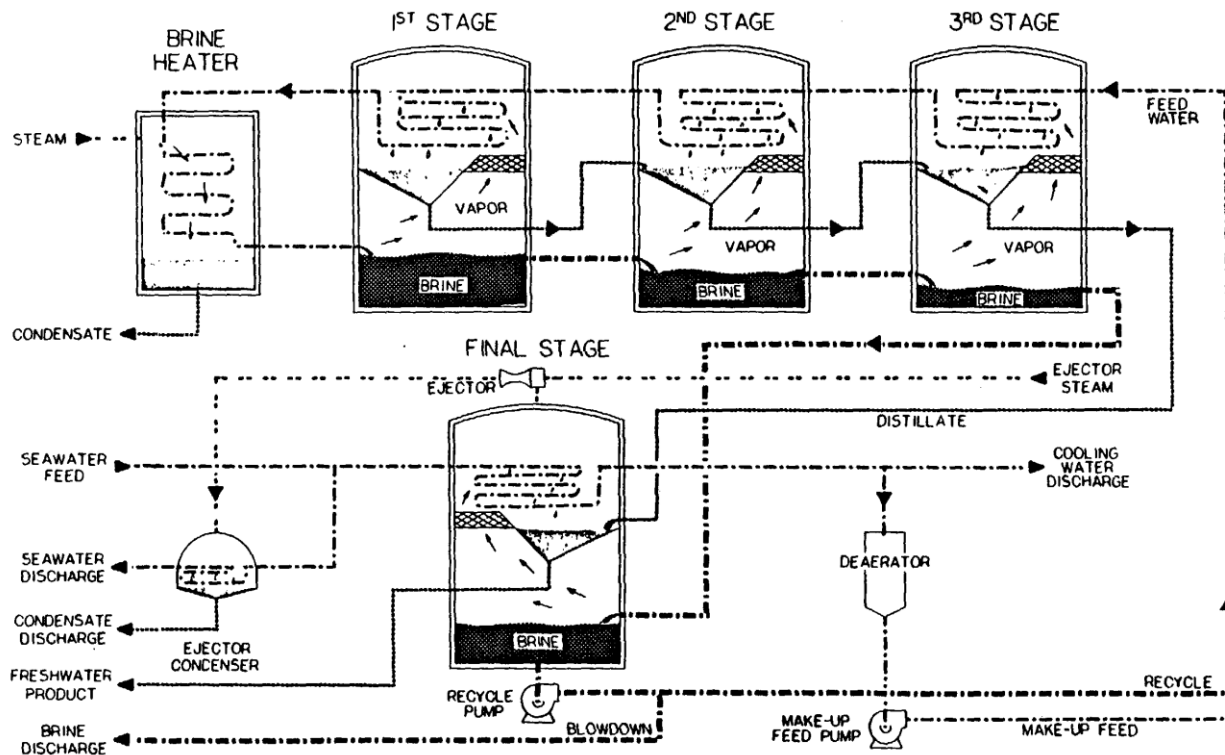
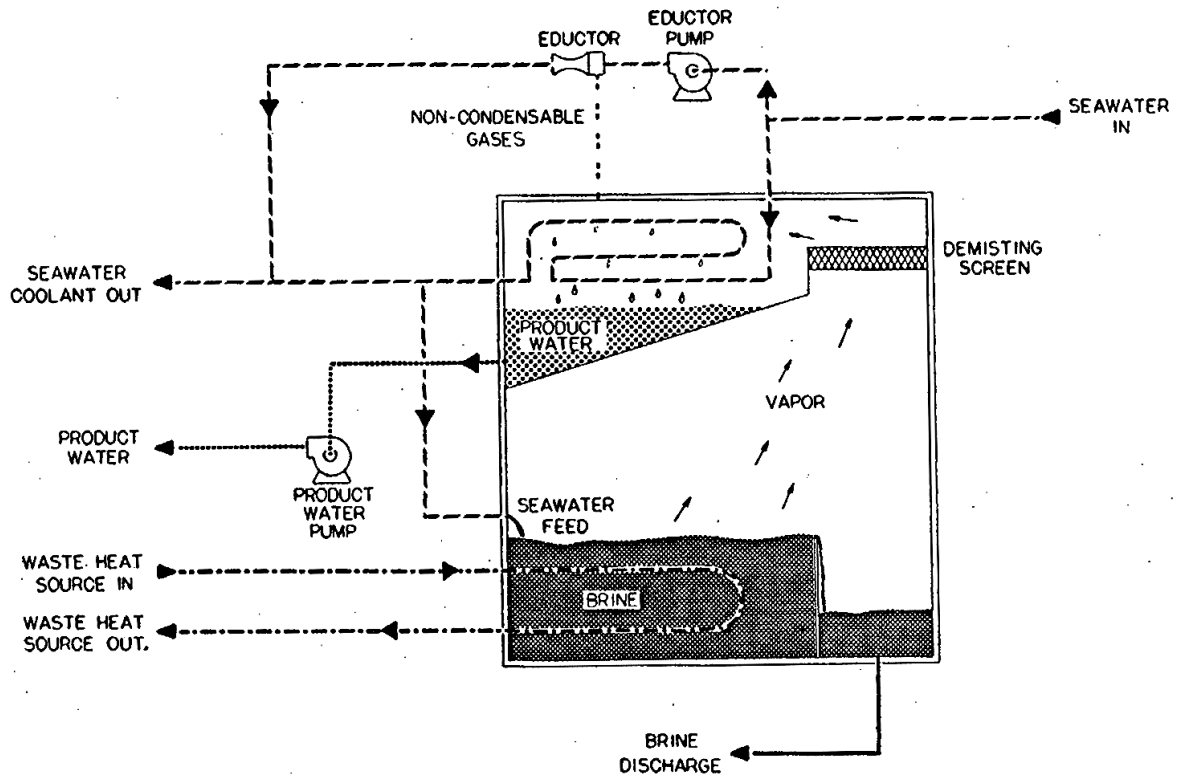Figure 4-3

Multistage flash distillation facility.

Figure 4-4

Waste heat recovery evaporation process

4.4.2 Waste heat. Adding waste heat to vapor compression systems results in a highly efficient distillation/condensation process. These systems are designed to maximize the production of product water with minimal energy input. A typical vapor-compression multiple-effect system is shown in figure 4-5.
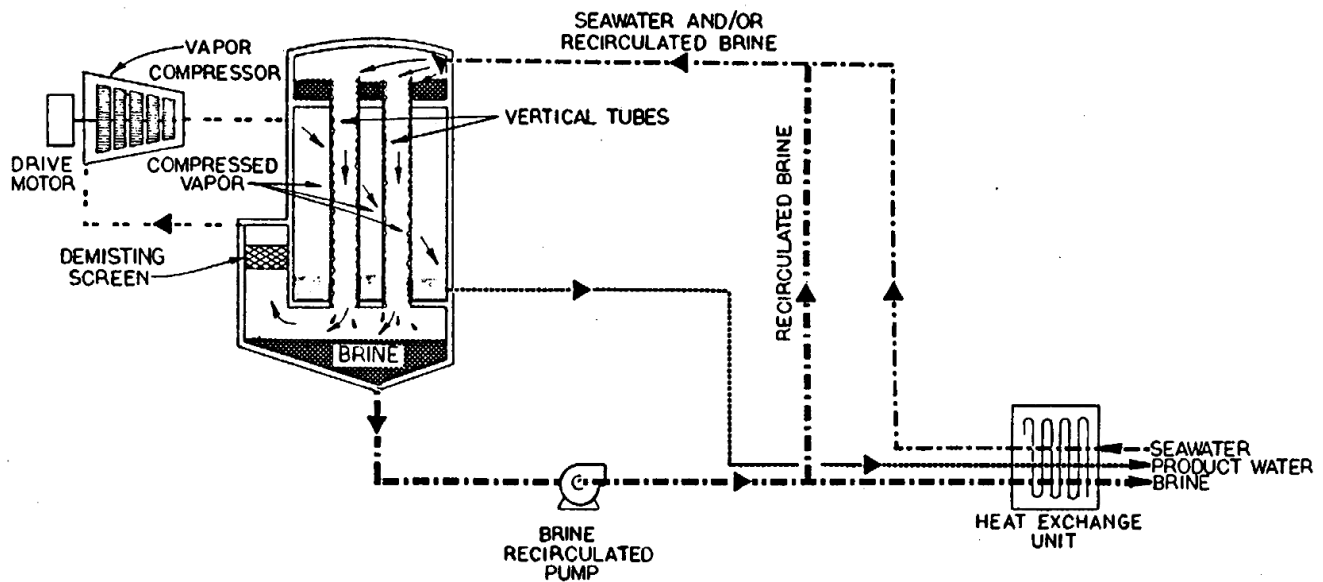

Figure 4-5
Vapor-compression vertical-tube distillation system.

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The advantages of this type of system include a lower energy demand than high-temperature distillation, less corrosion due to possible use of thermoplastic materials, and lower operational temperatures.

4.5 Thermal discharge. A problem resulting from all distillation/condensation facilities is thermal discharge of liquids. Older high temperature facilities produce brine at very high temperatures. Cooling towers, heat exchangers, or similar equipment must be designed into the process to handle the thermal discharge from distillation/condensation facilities. More sophisticated desalination units employ a system of heat exchange devices that use the raw

feed water to cool the brine and reclaim this waste heat to help provide thermal energy for system operation.

4.6 Design analysis. When it is necessary to review several water distillation/condensation designs, standard dimensionless analysis will be used for design comparison. If dimensionless correlations for particular aspects of design do not exist, a bench- or pilot-scale study should be done.

4.7 Materials of construction. The corrosive nature of high-temperature brines, acid pretreatments, and chemical scaling can cause plant failure. Presently, the only acceptable construction materials for wetted surfaces in high-temperature systems are an austenitic stainless steel, such as AISI Type 316L of titanium. Anodized aluminum and many thermoplastic materials are acceptable for use in low-temperature systems.

4.8 Distillation/condensation system design . Pursuant to finalized site and process selection, one distillation/condensation system will usually be chosen. When the process selection does not yield a single process, then designs must be prepared for more than one process.

4.8.1 Identification of work. When the base site has been selected and a schedule for construction has been prepared, this information will be made available to the water treatment engineer. The identification of the location and the time schedule will be considered in the design; this includes the date the system must be online. The minimum number and minimum size of the modules will be determined. Any restrictions that storage will place on maximum allowable downtime will also be determined. With distillation/ condensation systems, the design must address the maximum allowable total dissolved solids and, where applicable, the minimum allowable rejection of distillable material. Distillable material is defined as non-aqueous, volatile water contaminants.

4.8.2 Existing or planned facilities. Distillation/ condensation systems design must include availability of energy information. Alternative steam sources considered in the design must include steam temperature, steam pressure, and available quantity of steam. The design

must show available electrical power including voltage, amperage, phase of the available electricity, and frequency of the available electrical power.

4.8.3 Raw water information. One of two circumstances will limit the quantity of raw water consumed. Both of these limitations must be considered in the design:

- The availability of raw water may place a limitation on the raw water used in the process.
- The maximum amount of waste brine that can be economically disposed of may limit the raw water used in the process.

The principle requirement in a desalination design is an accurate projection of the chemical makeup of the worst quality water that will be used as raw feed water at the site being investigated. The design must include consideration of the maximum total dissolved solids, individual ions, maximum amount of total suspended soiled present in the feed water, maximum organic contaminant loading, and any gas or potential corrosive agent that may be in the feed water. All known or anticipated future qualities of the feed water shall be considered in the design.

4.8.4 Process design. When a distillation/condensation process has been identified as the most economical, then the design will be limited to the single process. The process design for any distillation/condensation process will include a minimum required input temperature and some maximum required heat sink temperature. Between these two temperature criteria, the process must be capable of producing the required product water quality and quantity. When a particular metallurgy is required for strategic, corrosion design, or economic reasons, this metallurgy shall be designated for all applicable parts, as well as spare parts. All required instrumentation must be included in the design. The design must show the required output water quality based on the worst raw water input chemistry and quality. The system design must be based on equipment with a history of successful water treatment system experience. The required experience history should include a minimum of 2 years of operating experience meeting water quality and system design goals, treatment capacity, maximum allowable repair frequency and duration, and a maximum allowable ratio of experienced capital cost to

repair cost. The requirement for successful experience will limit the amount of untested innovation used at a facility.

5. MEMBRANE TECHNIQUES

5.1 Electrodialysis. The ions in a water solution can be made to migrate by applying an electric field to the solution. By arranging various barriers to the flow of ions, it is possible to directly desalinate water with electricity. Such barriers are called ion-exchange membranes. Membranes that allow a reasonable flow of cations, but block or reduce the flow of anions, are called cationic-exchange membranes. Membranes that allow a reasonable flow of anions, but block or reduce the flow of cations, are called anion-exchange membranes. Membranes that pass both anions and cations are called neutral membranes.

5.1.1 Theory. In solutions containing dissolved ions, electric currents are carried by movement of the ions. Positive ions migrate in the direction of the current flow, and negative ions migrate against the current direction. When the anions are blocked by a cationic-exchange membrane, they stop and form a localized charge at the membrane face. This accumulated negative charge is neutralized by the flow of cations across the cationic membrane. This generates a concentrated solution on the side of a cationic-exchange membrane that faces the negative electrode. It also generates a dilute solution on the side of the cationic membrane that faces the positive electrode as shown in figure 5-1.

5.1.2 Electrodialysis stack. If both a cationic and anionic membrane are placed across a current flow in an electrolyte solution, the side of the cationic membrane facing the positive electrode and the side of the anionic membrane facing the negative electrode will become less saline. If the cationic membrane is closer to the negative electrode and the anionic membrane is closer to the positive electrode, the solution between the membranes will become less saline as the ions migrate in their respective directions. Any number of pairs of cationic and anionic membranes can be placed across a current-carrying solution, such that the cationic membrane is closest to the negative electrode, and the solution between will be diluted (fig. 5-1). A battery of several such membrane pairs is called an electrodialysis stack. Several variations of the standard electrodialysis stack have been developed, but none have been proven superior to this standard stack of alternating cationic and anionic-exchange membranes to desalinate natural brackish water.
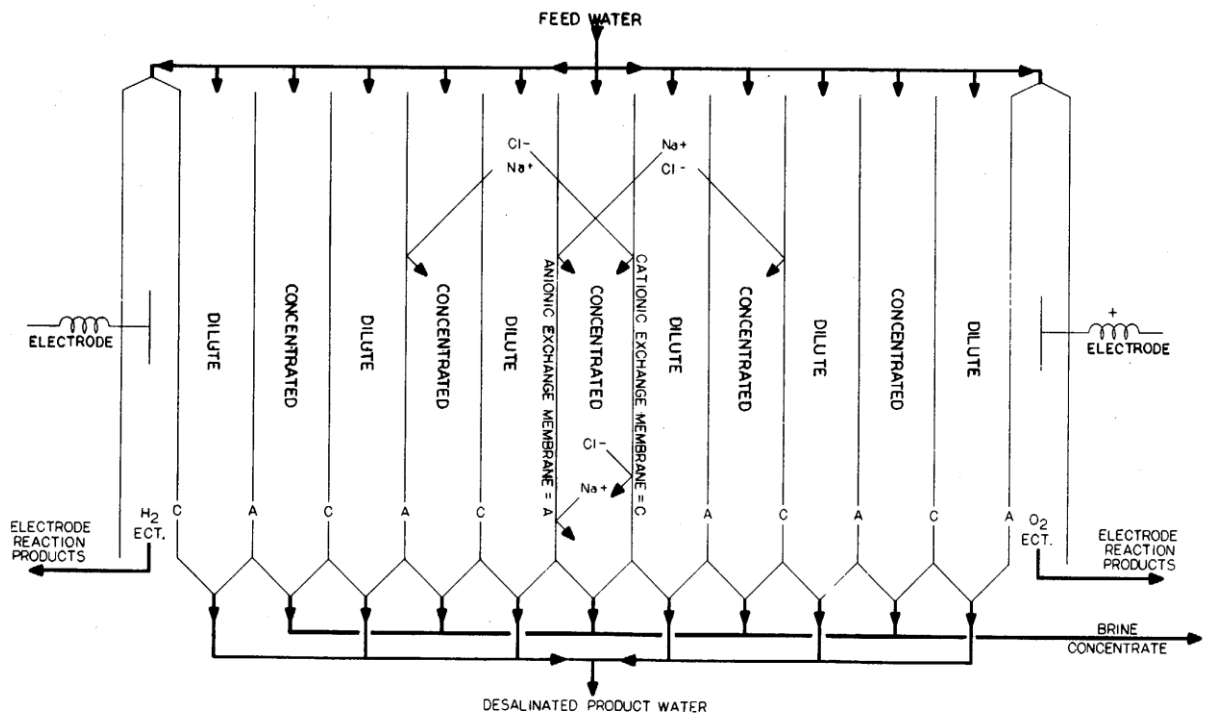
Figure 5-1

Principles of electrodialysis desalination

5.1.3 Electrodialysis reversal. One important improvement now used in electrodialysis installations is to reverse the polarity periodically and move the ions in the opposite direction. This returns anions across the anionic membranes and helps break up scale formed on the concentrating face of the membranes. Water will flow osmotically across both membranes from the dilute product stream to the concentrated brine stream in an electrodialysis-reversal stack. This osmotic product water loss concentrates uncharged material, such as turbidity and bacteria. This concentration effect must be considered during the design to ensure meeting water turbidity and product water bacterial count requirements. Most electrodialysis membranes are not tolerant of chlorine. When possible, water desalinated by electrodialysis reversal should be disinfected after desalination is completed. The membranes should be protected by a 10-micron cartridge filter.

5.2 Electrodialysis-reversal design. When electrodialysis reversal can be shown to be the most economical process for desalination, then only an electrodialysis-reversal system will be designed. When the process selection does not yield a specific process, then designs must be prepared for more than one process.

5.2.1 Identification of work. The design engineer will be made aware of the site and construction schedule. The location and time schedule will be considered in the design; this includes the date the system must be online. The minimum number and minimum capacity of the modules will be determined. Any restrictions that storage will place on maximum allowable downtime will also be considered. A maximum allowable output conductivity in the product water will be determined, based on the worst possible feed water.

5.2.2 Existing on planned facilities. When electrodialysis reversal is being designed, it is essential to determine the types of available electrical power. The voltage, phase, frequency, and available amperage of all electrical power sources, planned or existing, must be considered in the design.

5.2.3 Raw water information. One of two circumstances will limit the quantity of raw water consumed. Both of these limitations must be considered in the design:

- The availability of raw water may place a limitation on the raw water used in the process.
- The maximum amount of waste brine that can be economically disposed of may limit the raw water used in the process.

The principle requirement in a desalination design is an accurate projection of the chemical makeup of the worst quality water that will ever be used as a raw feed water at the site being investigated. The design documentation must include maximum total dissolved solids, the individual ions, the maximum amount of total suspended solids present in the feed water, and any gas or potential corrosive agent that may be in the feed water.

5.2.4 Process specifications. When an electrodialysis- reversal process has been identified as most economical, the design will be limited to the single process. The process design for any electrodialysis-reversal process will include a minimum/maximum allowed product water conductivity. The design must show the required product conductivity that must be obtainable at the required product flow, based on the worst conductivity raw water. A 10-micron cartridge filter to be placed before the membranes must be included in the design. When a particular metallurgy or material is required for strategic, corrosion design, or process economic reasons, this metallurgy or material will be designated for all applicable parts and spare parts and equipment. All required instrumentation, including a voltmeter and an ammeter, for each electrodialysis-reversal stack must be designed. The system design must be based on equipment with a history of water treatment system experience. The required experience history should include a minimum of 2 years of operating experience meeting water quality and system design goals, current operating capacity, maximum allowable repair frequency and duration, and maximum allowable ratio of experienced capital cost to repair cost. The requirement for successful experience will limit the amount of untested innovation used at a facility.

5.3 Reverse osmosis. Diffusion through materials is influenced by the nature of the diffusing material. A number of materials allow water to pass through with relative ease. Some of these materials allow only a minute passage of ionized material compared to the passage of water through them. These semipermeable materials are used for desalination. If a thin barrier or membrane is used, water can be forced through the membrane while ions are stopped by the membrane. In general, non-ionized materials, such as some gases and many organics, will not be removed by these membranes. Some larger organic molecules may not pass through the membranes.

5.3.1 Osmotic pressure. When a semipermeable membrane that will pass solvent is placed between two solutions of different concentrations containing the same solvent at identical temperatures, the solvent must pass from the less concentrated to the more concentrated solution as shown in figure 5-2. This flow of solvent produces a pressure head difference. The equilibrium liquid pressure head difference is called the osmotic pressure difference of
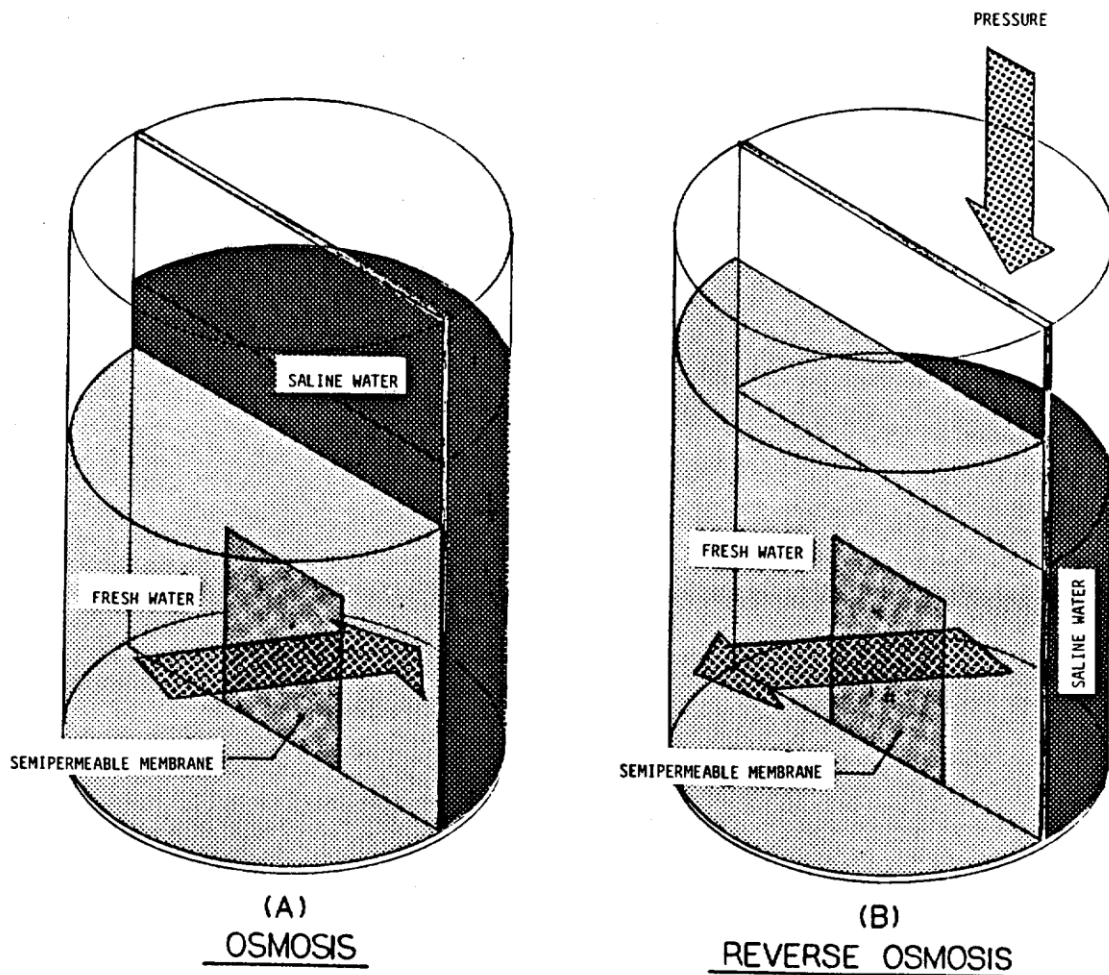
Figure 5-2

Reverse osmosis principles

the solutions. If these pressures are reversed, pure water will be forced from the more concentrated solution through the membrane into the less concentrated solution, provided that the pressure differential exceeds the osmotic pressure. A typical reverse osmosis flow sheet is shown in figure 5-3.

5.3.2 Energy recovery. Reverse osmosis produces a concentrated, high-pressure brine. With reverse osmosis, the energy lost in depressurizing the brine can be returned efficiently to
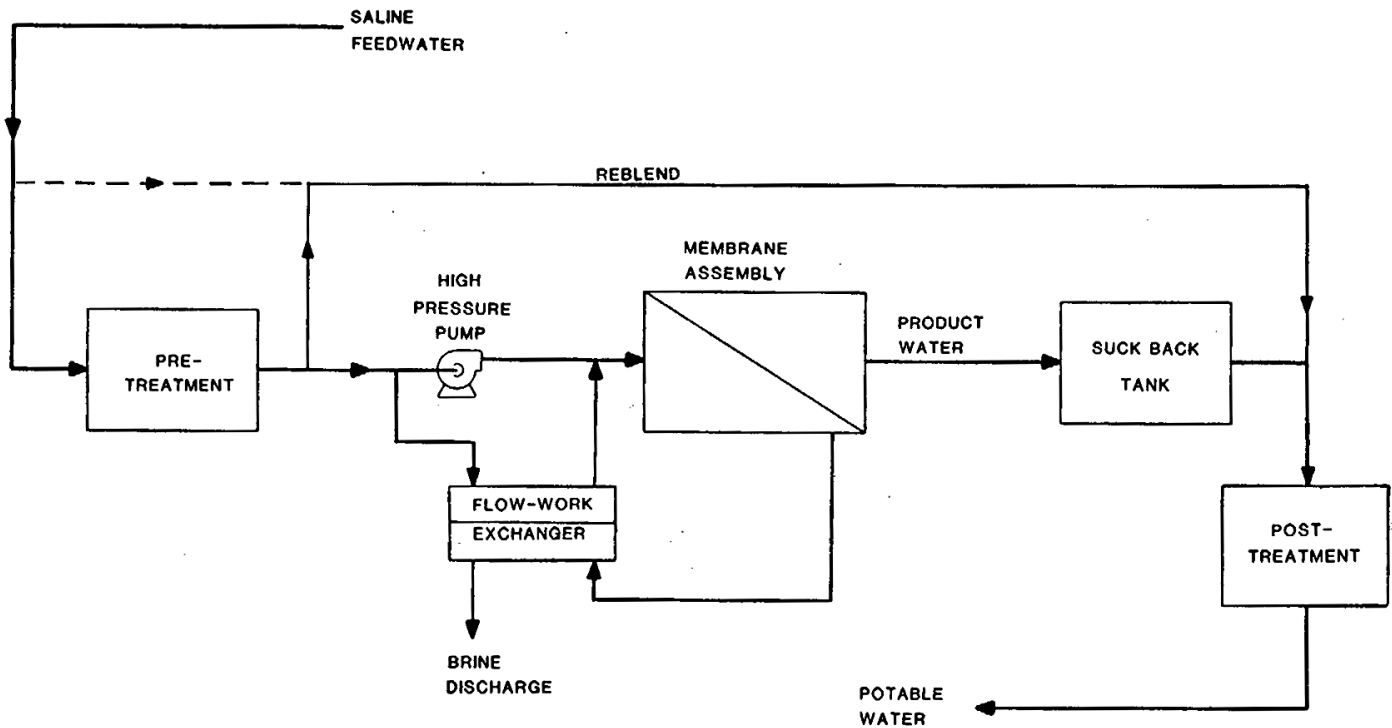
Figure 5-3

Reverse osmosis desalination system

the feed water by mechanical methods. In small systems, consider a flow-work exchanger; in large systems, consider an energy recovery turbine.

5.3.2.1 Flow-work exchanger. A flow-work exchanger, figure 5-4, is a simple piston driven by pressurized brine to compress the saline feed. When the piston has traveled a full stroke, the valving is changed, and the saline feed is used to expel depressurized brine. Flow-work exchangers have been under development since 1980.

5.3.2.2 Energy recovery turbines. Several large reverse osmosis systems have been built with energy recovery turbines. These turbines can be installed to assist directly in pumping or

STEP I
CHARGE
PROCESS

STEP 2
PRESSURIZATION
PROCESS

LOW PRESSURE
SALINE WATER
FEED STREAM

DEPRESSURIZED
BRINE
STREAM

PISTON

PISTON

VALVES

⋈ OPEN

▶◀ CLOSED

SALINE WATER
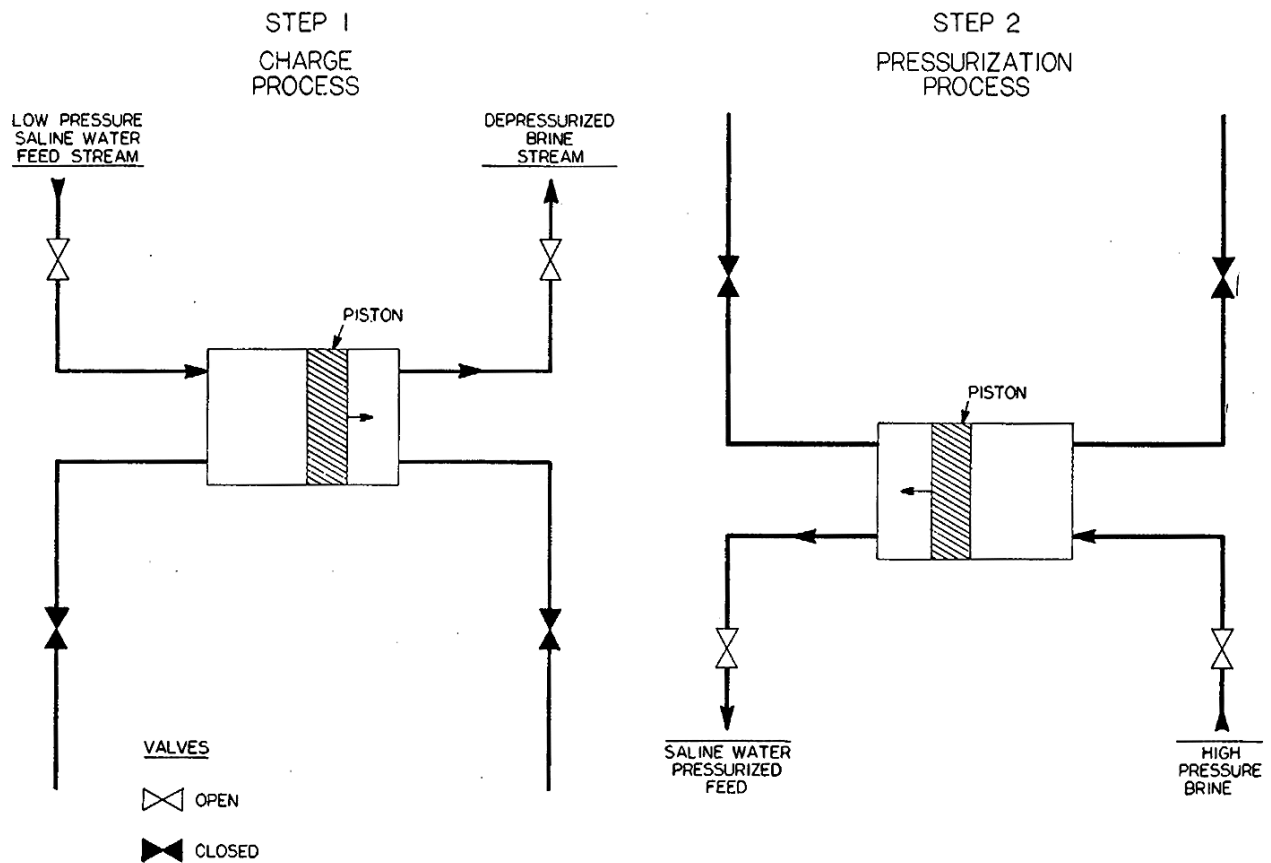PRESSURIZED
FEED

HIGH
PRESSURE
BRINE

Figure 5-4

Flow-work exchanger principles

to drive synchronous motors and generate electricity. While reverse osmosis is an energy efficient desalination process for highly saline waters, energy recovery can reduce the amount of energy used by as much as one-third.

5.3.3 Mechanical strength and packing of membranes. For containment of high pressures with thin membranes in reverse osmosis, three alternative arrangements have been developed.

5.3.3.1 Porous tubes. Porous tubes lined with semipermeable membrane material have been developed for concentration of valuable products in industry. Such systems are no longer used for water desalination. A packing density of less than 110 square feet of surface area per cubic foot of volume makes this configuration too expensive for water production. See figure 5-5.
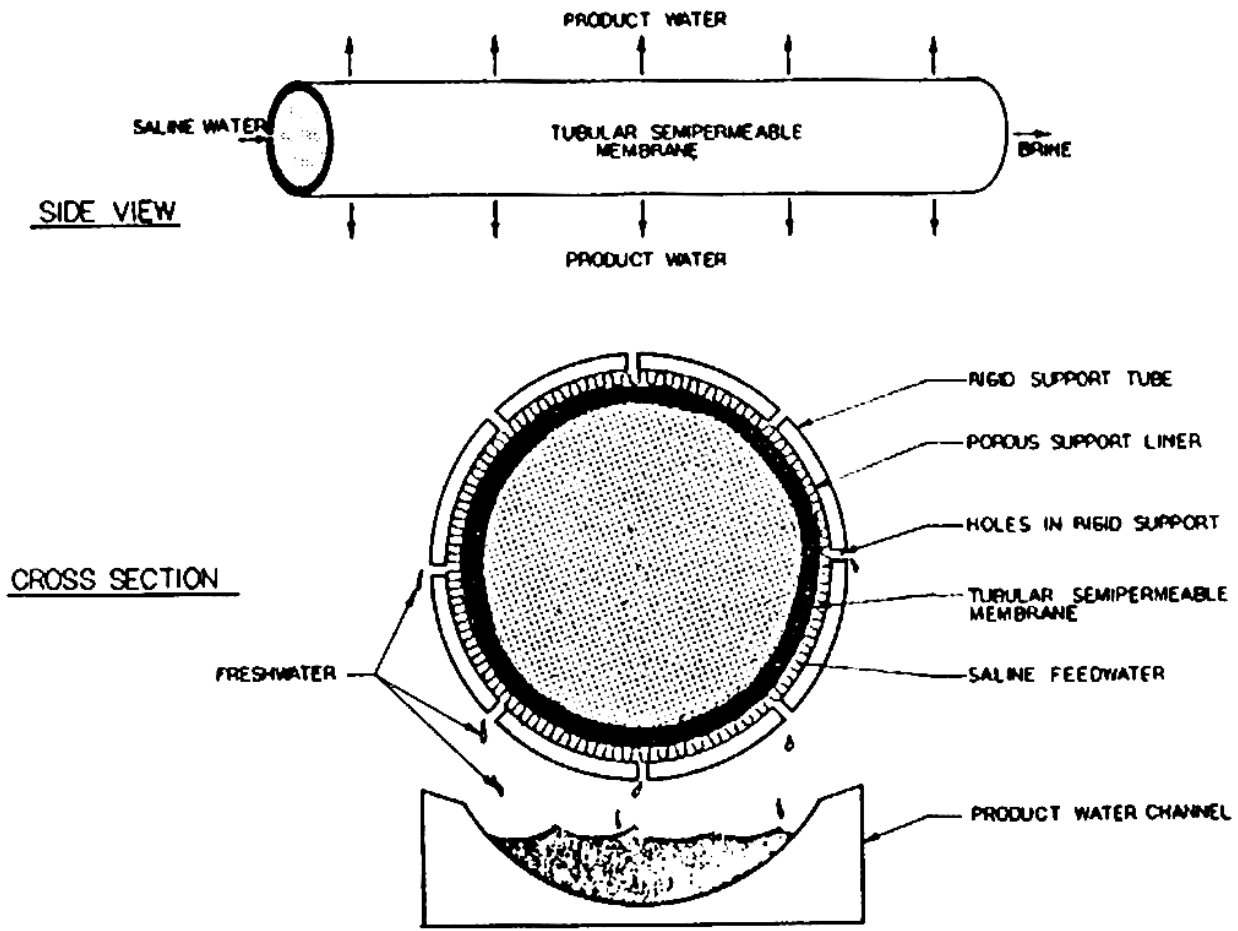

Figure 5-5

Construction of a tubular reverse osmosis membrane

5.3.3.2 Spiral-wound membranes. By using spacers it is possible to roll a membrane envelope onto a slotted product water tube as shown in figure 5-6. This reverse osmosis membrane configuration is known as the spiral-wound configuration. This arrangement allows
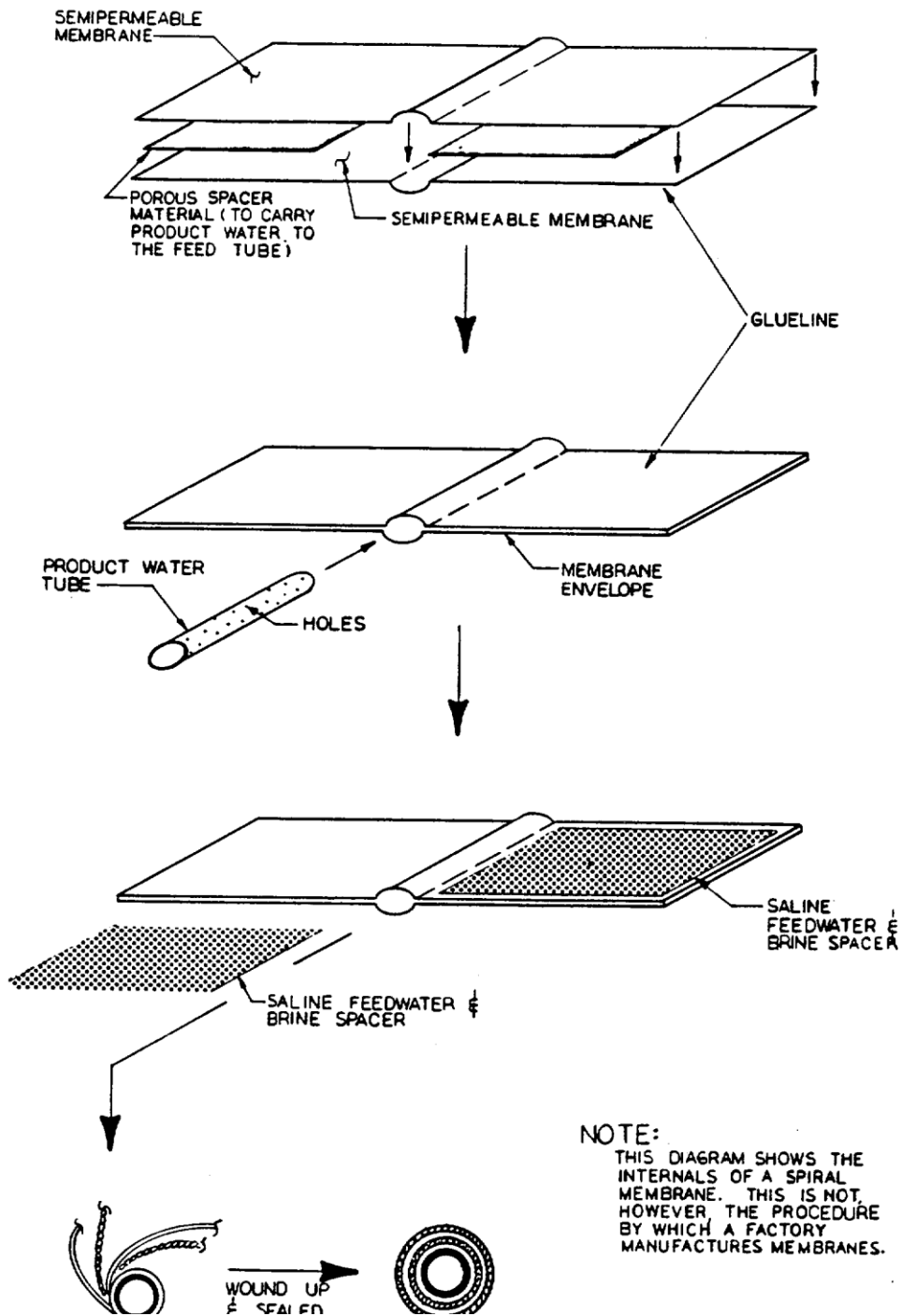
Figure 5-6

Internal construction of a spiral-wound membrane

for surface densities of greater than 250 square feet of surface area per cubic foot of volume. With the development of this spiral-wound configuration, water production from brackish water sources by reverse osmosis became economical in many applications. See figure 5-6.

5.3.3.3 Hollow fine fibers. A large research and development effort made it possible to coat minute hollow fibers, smaller in diameter than a human hair, with semipermeable membrane material. This reverse osmosis membrane configuration is known as the hollow fine-fiber configuration. Packing densities with hollow fine fibers have exceeded 4,900 square feet of surface area per cubic foot of volume. See figure 5-7.

5.3.4 Membrane materials. There are a number of successful reverse osmosis membrane materials. Currently, two principal types of membrane materials are being used: cellulose acetate and polyaromatic amide. Both materials are destroyed by dehydration of the membranes. To avoid dehydration, product water must be supplied to allow osmotic water to flow back through the membranes in order to dilute the feed water to approximate product water concentrations. If product water is not supplied, then the osmotic suction, if the feed water side of the membrane is depressurized, will draw air back into the membranes and dehydrate them. Usually, the required volume of product water is supplied by a suck-back tank, which maintains a minimum volume and back pressure on the reverse osmosis membranes.

5.3.4.1 Cellulose acetates. This material suffers from slow chemical decomposition through a process called hydrolysis. The use of acids to prevent scaling increases the rate of this form of membrane decay. Cellulose acetates are also biodegradable and must be protected from bacterial attack. One of the important advantages of cellulose acetate is its resistance to attack by chlorine. Most cellulose acetate membranes can be used with feed waters containing less than 1 milligram per liter of residual chlorine, which will protect the membranes from biological attack.

5.3.4.2 Polyaromatic amides. These membranes are stable, biologically and chemically. Despite this chemical stability, these membranes cannot tolerate any residual oxidant. If chlorination is required to reduce the amount of biological suspended solids, then dechlorination must be complete if polyaromatic amide membranes are used.
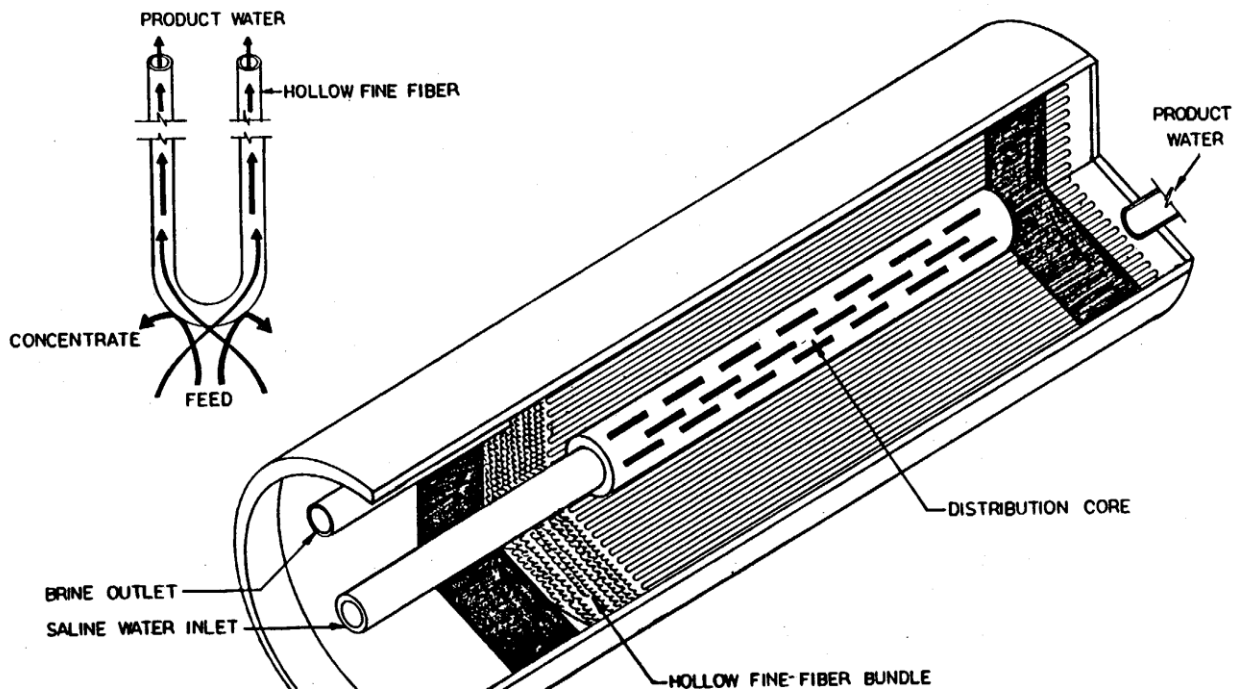
Figure 5-7

Internal construction of a hollow fine-fiber reverse osmosis membrane module

5.4 Reverse osmosis membrane staging configurations. Two kinds of membrane staging are commonly used in reverse osmosis desalination plants: product staging and reject staging. Reject staging is used to treat waters with low salinity, so that most of the raw feed water will eventually be recovered as product water. Product staging is used to treat highly saline waters, whose product water salinity cannot be reduced to the required concentration by a single pass through the membrane under consideration. Banking is the term usually used for parallel arrangement of a number of membrane modules operating from the discharge of a single pump. Banking of membranes usually require a flow restraint on the brine reject of each module in the bank. A pigtail of nylon tubing is often used for this flow equalization headloss. This pressure drop maintains a balanced flow of brine out of each membrane module in the bank. Unbalanced flow can shorten the useful life of membrane modules. While higher flow rates will tend to clean membranes, excessive flow can fatigue or fray both spiral and hollow fine-fiber membranes. Low flow rates allow the concentrated brine to stagnate, which leads to scaling and fouling of membrane surfaces.

5.4.1 Product staging. Product staging is true series operation of two or more reverse osmosis membrane systems, as shown in figure 5-8. Product staging is used when a single pass through one reverse osmosis membrane does not bring a constituent concentration down to specification. The second stage always requires its own pressurizing pump, taking suction from the suck-back or storage tank of the first stage reverse osmosis system. When the water produced from the second stage is significantly lower in dissolved constituents than required, the product water from the first stage may be blended with the second stage product to produce the desired water quality. When potable water and other waters with lower dissolved solids content are required, a product staging system can be used to supply the desired quality or qualities between that of the first and second stage product. Life cycle costing should be used to evaluate dual- and triple-distribution systems where product staging is required.

5.4.2 Reject staging. Reject staging, figure 5-9, is used when the low salinity of the raw water permits a high water-recovery ratio. Most membrane module manufacturers have a minimum allowable brine reject flow for any given membrane of their manufacture. The manufacturer's recommended maximum feed water flow rate and minimum recommended brine reject flow can be used to calculate a maximum recommended single stage recovery fraction by use of the following equation:

$$(F - B)/F = R$$

Where:

F = Maximum recommended feed flow per module
B = Minimum recommended brine reject flow per module
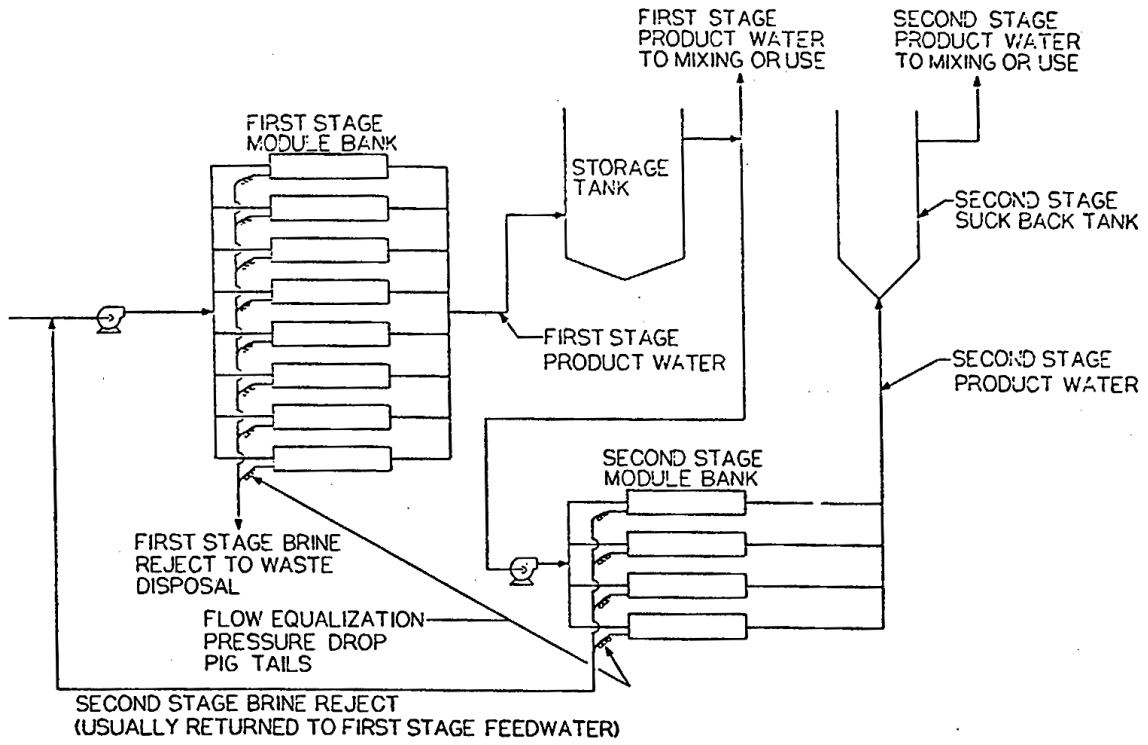R = Maximum recommended recovery rate

Figure 5-8

Reverse osmosis product staging

RAW FEED WATER
OF CONCENTRATION C

FIRST STAGE
HIGH
QUALITY
WATER
TO
SPECIAL
USE

BACK
TANK

THIRD STAGE
PRODUCT WATER

SECOND STAGE
PRODUCT WATER

SECOND STAGE
MODULE BANK

FIRST STAGE
BRINE REJECT

FLOW EQUALIZATION
PRESSURE DROP
PIG TAILS

SECOND STAGE
BRINE REJECT

THIRD STAGE
MODULE BANK
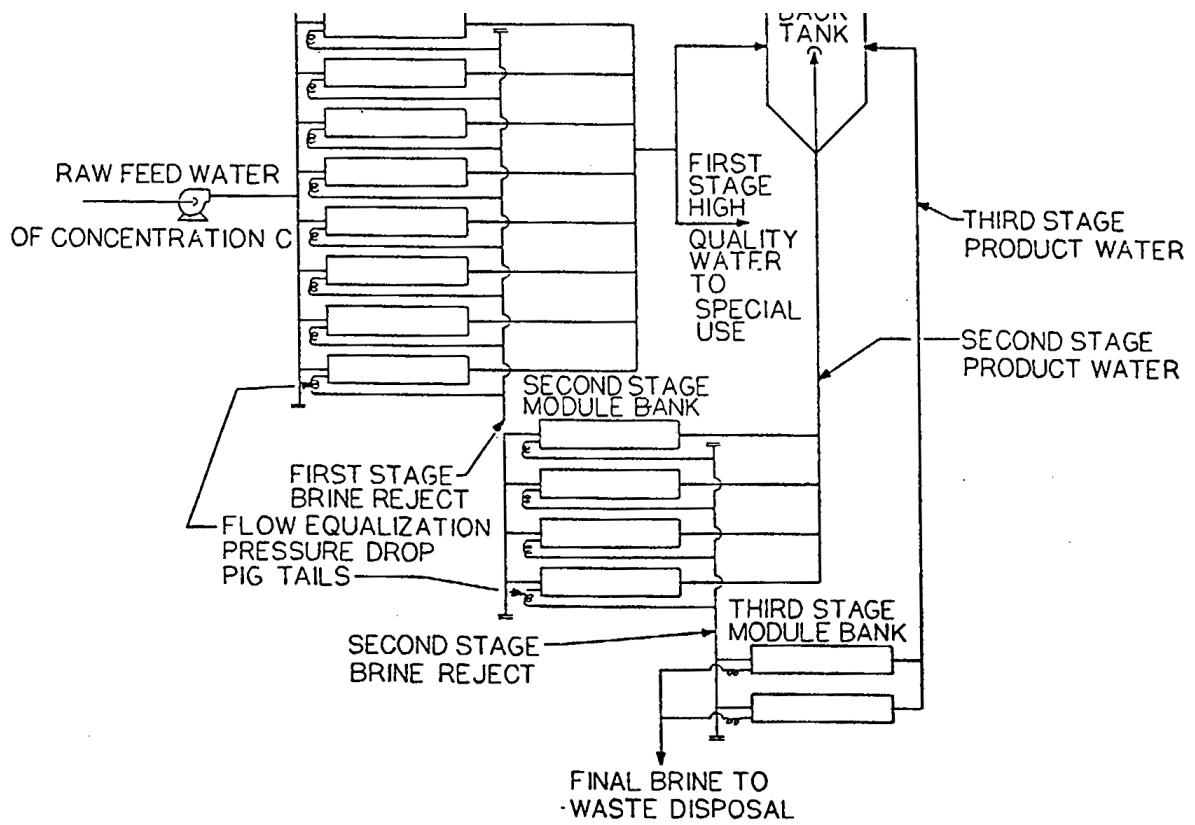
FINAL BRINE TO
·WASTE DISPOSAL

Figure 5-9

Reverse osmosis membrane reject staging

This maximum single stage water recovery is one means of evaluating a membrane module being considered for low salinity reverse osmosis desalination. When the reject stream is still diluted enough for further concentration after the maximum recommended recovery ratio is reached, the brine can be piped directly into another membrane module for further water recovery. This is accomplished by combining the brine flow from a number of first stage modules onto a fewer number of secondary membrane modules. It is occasionally possible to further concentrate the brine on a third reject stage as shown in figure 5-9. The design of reject staging, in order to balance the utilization of the membrane modules for optimum economical life cycle cost, is a complex activity to be performed by the membrane manufacturer.

5.4 3 Combined product and reject staging. In the desalination of highly saline waters such as seawater, product and reject staging can be effectively combined. The second stage of a product staged system can be designed as a reject staged subsystem. Any of three factors may limit reverse osmosis water recovery: osmotic pressure; sparingly soluble salts; or turbidity. Water from a primary reverse osmosis treatment system will have three properties pertaining to these limitations:

- A lower osmotic pressure than the raw feed water.
- A disproportionately reduced concentration of divalent ions.
- No turbidity.

These qualities of primary reverse osmosis product water can allow for greater water recovery from a secondary product staged reverse osmosis subsystem than is allowed by the manufacturer's maximum recommended recovery rate. When the water recovery of the second stage of a product staged system can be increased by reject staging, the secondary stage shall be reject staged. When the brine from the secondary stage of a product staged system is less concentrated than the primary stage feed water by more than 1,000 milligrams of total dissolved solids per liter, the use of dedicated desalination of this lower concentration water shall be life cycle costed. This life cycle cost for dedicated secondary stage brine desalination shall be compared with the life cycle cost of blending the secondary stage brine into the primary stage feed water.

5.5 Reverse osmosis system design. When process selection does not yield a specific membrane or even a particular process, then designs must be prepared for more than one process.

5.5.1 Identification of work. When a schedule and a base site have been selected, this information will be made available to the design engineer. The identification of the location and the time schedule will be considered in the design; this includes the date the system must be online. The minimum number of independently operable membrane banks and the minimum capacity of the banks must be determined. Any restrictions that storage will place on maximum allowable downtime will also be determined. All reverse osmosis designs will consider a minimum membrane rejection for all objectionable materials in the pretreated saline water.

5.5.2 Existing or planned facilities. Reverse osmosis design must include information on the available sources of mechanical energy. Electrical power is the most common energy source for conversion to mechanical pumping energy. The phase, voltage, frequency, and amperage of all available or planned electrical power will be determined. The process design, particularly with respect to pumping and pretreatment, must be detailed clearly.

5.5.3 Raw water information. As with other desalination systems, one of two limitations exist on the quantity of raw water to be desalinated. Both of these limitations must be considered in the design:

- The maximum amount of waste brine that can be economically disposed of may place a limitation on the raw water used in the process.
- Availability of the raw water may limit the raw water used in the process.

The principle requirement in a reverse osmosis design is an accurate projection of the chemical, biological, and physical makeup of the poorest quality water that will ever be used as raw feed water at the site being investigated. The design documentation must include the following:

- Maximum total dissolved solids.

- Maximum concentration of every ion that could precipitate or influence the activity coefficient of a precipitation reaction.

- Maximum concentration of each ion that must be controlled in the product water.

- Concentration of both molybdate reactive and molybdate nonreactive silica.

- Maximum allowable concentration of non-ionizable material.

- An oil and grease analysis to levels below 10 milligrams per liter.

- Any gas or potential corrosive agent that may be in the feed water.

5.5.4 Process design. When a particular membrane has been identified as the most economic, the design will be limited to the one membrane type. The process design for any reverse osmosis process will consider raw water quality and the required final product water quality. A suitable tank to meet suck-back requirements will be designed for all membranes that could be damaged by dehydration. The system design must be based on equipment with a history of successful water treatment experience. The required experience should include a minimum of 2 years of experience, treatment capacity, repair frequency and duration, and a ratio of repair cost to capital cost. The requirement for successful experience will limit the amount of untested innovation used at a facility. When a particular metallurgy or material is required for strategic, corrosion design, or process economic reasons, this metallurgy will be included for all applicable parts and spare parts and equipment.

5.6 Materials of construction. Ferric ions will cause severe problems in membrane systems. For this reason, never permit carbon steel to be in contact with the feed water being supplied to a membrane desalination plant. Use nylon or other plastics capable of maintaining the desired pressures whenever possible. Use 316L stainless steel for pump impellers and other feed-water-contact metal surfaces if hexametaphosphate is used for scale control. If no scale inhibition is necessary, use bronze for pump impellers.

6. ION EXCHANGE TECHNIQUES

6.1 General. Some naturally occurring and synthetic materials can exchange one type of ion for another dissolved ion of like charge, e.g., one positive ion for another positive ion. The number of charges on the ions removed from solution must equal the number of charges on the ions exchanged from the material. The major types of synthetic ion-exchange resins that have been developed are as follows: strong acid cation resins, weak acid cation resins, strong base anion resins, and weak base anion resins. Strong acid and weak acid cation resins exchange hydrogen ions (H+) for other cations. Strong acid cation resins may also exchange monovalent sodium ions (Na+) for such divalent cations as calcium (Ca+ +) and magnesium (Mg+ +). Strong base anion resins exchange hydroxyl (OH-) or bicarbonate (HCO3) ions for other anions. Weak base anion resins adsorb acidic ionic materials, such as hydrochloric acid, sulfuric acid, and carbonic acid from solutions. Once adsorbed on the weak base anion resin, the anion part of the acid may be exchanged for other anions. These exchanges occur during the service cycle when treated water is produced. When the capacities of resins have been used up or exhausted, they are regenerated with acid or base or salt to restore the resin to the original ionic state. Illustrations of the strong acid cation resin hydrogen ion-cation exchange and the strong base anion hydroxyl ion-anion exchange that occur in the complete demineralization of water are shown in figure 6-1.

6.2 Pretreatment. Ion exchange can be used as a pretreatment method in the desalination process to reduce the levels of sparingly soluble salts. A strong acid cation resin in the sodium form and a weak acid cation resin in the hydrogen form can be used. In both processes the levels of alkaline earth metal cations, such as calcium (Ca+ +) and magnesium (MG+ +), are reduced. The use of the strong acid cation resin in the sodium form is called water softening, and the use of the weak acid cation resin in the hydrogen form in conjunction with a carbon dioxide degasifier is called dealkalization-softening.

6.2.1 Softening. Water softening by sodium ion exchange can be used as a pretreatment method in a desalination process. During water softening, monovalent sodium ions on the strong acid cation resin are exchanged for the divalent calcium and magnesium in the water.

CALCIUM, MAGNESIUM AND SODIUM REMOVAL

REGENERATION BY H_2SO_4

DE-CATIONIZING WATER-CATION EXCHANGE (HYDROGEN CYCLE)

SULFATE AND CHLORIDE REMOVAL

REGENERATION BY NaOH

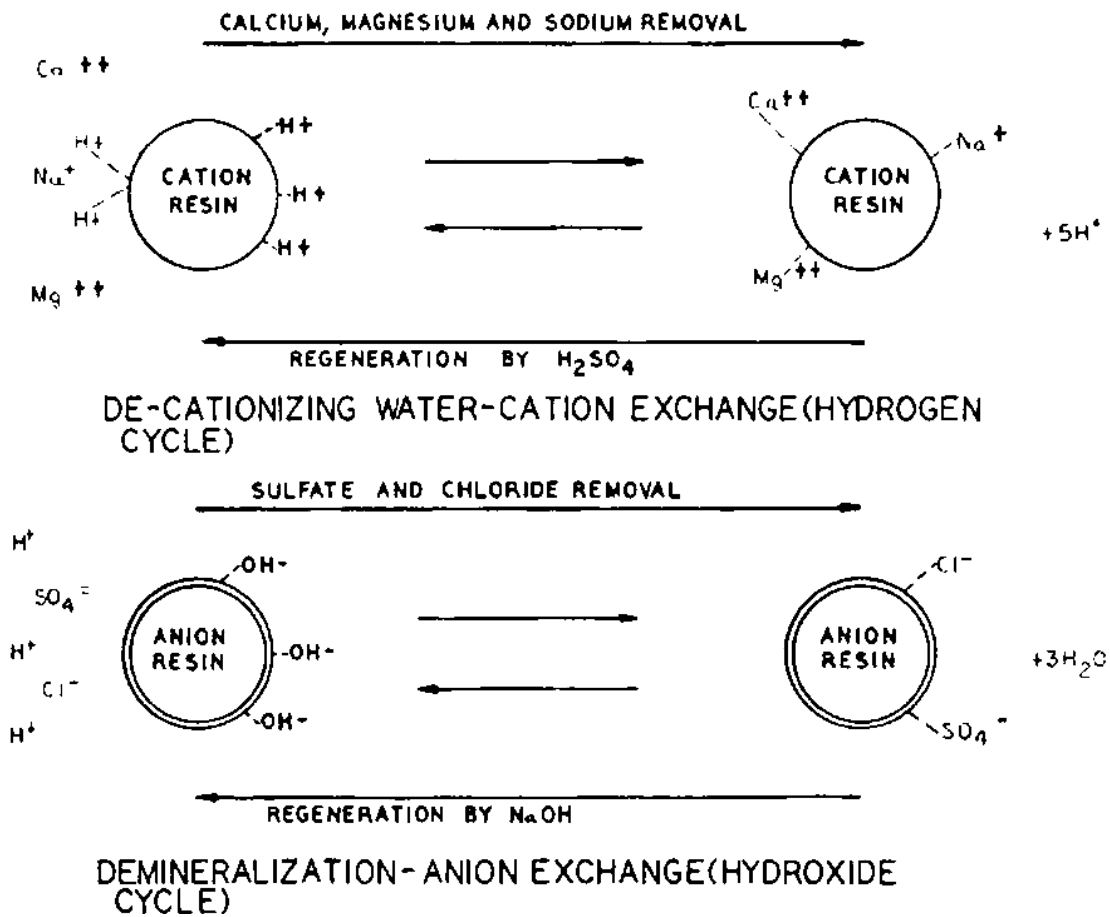DEMINERALIZATION-ANION EXCHANGE (HYDROXIDE CYCLE)

Figure 6-1

Principles of ion-exchange processes

Although not desalination, the exchange of sodium ions for divalent cations produces a change in the type of salinity. This change in the salinity reduces the levels of the calcium and magnesium ions, such that the concentration of other ions in the reject or blowdown stream can be increased in the desalination process with a resultant increase in water recovery. Saturation of scale-forming materials, such as calcium carbonate, calcium sulfate, and magnesium hydroxide, is still reached, but the total concentration of salts in the reject attains a higher overall level than would be possible without softening.

6.2.2 Dealkalization-softening. Desalination processes can best utilize dealkalization-softening as a pretreatment method when the raw water contains high levels of alkalinity, bicarbonate and carbonate ions, and high levels of hardness, calcium and magnesium ions.

A properly operated pretreatment that utilizes a weak acid cation resin will produce water with an alkalinity level of no more than 10 parts per million (as CaCO3) and a residual hardness approximately equal to the original raw water non-carbonate hardness.

6.2.2.1 Treatment process. The major benefit of dealkalization-softening using carboxylic (weak acid cation) resins lies in the actual reduction of the dissolved solids content of the water. Hydrogen (H+) ions from the resin exchange with the divalent calcium and magnesium ions in the water. This exchange occurs only if the anions of weak acid salts, such as bicarbonate or carbonate ions, are present. Carbonic acid is formed when the hydrogen and bicarbonate ions react. The carbonic acid is weakly ionized and reverts to its basic constituents of carbon dioxide and water. The dissolved carbon dioxide can be removed by using degasification methods. The combination of the weak acid cation exchange with degasification reduces both the calcium and magnesium levels as well as the alkalinity level in the raw water.

6.2.2.2 Dealkalization-softening uses. This pretreatment should be investigated when pH adjustment of the raw water by an acid addition is indicated for the desalination process. Weak acid resins use about 10-percent more acid than that required for pH adjustment alone and will reduce the calcium and magnesium concentration as an additional advantage.
In brackish waters containing essentially only calcium, magnesium, and alkalinity, the use of weak acid cation resins with degasification could be considered as a possible desalination process. Since some types of weak acid cation resins also permit the efficient removal of sodium bicarbonate, the process becomes applicable as a desalination process when the raw water contains mainly sodium and alkalinity.

6.3 Desalination. Ion exchange can be used as a desalination process in the production of potable water.

6.3.1 Requirements. There are several basic requirements for the ion-exchange process to be used economically for the desalination of brackish waters.

- The ion-exchange resins should operate at high capacities.
- The ion-exchange resins should be regenerated close to the stoichiometric equivalence capacity.

- The acid and base regenerants should be low cost.
- The waste regenerants should be rinsed from the ion-exchange resins with a minimum of water, so that the capacity of the resin is not exhausted significantly.
- Regenerant waste volumes should be minimized, and unused regenerants should be recovered and reused to reduce the waste disposal volume.

6.3.2 Limitations. The use of ion exchange in the desalination of brackish water has several limitations. The volume of water treated is inversely proportional to the ionic concentration in the water. Regenerant consumption per unit volume of treated water is high and becomes higher as the salinity of the brackish water increases. The size of the ion-exchange equipment follows the same rationale-the more saline the water, the larger the ion-exchange equipment. A low salinity water, usually product water, is required for regeneration of the ion-exchange resins.

6.3.3 Treatment processes. The treatment processes employed have either been on a pilot plant scale or have been used in a limited number of full-size installations. The processes have generally utilized weak acid cation and weak base anion resins. These resins have higher capacities and require less acid and base regenerants than strong acid cation and strong base anion resins. Two ion-exchange desalination treatments that have been developed are the Desal Process and the RDI Process.

6.3.3.1 Desal process. The Desal Process has several variations, but the main thrust of the process is the use of the weak base anion resins in the bicarbonate form.

6.3.3.2 RDI Process. The RDI Process is a three-unit system using four different resins. The water first passes through a strong base anion resin where the strong acid anions, such as chloride, sulfate, and nitrate, are replaced with the bicarbonate ion from the resin. The water then moves through a layered ion exchange unit of weak acid cation and strong acid cation resins, where the calcium, magnesium, and sodium are removed, the bicarbonates are converted into carbonic acid, and the neutral salt leakage from the previous anion unit is converted into free mineral acidity, i.e., sulfuric, hydrochloric, and nitric acids. Then, the water travels through a weak base anion resin, where the free mineral acidity is adsorbed but the carbonic acid passes through unaffected. The water is then degasified, which removes the dissolved carbon dioxide. The weak acid cation and strong acid cation resins are regenerated

with either sulfuric or hydrochloric acid, first through the strong acid cation resin and then through the weak acid cation resin. The strong base anion and weak base anion resins are regenerated in series with sodium bicarbonate, first through the strong base anion resin and then through the weak base anion resin. The RDI Process is shown in figure 6-2.

6.3.4 Three-unit variation. In the three-unit variation, the strong acid anions in the water, such as chloride, sulfate, and nitrate, are replaced with the bicarbonate ion from a weak base anion resin in the bicarbonate form. The process then employs a weak acid cation resin that replaces the calcium, magnesium, and sodium in water with the hydrogen ion from the resin. The carbonic acid that is formed is adsorbed by a second weak base anion resin in the free-base form. When the system has exhausted its treating capability, the lead weak base anion resin is regenerated with ammonia, caustic, or lime, the weak acid cation resin is regenerated with sulfuric, hydrochloric, nitric, or sulfurous acid, and the tail-end weak base anion is not regenerated. The lead weak base anion resin is now in the free-base form and the weak acid cation resin in the hydrogen form. After its adsorption of carbonic acid in the previous service cycle, the tail-end weak base anion is in the bicarbonate form. The service flow direction is reversed for the next service cycle, with the former tailend weak base anion in the lead position and the former lead weak base anion in the tail-end position. The direction of service flow is reversed on each succeeding service cycle after regenerating only the weak acid cation and the former lead weak base anion. This three-unit variation of the Desal Process is shown in figure 6-3, with the following sequence of operation: Service-A followed by Regeneration-B, Regeneration-B followed by Service-C, Service-C followed by Regeneration-D, Regeneration-D followed by Service-A, Service-A followed by Regeneration-B, etc., in a repeating sequence.

6.3.5 Two-unit variation. In the two-unit variation, carbon dioxide is fed to the raw water. The carbon dioxide in the water (carbonic acid) converts the weak base anion resin in the lead unit to the bicarbonate form and the strong acid anions in the water, such as chloride, sulfate, and nitrate, are replaced with the bicarbonate ion from the resin. The process then employs a weak acid cation resin, in the same manner as the three-unit variation, which replaces the calcium, magnesium, and sodium in the water with the hydrogen ion from the resin. The carbonic acid or dissolved carbon dioxide that is formed is now removed by a degasifier.
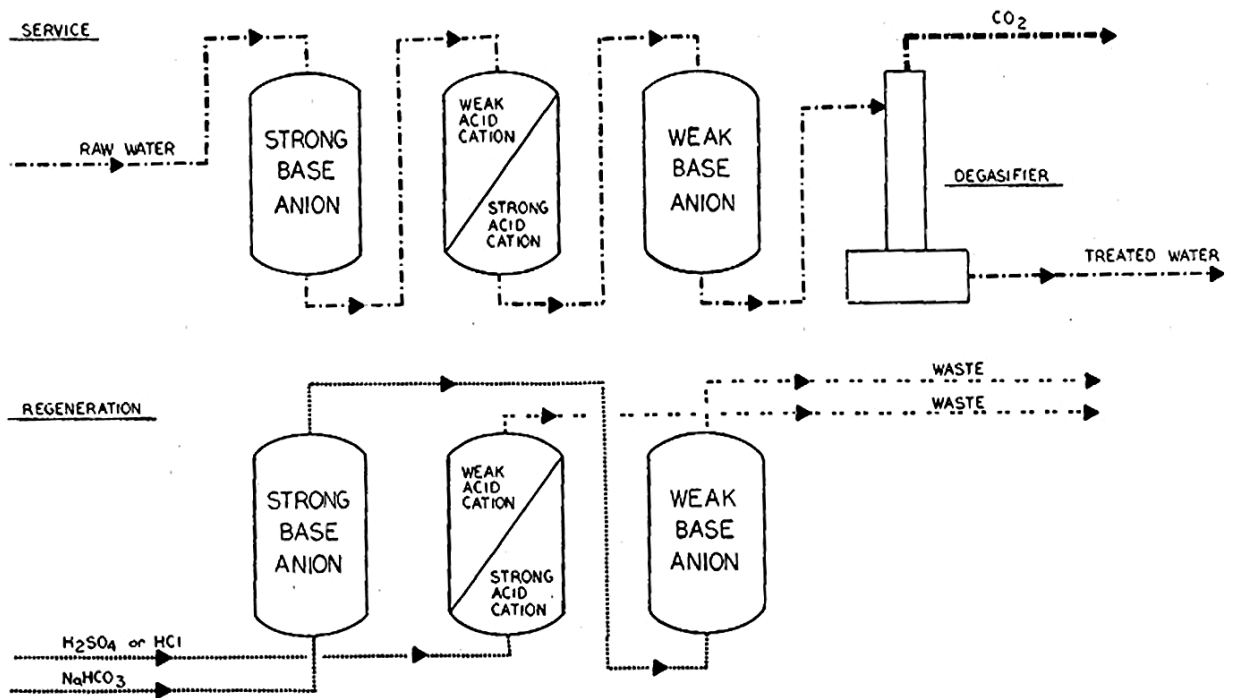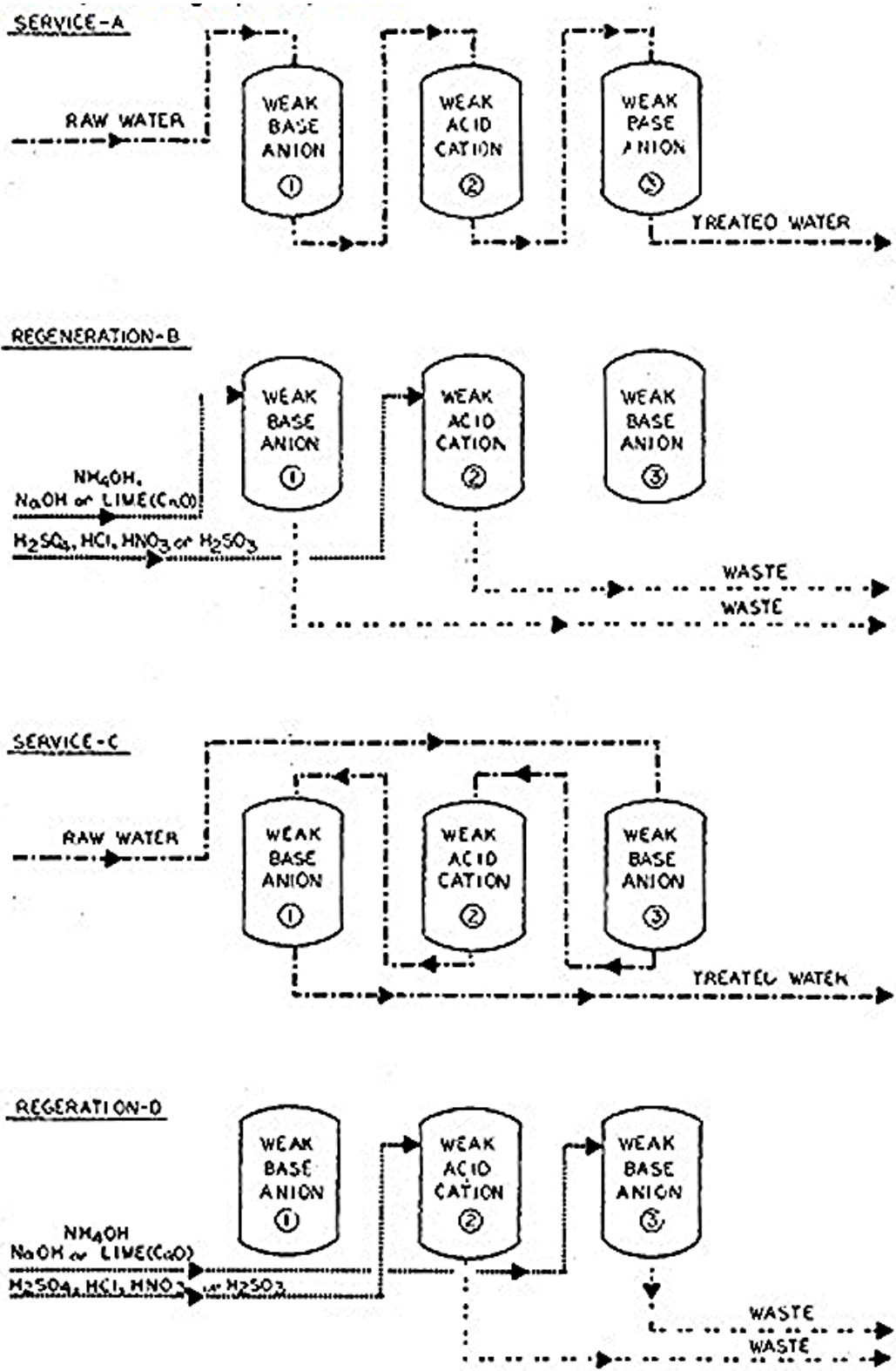
Figure 6-2

RDI Process

Figure 6-3

Three-unit variation Desal Process

Ammonia, caustic, or lime can be used to regenerate the weak base anion resin and sulfuric, hydrochloric, nitric, or sulfurous acid can be used to regenerate the weak acid cation resin. The two unit variation of the Desal Process is shown in figure 6-4.

6.4 Demineralization. No other demineralization or desalination technique can, in a single pass, produce water as pure as does ion exchange. In the production of steam, it is sometimes necessary to use water with a lower level of total dissolved solids. Ion exchange should be considered if water with less than approximately 300 milligrams per liter of total dissolved solids must be purified further. A typical cation-anion two-bed demineralization flow sheet is shown in figure 6-5. The cost of ion-exchange regeneration, including regeneration waste disposal, is directly related to the amount of dissolved solids to be removed. For many small users, such as laboratories, replaceable mixed-bed ion-exchange cartridges are the most economical method used to obtain ultrapure water.
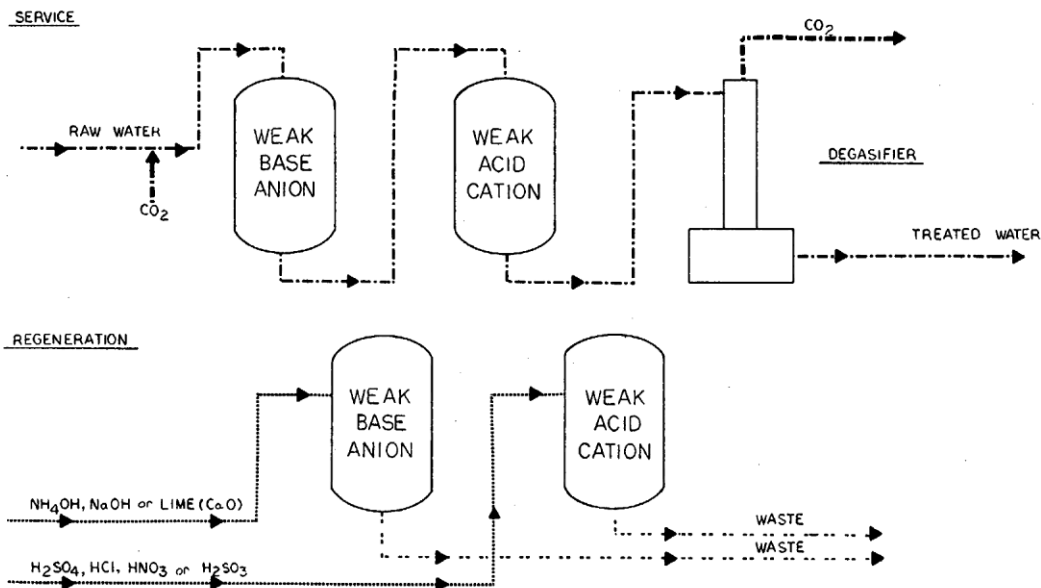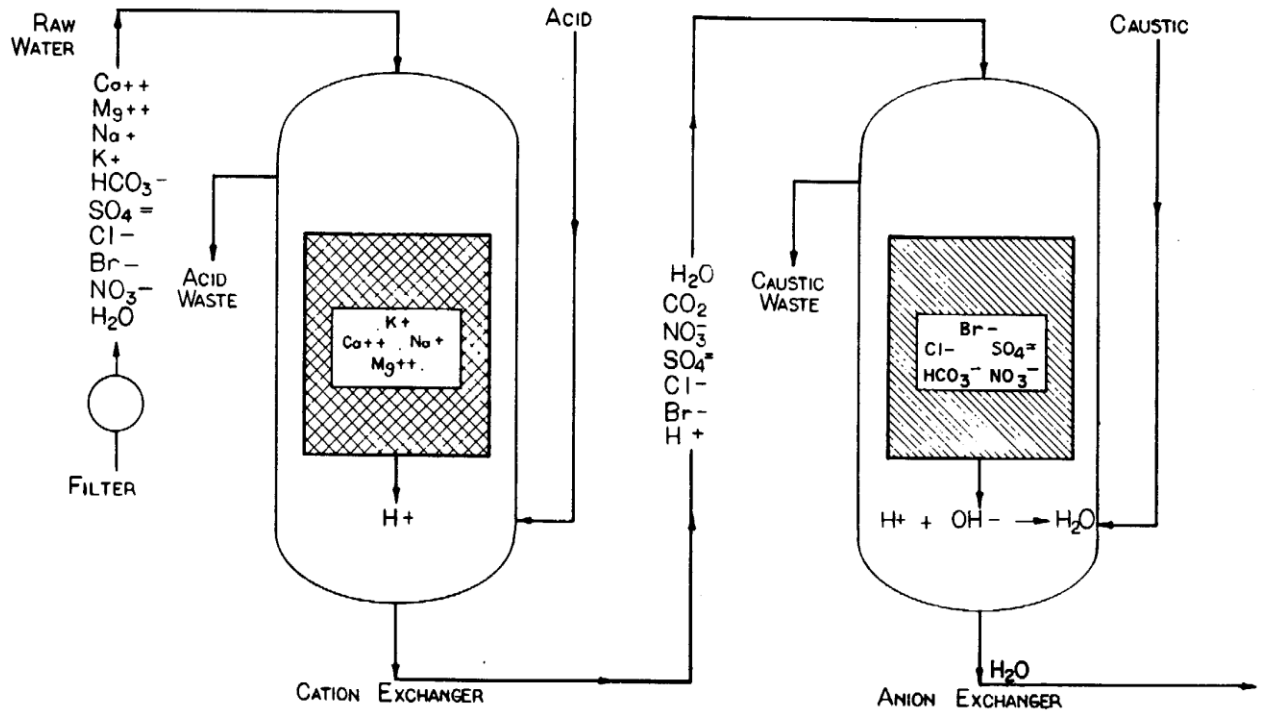

Figure 6-4
Two-unit variation Desal Process

Figure 6-5

Demineralization two-bed flowsheet