

*An Online PDH Course  
brought to you by  
CEDengineering.com*

# **Introduction to Ion Exchange Techniques for Water Desalination**

Course No: H02-004

Credit: 2 PDH

---

J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

---



Continuing Education and Development, Inc.

P: (877) 322-5800  
[info@cedengineering.com](mailto:info@cedengineering.com)

[www.cedengineering.com](http://www.cedengineering.com)

*This course was adapted from the Unified Facilities Criteria of the United States government, which is in the public domain.*

## **CONTENTS**

- 1. SITE SELECTION**
- 2. WATER SOURCE SELECTION**
- 3. GENERAL PROCESS SELECTION**
- 4. ION EXCHANGE TECHNIQUES**

The Figures, Tables and Symbols in this document are in some cases a little difficult to read, but they are the best available. **DO NOT PURCHASE THIS COURSE IF THE FIGURES, TABLES AND SYMBOLS ARE NOT ACCEPTABLE TO YOU.**

## **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 3-1. A typical desalination system layout, using reverse osmosis as a sample process, is shown in Figure 3-2.

**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

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.

## **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 solid 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 to 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 needed potable water 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.

**2.2.1.3 TURBIDITY AND SILT DENSITY INDEX.** These two characteristics provide two different measures of the amount of fine particulate matter in the water. Turbidity is measured in nephelometric turbidity units (a measure of the amount of light scattered by a known water sample thickness). Silt density index is a measure of the amount of 0.45-micron filter plugging caused by passing a sample of water through the filter for 15 minutes. Turbidity must be determined for all desalination processes. Also, the silt density index must be determined for water being considered for reverse osmosis treatment.

**2.2.2 CHEMICAL CONSTITUENTS.** The chemical constituents of the raw water must be determined to provide information for treatment selection. Table 2-1 shows the water testing analyses required for desalination treatment.

WATER TESTING REQUIRED FOR DESALINATION TREATMENT

TEST	PROCESS		
	Electrodialysis Reversal	Reverse Osmosis	Distillation
TDS	O-P	O-P	D-P
Temperature	O	O	O
Turbidity	O-P	O-P	D-P
Suspended Solids	P	P	P
Color	O-P	O-P	D-P
Corrosivity	O	O	O
Odor	P	P	P
pH	O-P	O-P	D-P
Alkalinity	O-P	O-P	D-P
Total Hardness	O-P	O-P	D-P
Noncarbonate Hardness	O-P	O-P	D-P
Carbonate Hardness	O-P	O-P	D-P
H2S	O	O	O
Chlorine Demand	O	O	O
Bacterial Contamination	O-P	O-P	D-P
Plankton	O	O	O
Oil and Grease	O	O	O
Endrin	O-P	O-P	D-P
Lindane	O-P	O-P	D-P
Methoxychlor	O-P	O-P	D-P
Toxaphene	O-P	O-P	D-P
2, 4-D	O-P	O-P	D-P
2, 4, 5-TP Silvex	O-P	O-P	D-P
Trihalomethanes	P	P	P
Ammonia	O-P	O-P	D-P
Arsenic	O-P	O-P	D-P
Barium	O-P	O-P	D-P
Cadmium	O-P	O-P	D-P
Chromium	O-P	O-P	D-P
Lead	O-P	O-P	D-P
Mercury	O-P	O-P	D-P
Nitrate	O-P	O-P	D-P
Selenium	O-P	O-P	D-P
Silver	O-P	O-P	D-P
Fluoride	O-P	O-P	D-P
Zinc	O-P	O-P	D-P
Copper	O-P	O-P	D-P
Boron	O-P	O-P	D-P
Calcium	O-P	O-P	D-P
Magnesium	O	O	O
Strontium	O	O	O
Sodium	O	O	O
Potassium	O	O	O
Bicarbonate	O	O	O
Carbonate	O	O	O
Sulfate	O-P	O-P	D-P
Chloride	O-P	O-P	D-P
Iron	O-P	O-P	D-P
Manganese	O-P	O-P	D-P
Molybdenum Reactive Silica		O	
Molybdenum Nonreactive Silica		O	
Silt Density Index		O	

Legend:

- D = Required for desalination process design
- P = Required for potable water design

Table 2-1

Water Testing Required for Desalination Treatment

**2.2.3 BACTERIOLOGICAL QUALITY.** The bacteriological testing of the raw water must include a type of a coliform indicator organism count. For procedures for filter membrane,

most probable number fermentation tube, and standard plate count, coliform organism bacteriological testing techniques can be found in the professional literature. Manufacturers' recommendations as to the media and procedures used to identify microbiological activity detrimental to the operation of a particular desalination system shall be followed.

**2.3 SELECTION VERSUS REJECTION OF POTENTIAL RAW WATER SOURCES.** After the completion of physical, chemical, and bacteriological testing, a final water source may be selected. Extreme care must be taken in the selection of a source where the usage rate is greater than the recharge rate. In most cases, selection will involve choosing the brackish water with the lowest level of total dissolved solids. When brackish water is not available, use sea water or water as the feed water source. When the coliform indicator organism count of water is greater than 10,000 most probable number (MPN), then the water source should be rejected for sanitary reasons and a more saline water chosen (per Standard Methods for the Examination of Water and Wastewater). If other water is available, water containing more than 1,000 nephelometric turbidity units should be rejected on the basis of the high cost and difficulty of clarification, even if the alternative water is more saline. When the total delivery pumping pressure of less saline water is greater than the operating pressure of a reverse osmosis system, then the desalination of the more saline water by reverse osmosis may be more economical than the combined cost of delivery and desalination of the less saline source. The final selection of a raw water source will be based on economic studies. In some cases, the decision cannot be made until all systems are fully designed and life cycle costed.

### **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.

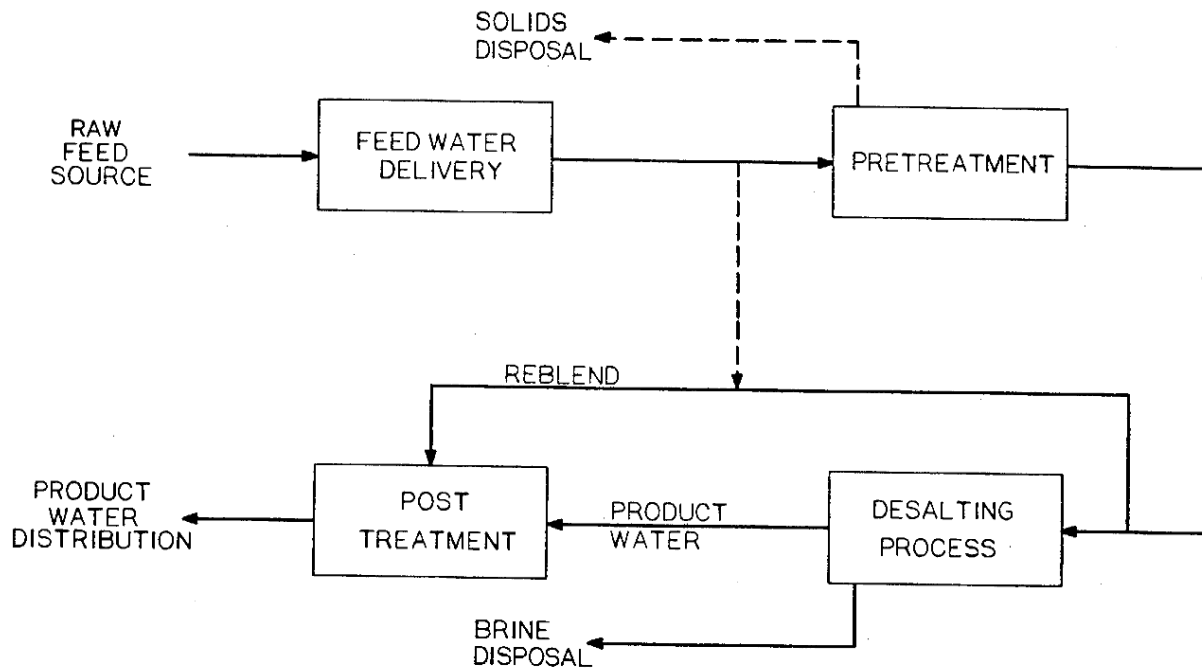


Figure 3-1

Typical desalination flowsheet

**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 course addresses the production of potable water containing less than 500 milligrams per liter of total dissolved solids. Laundries, boilers, mess 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:

$$100\% \text{ recovery of product water} \times \text{water demand} = \text{saline feed water flow}$$

In some cases, the limited quantity of 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 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. The following equation can be used to calculate the concentration of a blended water stream:

$$\left( \sum_{i=1}^{i=n} \text{concentration } i \times \text{flow } i \right) / \text{total flow} = \text{blended concentration}$$

When only two streams are blended, the equation can be rearranged to show the flow of concentrated water that when blended with a dilute flow will result in the desired product concentration. This rearranged equation is as follows:

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

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.

**3.4 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 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.

**3.4.1 HIGH-TEMPERATURE DISTILLATION.** High-temperature distillation is limited by the saturation of alkaline earth metal salts, such as  $\text{CaSO}_4$ ,  $\text{BaSO}_4$ ,  $\text{SrSO}_4$ ,  $\text{CaCO}_3$ ,  $\text{BaCO}_3$ , and  $\text{SrCO}_3$ . 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.

**3.4.2 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.

**3.4.3 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  $\text{SiO}_2$  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.

**3.4.3.1 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.

**3.4.3.2 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.

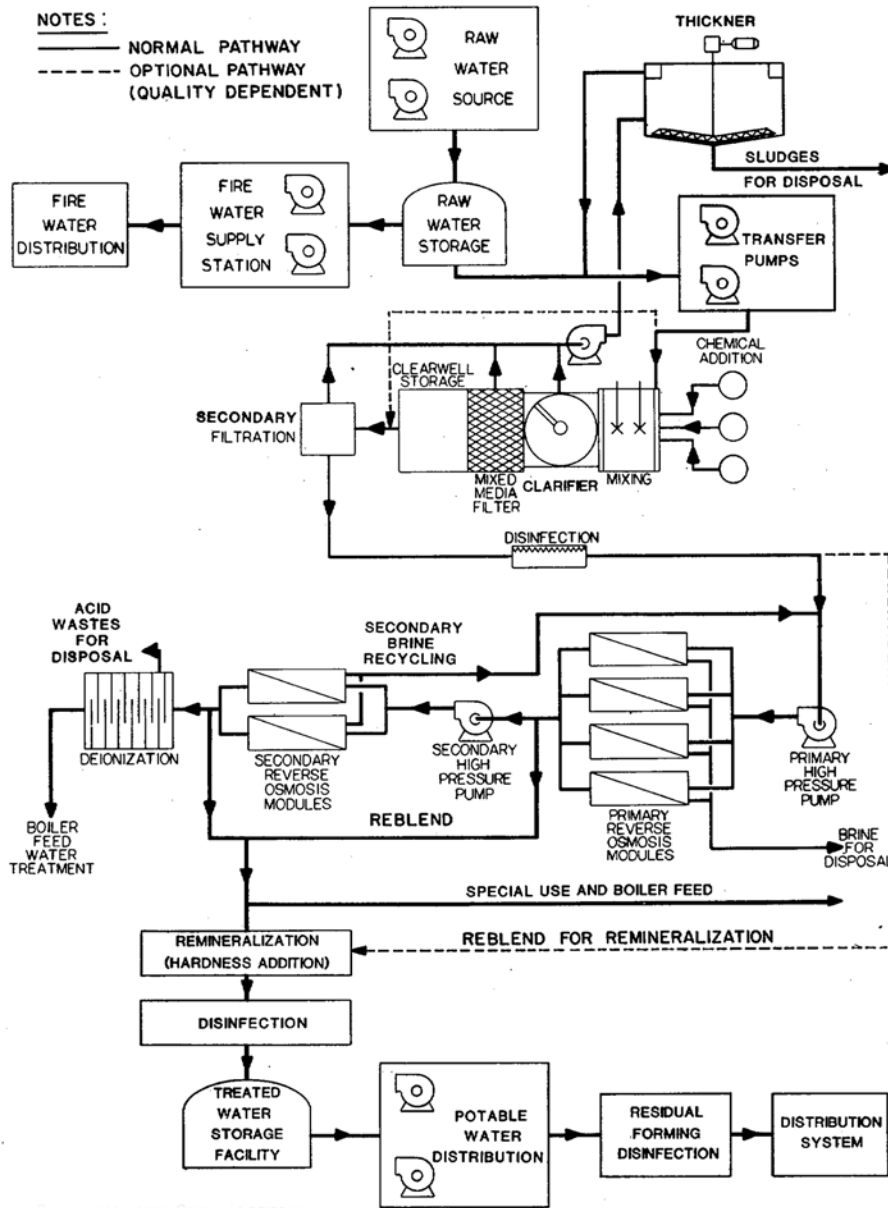


Figure 3-2

Typical reverse osmosis desalination system

**3.5 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.

**3.6 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 investigated.

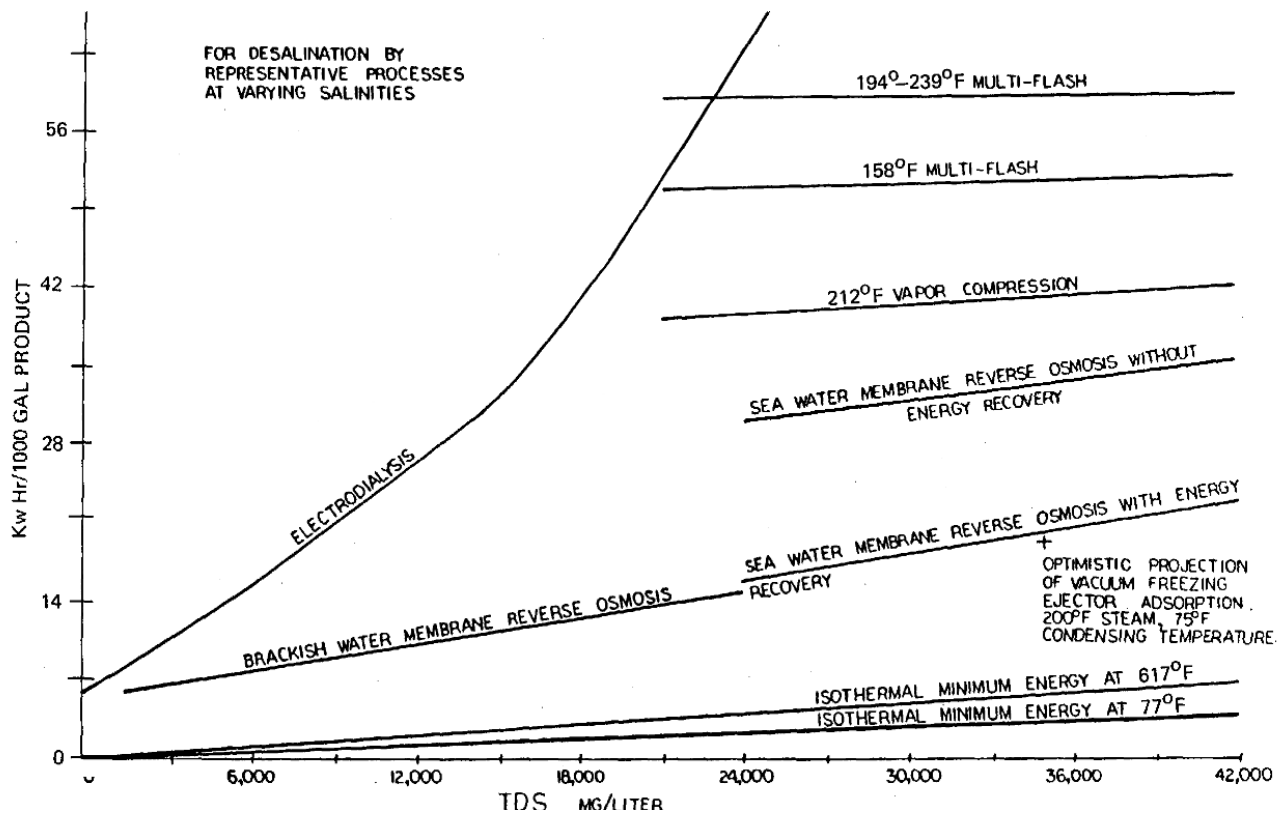


Figure 3-3  
Energy Consumption

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 3-3.

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:	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 <sub>4</sub> , CO <sub>3</sub> , pH
3	Sea water	Potable water	By steam turbine	Greater than 10 <sup>7</sup> BTU/kwh	Thermal distillation either with or without vapor compression	TDS, Ca, SO <sub>4</sub> , CO <sub>3</sub> , 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 <sup>7</sup> BTU/kwh	Reverse osmosis	TDS, Ca, SO <sub>4</sub> , CO <sub>3</sub> , pH, bacterial count, silt density index, turbidity, oil & grease
6	Brackish water	Potable water			Reverse osmosis	TDS, Ca, SO <sub>4</sub> , CO <sub>3</sub> , 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

**3.7 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 3-3. As membrane materials are developed, energy consumption may be reduced.

**3.8 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.

**3.9 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	B	C	D	E	F
	If the feedwater TDS is (mg/liter):	And if the raw feed water suspended solids are:	And if the product of (Ca)(SO <sub>4</sub> ) moles <sup>2</sup> /liter <sup>2</sup> 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	Over 20 NTU	Considerably less than $2 \times 10^{-4}$	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	Over 1 NTU		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 1 NTU; SDI greater than 3		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	SDI under 3		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	Over 1,000 mg/liter	Considerably less than $2 \times 10^{-4}$	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. ION EXCHANGE TECHNIQUES

**4.1 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<sup>+</sup>) for other cations. Strong acid cation resins may also exchange monovalent sodium ions (Na<sup>+</sup>) for such divalent cations as calcium (Ca<sup>++</sup>) and magnesium

(Mg<sup>++</sup>). Strong base anion resins exchange hydroxyl (OH<sup>-</sup>) or bicarbonate (HCO<sub>3</sub>) 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 4-1.

**4.2 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<sup>++</sup>) and magnesium (Mg<sup>++</sup>), 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 dealcalization-softening.

**4.2.1 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. 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.

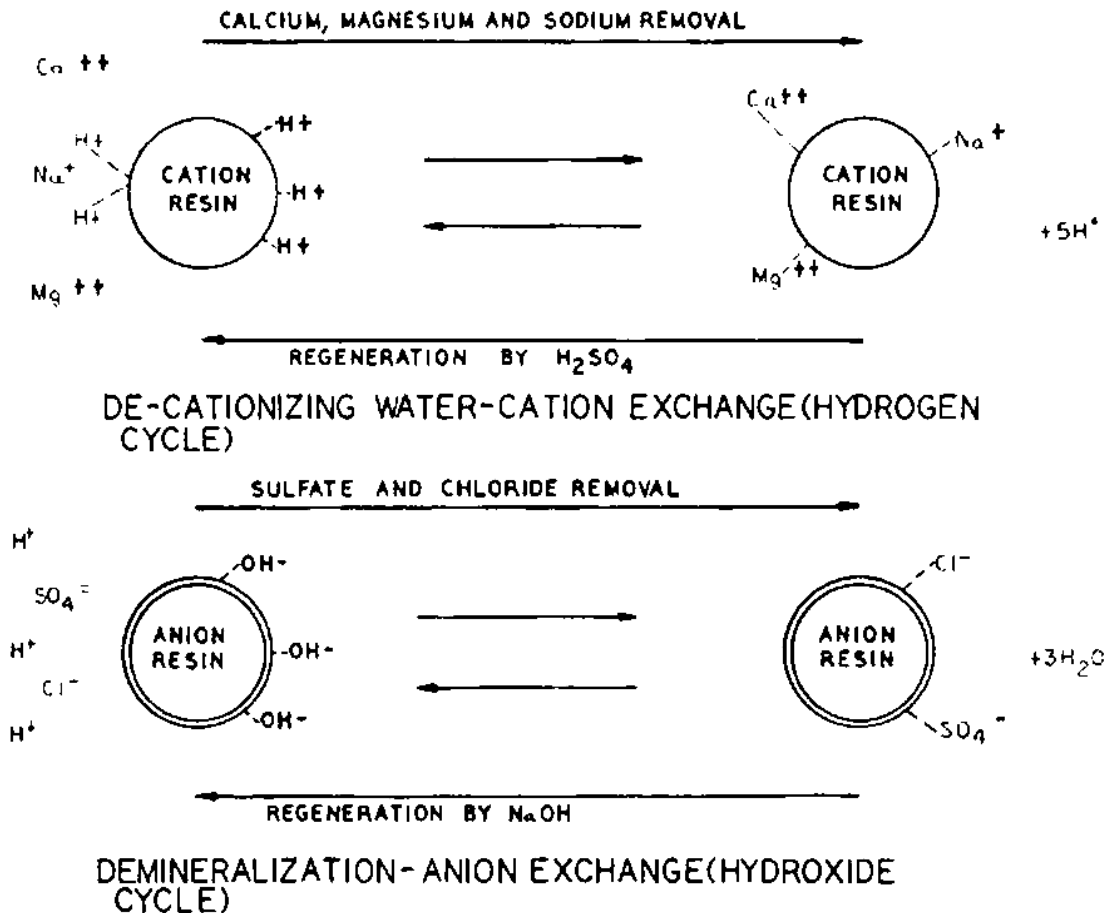


Figure 4-1

Principles of ion-exchange processes

**4.2.2 DEALKALIZATION-SOFTENING.** Desalination processes can best utilize dealkalinization-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  $\text{CaCO}_3$ ) and a residual hardness approximately equal to the original raw water non-carbonate hardness.

**4.2.2.1 TREATMENT PROCESS.** The major benefit of dealkalinization-softening using carboxylic (weak acid cation) resins lies in the actual reduction of the dissolved solids content of the water. Hydrogen ( $\text{H}^+$ ) 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.

**4.2.2.2 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.

**4.3 DESALINATION.** Ion exchange can be used as a desalination process in the production of potable water.

**4.3.1 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.

**4.3.2 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. Low salinity water, usually product water, is required for regeneration of the ion-exchange resins.

**4.3.3 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.

**4.3.3.1 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.

**4.3.3.2 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 results in the removal of 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 4-2.

**4.3.4 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 is 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 4-3, 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.

**4.3.5 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. 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 4-4.

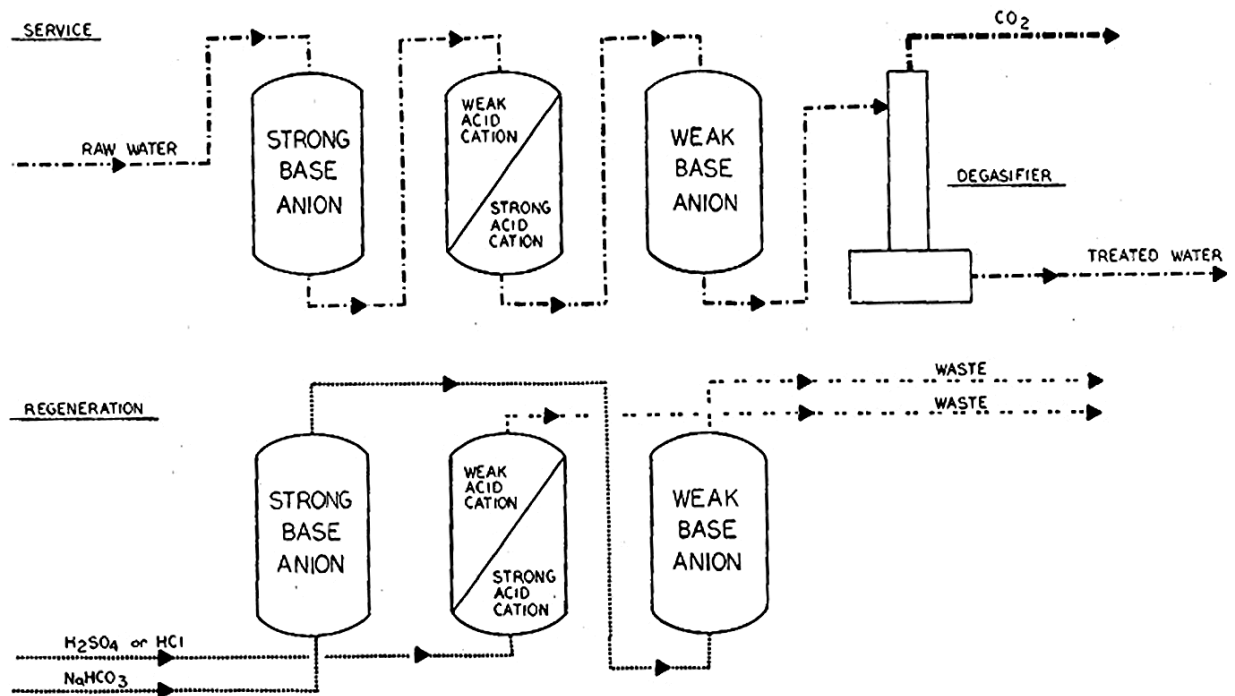


Figure 4-2  
RDI Process

**4.4 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 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 4-5. 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.

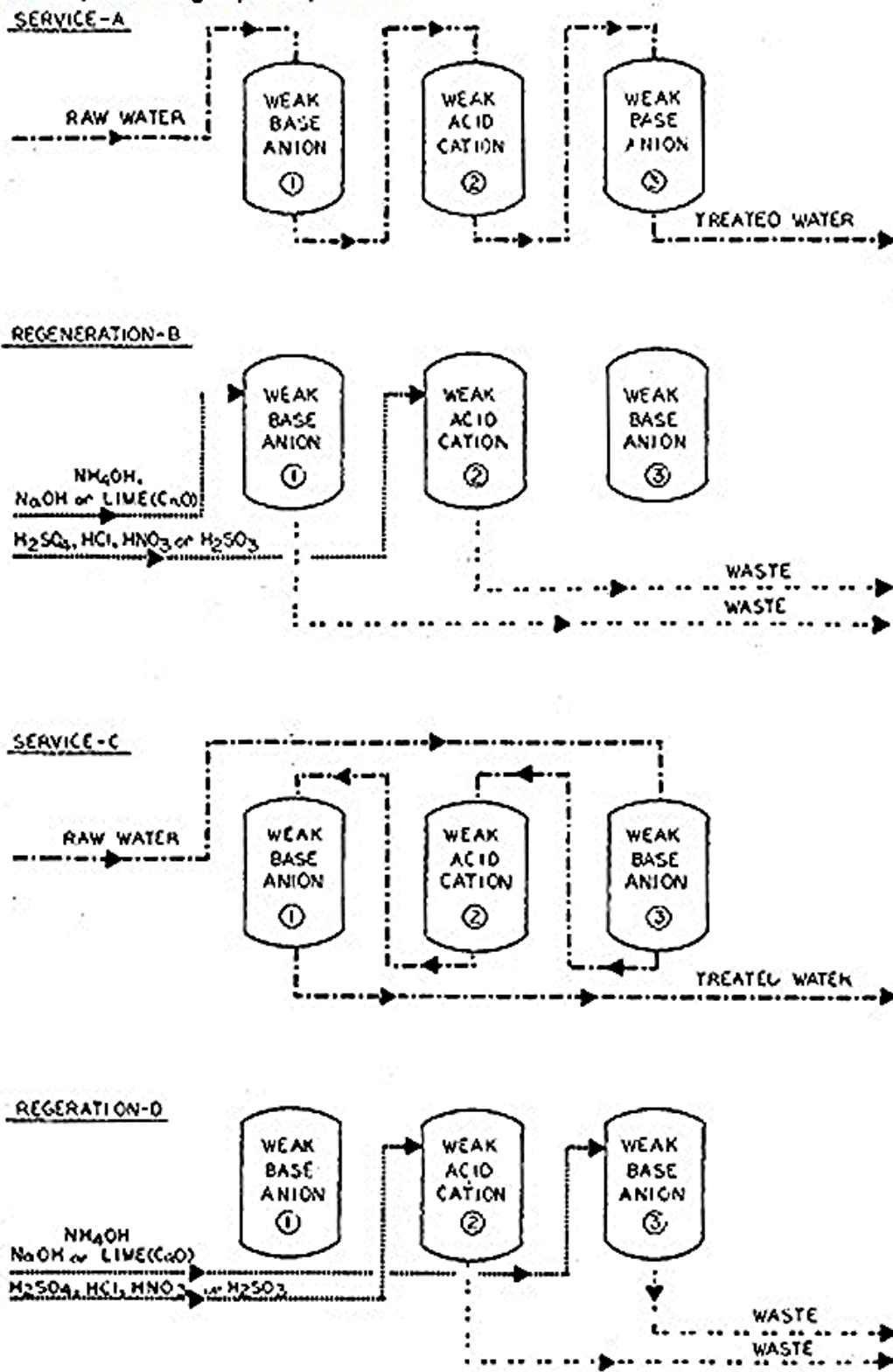


Figure 4-3

Three-unit variation Desal Process



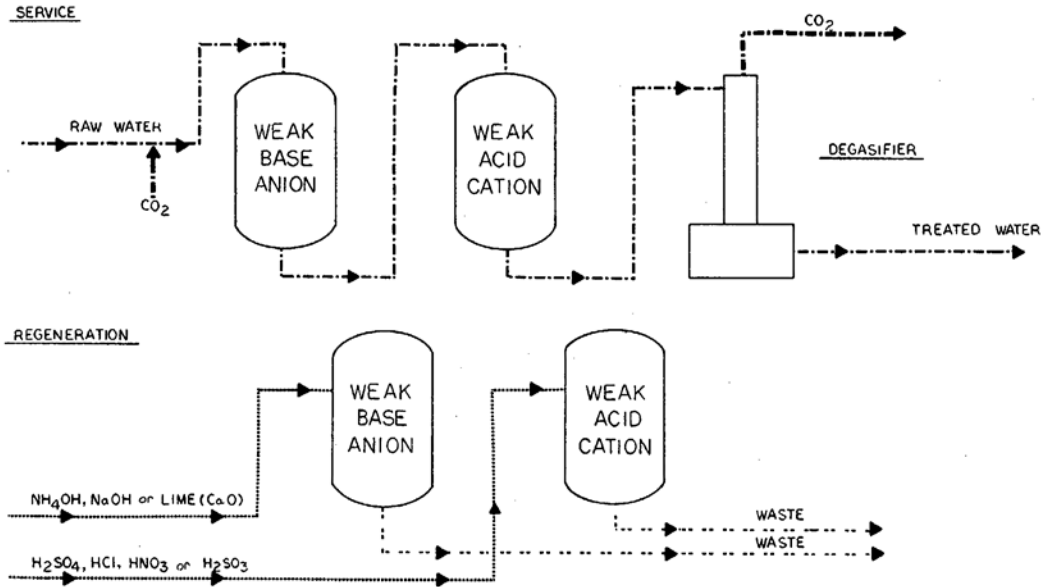


Figure 4-4

Two-unit variation Desal Process

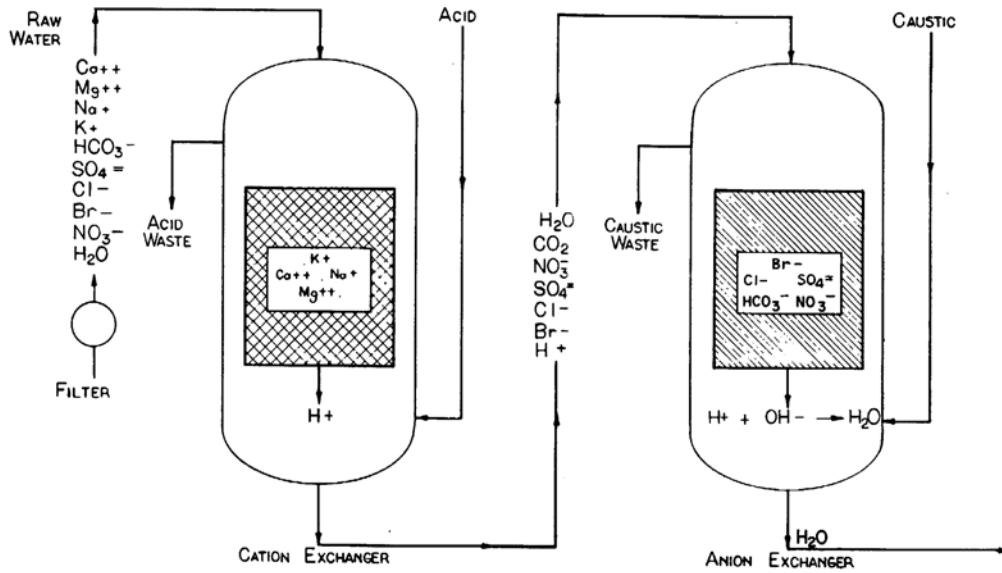


Figure 4-5

Demineralization two-bed flowsheet