

Dow
Water Solutions



DOWEX™

Ion Exchange Resins

WATER CONDITIONING MANUAL



WATER CONDITIONING MANUAL

A Practical Handbook for Engineers and Chemists

- Products
- Applications
- Operation
- Design
- Equipment
- Engineering Information

What this handbook is about...

This is a handbook for people responsible for water supplies, but who are not necessarily water chemists. Here are basic data on ways of conditioning water with DOWEX™ ion exchange resins and straightforward explanations of how you can determine costs and results using the various methods on your own water.

Better Water = Better Operation

Because water is one of the most important raw materials brought into any plant, it follows that better water will cut overall costs and improve plant operating efficiency. These improvements can range from elimination of scale and corrosion in water- and steam-carrying equipment through reduced maintenance and outage time to better finished products.

Ion Exchange Versatility

DOWEX cation and anion exchange resins, used separately or in combination, with or without other water-treating materials, do an amazing variety of water-conditioning jobs; from simple softening of hard water supplies to removal of dissolved solids down to ***a part per billion!***

The following trademarks are used in this handbook:

DIRECTORSM services
DOWEX™ ion exchange resins
DOWEX™ MAC-3 ion exchange resin
DOWEX™ MARATHON™ ion exchange resins
DOWEX™ MONOSPHERE™ ion exchange resins
DOWEX™ UPCORE™ Mono ion exchange resins
FILMTEC™ reverse osmosis membranes
UPCORE™ system

TABLE OF CONTENTS

1	Introduction to Ion Exchange.....	7
1.1	What is Ion Exchange?	7
1.2	Selecting DOWEX™ Resins	8
2	Terms, Acronyms, And Abbreviations	9
3	Sodium Cycle Ion Exchange Process (Water Softening).....	19
3.1	Ion Exchange Resins Specified	19
3.2	Typical Reaction and Chemicals Used	19
3.3	Equipment Required	20
3.4	Softener Design for Co-current and Counter-current Operation.....	20
3.5	Precautions	25
4	Brackish Water Softening	26
4.1	Ion Exchange Resin Specified	26
4.2	Typical Reactions and Chemicals Used	26
4.3	Equipment Required	27
5	Dealkalization: Salt Splitting Process	30
5.1	Ion Exchange Resin Specified	30
5.2	Typical Reactions and Chemicals Used	30
5.3	Equipment Required	30
5.4	General Advantages	32
5.5	Precautions	32
5.6	Reference Documents	32
6	Dealkalization: Weak Acid Cation Resin Process	33
6.1	Ion Exchange Resin Specified	33
6.2	Typical Reactions and Chemicals Used	33
6.3	Equipment Required	33
6.4	General Advantages	34
6.5	Reference Documents	35
7	Demineralization (Deionization) Process	36
7.1	Ion Exchange Resins Specified	36
7.2	Typical Reactions and Chemicals Used	36
7.3	Equipment Required	37
7.4	Product Water Quality	39
7.5	Product Water Quantity.....	39
7.6	Other Demineralization Techniques.....	39
7.7	Reference Documents	40
8	The UPCORE™ Counter-Current Regeneration System	41
8.1	Process Description	41
8.2	Self-Cleaning Ability	42
8.3	Regeneration Cycle	42
8.4	UPCORE and the Layered Bed Anion Option	43
8.5	Comparison with other Regeneration Systems	43
8.6	Reference Documents	45

9	Ion Exchange Resin Operational Information.....	46
9.1	Storage and Handling of Ion Exchange Resins	46
9.2	Loading/Unloading Resins	47
9.3	Resin Sampling	48
9.4	Analytical Testing of Ion Exchange Resins.....	50
9.5	Backwash of an Ion Exchange Resin Bed	50
9.6	Resin Stability and Factors	52
9.7	Useful Life Remaining on Ion Exchange Resin	55
10	Ion Exchange Cleaning Procedures	57
10.2	Ion Exchange Troubleshooting	61
11	Designing an Ion Exchange system	64
11.1	Product Water Requirements.....	64
11.2	Feed Water Composition and Contaminants.....	64
11.3	Selection of Layout and Resin Types (Configuration)	64
11.4	Chemical Efficiencies for Different Resin Configurations	65
11.5	Atmospheric Degasifier	66
11.6	Resin Operating Capacities and Regenerant Levels.....	66
11.7	Vessel Sizing.....	67
11.8	Number of Lines.....	69
11.9	Mixed Bed Design Considerations.....	69
12	Useful Graphs, Tables, and Other Information.....	70
12.1	Particle Size Distribution	70
12.2	Conversion of U.S. and S.I. Units	72
12.3	Conversion of Concentration Units of Ionic Species.....	73
12.4	Calcium Carbonate (CaCO ₃) Equivalent of Common Substances.....	75
12.5	Conversion of Temperature Units.....	76
12.6	Conductance vs. Total Dissolved Solids.....	77
12.7	Handling Regenerant Chemicals	78
12.8	Concentration and Density of Regenerant Solutions.....	80
12.9	Solubility of CaSO ₄	85
12.10	Removal of Oxygen.....	86
12.11	Removal of Chlorine.....	87
12.12	Tank Dimensions and Capacities	88
12.13	Other Information	89
13	Bibliography	90
14	Index.....	91

TABLE OF TABLES

Table 1. Terms common to ion exchange.....	9
Table 2. Acronyms and abbreviations common to ion exchange.....	17
Table 3. Recommended concentrations and flow rates for H ₂ SO ₄ regeneration.....	27
Table 4. TDS range for weak acid cation softening.....	28
Table 5. Results of high TDS water softening using weak acid resin.....	28
Table 6. Results of dealkalization by the salt splitting process.....	30
Table 7. Regenerant concentration and flow rate.....	32
Table 8. Results of dealkalization by the weak acid cation resin process.....	34
Table 9. Regenerant concentration and flow rate.....	34
Table 10. Results of treatment by the demineralization process.....	37
Table 11. Basic types of demineralizers with DOWEX™ resin used.....	38
Table 12. Characteristics of co-current regeneration system.....	43
Table 13. Characteristics of blocked counter-current regeneration systems.....	44
Table 14. Characteristics of upflow counter-current regeneration systems.....	44
Table 15. Analyses available from Dow Water Solutions.....	50
Table 16. Guidelines for strong acid cation resins.....	52
Table 17. Guidelines for strong base anion resins.....	52
Table 18. Guidelines for weak functionality resins.....	52
Table 19. Recommended maximum free chlorine levels (ppm as Cl ₂).....	54
Table 20. System loss of throughput capacity.....	61
Table 21. Failure to produce specified water quality.....	62
Table 22. Increased pressure drop.....	63
Table 23. Typical regeneration efficiencies for different resin types and combinations.....	66
Table 24. Typical regeneration level ranges for single resin columns.....	67
Table 25. Guidelines for amounts and concentrations of H ₂ SO ₄ in stepwise regeneration.....	67
Table 26. Design guidelines for operating DOWEX resins.....	68
Table 27. Main characteristics of sieves for bead size distribution analysis.....	70
Table 28. Recommended particle size ranges for DOWEX™ MONOSPHERE™ 650C.....	71
Table 29. List of conversion factors for U.S. and S.I. units.....	72
Table 30. List of conversion factors for concentration units of ionic species.....	73
Table 31. List of conversion factors for common units to meq/L and mg CaCO ₃ /L.....	74
Table 32. List of conversion factors for CaCO ₃ equivalents.....	75
Table 33. Recommended impurity levels for HCl.....	78
Table 34. Recommended impurity levels for H ₂ SO ₄	79
Table 35. Recommended impurity levels for NaOH.....	79
Table 36. Recommended impurity levels for NaCl.....	79
Table 37. Concentration and density of HCl solutions.....	80
Table 38. Concentration and density of H ₂ SO ₄ solutions.....	81
Table 39. Concentration and density of NaOH solutions.....	82
Table 40. Concentration and density of NH ₃ solutions.....	83
Table 41. Concentration and density of NaCl solutions.....	84
Table 42. Concentration and density of Na ₂ CO ₃ solutions.....	85

Table 43. Levels of sodium sulfite required to remove dissolved oxygen.	86
Table 44. Amount of reducing agent to add for given chlorine level.....	87
Table 45. Tank dimensions and capacities, vertical cylindrical, in U.S. and S.I. units.	88

TABLE OF FIGURES

Figure 1. Sodium cycle ion exchange process (water softening, co-current regeneration).....	19
Figure 2. Hardness leakage in co-current operation for DOWEX™ MARATHON™ C.	20
Figure 3. Hardness leakage in co-current operation for DOWEX MARATHON C-10.	21
Figure 4. Hardness leakage in co-current operation for DOWEX MARATHON MSC.	21
Figure 5. Operating capacity of DOWEX MARATHON resins for water softening.	22
Figure 6. Correction of operating capacity for feed TDS.	22
Figure 7. Correction of operating capacity for feed temperature.	23
Figure 8. Correction of operating capacity for %Na in feed.	23
Figure 9. Correction of operating capacity for TH endpoint.	24
Figure 10. Correction of operating capacity for flow rate.	24
Figure 11. Correction of operating capacity for resin bed depth.....	25
Figure 12. Weak acid resin polisher on strong acid system or weak acid series system.	27
Figure 13. Brackish (high TDS) softening capacity for DOWEX MAC-3 resin.....	29
Figure 14. Dealkalization by the salt-splitting process.	31
Figure 15. Effect of chloride on capacity of DOWEX MARATHON A2 resin in the chloride cycle.	31
Figure 16. Dealkalization by the weak acid cation resin process.	33
Figure 17. Co-current operational capacity data.....	35
Figure 18. Service and regeneration cycles with UPCORE™ system.	41
Figure 19. Vessel design without a middle plate.	43
Figure 20. Examples of devices for obtaining a core sample.	49
Figure 21. Example of device for obtaining a sample from top to bottom of a resin bed.	49
Figure 22. Diagram of backwash procedure.	51
Figure 23. Type 1 strong base anion resin: salt splitting capacity loss vs. temperature.....	53
Figure 24. Approximation of useful life of in-use cation exchange resins.....	56
Figure 25. Approximation of useful life of in-use anion exchange resins.	56
Figure 26. Graph for converting between °C and °F.....	76
Figure 27. Graph for converting between conductance and dissolved solids.	77
Figure 28. Relationship between dissolved solids and conductance in demineralization operations.	77
Figure 29. Solubility of CaSO ₄ in solutions of H ₂ SO ₄ in water.	85
Figure 30. Solubility of oxygen in water as a function of temperature.	86

1 INTRODUCTION TO ION EXCHANGE

1.1 What is Ion Exchange?

Ion exchange is the reversible interchange of ions between a solid (ion exchange material) and a liquid in which there is no permanent change in the structure of the solid. Ion exchange is used in water treatment and also provides a method of separation for many processes involving other liquids. It has special utility in chemical synthesis, medical research, food processing, mining, agriculture, and a variety of other areas. The utility of ion exchange rests with the ability to use and reuse the ion exchange material.

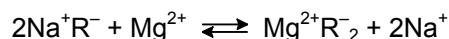
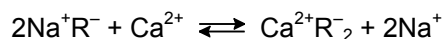
Ion exchange occurs in a variety of substances, and it has been used on an industrial basis since about 1910 with the introduction of water softening using natural and, later, synthetic zeolites. Sulfonated coal, developed for industrial water treatment, was the first ion exchange material that was stable at low pH. The introduction of synthetic organic ion exchange resins in 1935 resulted from the synthesis of phenolic condensation products containing either sulfonic or amine groups that could be used for the reversible exchange of cations or anions.

1.1.1 Cation Exchange

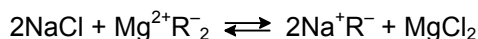
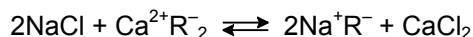
Cation exchange is widely used to soften water. In this process, calcium and magnesium ions in water are exchanged for sodium ions. Ferrous iron and other metals such as manganese and aluminum are sometimes present in small quantities. These metals are also exchanged but are unimportant in the softening process. Removal of the hardness, or scale-forming calcium and magnesium ions, produces "soft water."

The "sodium cycle" operation of cation exchangers is the term used when regeneration is accomplished with common salt. This is water softening in its simplest form. This reaction is shown below.

Operation:



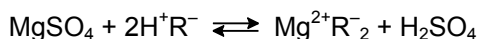
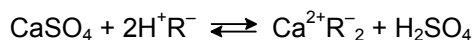
Regeneration:



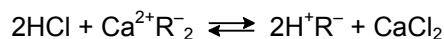
where $R = \text{DOWEX}^{\text{TM}}$ strong acid cation exchange resin

Alternatively, conditions may be used whereby all cations in water may be exchanged for hydrogen ions. The "hydrogen cycle" operation of cation exchangers is the term used when regeneration is accomplished with dilute acid, generally sulfuric acid (H_2SO_4) or hydrochloric acid (HCl). This reaction is shown below.

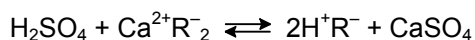
Operation:



Regeneration:



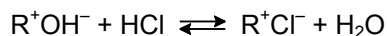
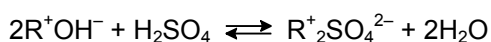
or

*where R = DOWEX™ strong acid cation exchange resin*

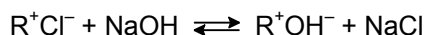
1.1.2 Anion Exchange

Anion exchange is the exchange of anions present in water (SO_4^{2-} , HCO_3^- , Cl^- , etc.) for hydroxide ions (OH^-). This exchange, following cation exchange, completely demineralizes water when carried to completion. An example of typical anion exchange reactions is shown below.

Operation:



Regeneration:

*where R = DOWEX strong base anion exchange resin*

1.1.3 Uniform Particle Size Resins

Uniform particle size (UPS) resins have gained in popularity over the last 20 years for systems focused on achieving the highest purity water and/or the lowest cost of providing high-quality water. As opposed to standard Gaussian-sized resins, UPS resins contain only beads that are produced in a very narrow particle size range. DOWEX™ MONOSPHERE™ and DOWEX MARATHON™ resins are produced using a UPS process that yields products with better kinetics, stronger physical strength, and better separation when used in mixed-bed applications. These advantages lead to higher regeneration efficiency and operating capacity, lower pressure drop and ionic leakage, and increased fouling resistance. UPS resins lead to both higher-quality and lower-cost water purification.

1.2 Selecting DOWEX Resins

Designers and manufacturers of water-treatment equipment include DOWEX ion exchange resins as part of a complete water-treatment plant. When you discuss your water-treatment needs with these suppliers, be sure to specify DOWEX resins to be assured of the ion exchange results you want.

This manual describes many commercial ion exchange applications, along with data on the right DOWEX resins for the job. Operational parameters, costs, chemical handling, and equipment are given practical consideration. Using this information, you can determine which of the different methods of implementing ion exchange best suits your needs.

If you require additional information, a broad assortment of product-specific technical data sheets, engineering brochures, and general technical papers are available on request or at www.dowex.com. Material Safety Data Sheets (MSDS) are also available on the web site or by request to our Dow Water Solutions Offices listed on the back cover.

2 TERMS, ACRONYMS, AND ABBREVIATIONS

Table 1 lists terms commonly used in ion exchange and Table 2 lists acronyms and abbreviations.

Table 1. Terms common to ion exchange.

Term	Definition
Absolute density	Weight of wet resin that displaces a unit volume, expressed as grams per unit volume in a specific ionic form.
Adsorption	Attachment of charged particles to the chemically active groups on the surface and in the pores of an ion exchange resin.
Air mixing	Process of using air to mix two ion exchange materials of different densities in a water slurry to yield a homogeneous mixed bed.
Alkalinity	Amount of carbonate, bicarbonate, and hydroxide present in water. Alkalinity is commonly expressed as "P" and "M" in parts per million (ppm) or mg/L as calcium carbonate (CaCO ₃). "P" represents titration with a standard acid solution to a phenolphthalein endpoint. "M" represents titration to a methyl orange endpoint.
Anion exchange resin	A positively charged synthetic particle that can freely exchange associated anions based on differences in the selectivities of the anions. Also referred to as anion resin.
Attrition	Breakage and abrasion of resin beads occurring when the beads rub against other beads or other solids.
Backwashing	Upward flow of water through an ion exchange resin bed to remove foreign material and reclassify the bed after exhaustion and prior to regeneration. Also used to reduce compaction of the bed.
Base exchange	Exchange of cations between a solution and cation exchange resin.
Batch operation	Method of using ion exchange resins in which the resin and the solution to be treated are mixed in a vessel, and the liquid is decanted or filtered off after equilibrium is attained.
Bed	Ion exchange resin contained in a column. See <i>Exchanger bed</i> .
Bed depth	Depth of ion exchange resin in a column.
Bed expansion	Separation and rise of ion exchange resin beads in a column during backwashing.
Bed volume	Volume of ion exchange material of specified ionic form contained in a column or operating unit, usually measured as the backwashed, settled, and drained volume.
Bed volume per hour	Measure of the volume flow rate through an ion exchange material contained in a column or operating unit, expressed as BV/h, m ³ /h/m ³ , or gal/min/ft ³ .
Bed warm-up	Step just prior to regenerant injection where hot dilution water is added to the resin bed to heat the bed to the appropriate temperature. This is to enhance polymerized silica removal.
Boiler feed water	Water used in steam boilers and some industrial processes. Boiler feed water may possibly be raw water, treated water, condensate, or mixtures, depending on the need.
Breakthrough	Volume of effluent where the concentration of the exchanging ion in the effluent reaches a predetermined limit. This point is usually the limit of the exhaustion cycle and where the backwash cycle begins.
CADIX	Computer-Aided Design of Ion eXchange systems. Computer software for designing ion exchange resin plants using DOWEX™ resins.
Capacity	Number of equivalents of exchangeable ion per unit volume, unit wet weight, or dry weight of an ion exchange material in specified ionic form.
Carboxylic	Term describing a specific group that imparts a weakly acidic exchange ability to some resins.
Cation exchange resin	Negatively charged synthetic particle that can freely exchange associated cations based on differences in the selectivities of the cations. Also referred to as cation resin.

Term	Definition
Caustic soda	Sodium hydroxide (NaOH), which is used to regenerate anion beds. Also referred to as caustic.
Channeling	Creation of isolated paths of lower resistance in an ion exchange resin bed caused by the introduction of air pockets, dirt, or other factors that result in uneven pressure gradients in the bed. Channeling prevents the liquid being processed from uniformly contacting the entire resin bed.
Chemical stability	Ability of an ion exchange resin to resist changes in its physical properties when in contact with aggressive chemical solutions such as oxidizing agents. Also the ability of an ion exchange resin to resist inherent degradation due to the chemical structure of the resin.
Chloride anion dealkalization	Anion exchange system that is regenerated with salt and caustic and exchanges chloride ions for bicarbonate and sulfate ions in the water being treated.
Classification	Obtained by backwashing an ion exchange resin bed, which results in a bed that is graduated in resin bead size from coarse on the bottom to fine on the top. This is less important when using uniform particle size resins.
Clumping	Formation of agglomerates in an ion exchange bed due to fouling or electrostatic charges.
Co-current operation	Ion exchange operation in which the process water and regenerant are passed through the bed in the same direction, normally downflow. Also referred to as co-flow operation.
Colloids	Extremely small particles that are not removed by normal filtration.
Color throw	Color imparted to a liquid from an ion exchange resin.
Column operation	Most common method for employing ion exchange in which the liquid to be treated passes through a fixed bed of ion exchange resin.
Condensate polisher	Use of a cation resin or mixed-bed column to remove impurities from condensate.
Conductivity	Ability of a current to flow through water as a measure of its ionic concentration, measured in micromhos/cm ($\mu\text{mho/cm}$) or microsiemens/cm ($\mu\text{S/cm}$).
Contact time	Amount of time that the process liquid spends in the ion exchange bed, expressed in minutes. Determined by dividing the bed volume by the flow rate, using consistent units.
Counter-current operation	Ion exchange operation in which the process liquid and regenerant flows are in opposite directions. Also referred to as counter-flow operation.
Crosslinkage	Binding of the linear polymer chains in the matrix of an ion exchange resin with a crosslinking agent that produces a three-dimensional, insoluble polymer.
Deaerator	See <i>Degasifier, vacuum</i> .
Dealkalization	Anion exchange process for the removal or reduction of alkalinity in a water supply.
Decationization	Exchange of cations for hydrogen ions by a strong acid cation exchange material in the hydrogen form. See <i>Salt splitting</i> .
Decrosslinking	Alteration of the ion exchange structure by degradation of the crosslinkage by aggressive chemical attack or heat. This causes increased swelling of ion exchange materials.
Degasifier	Used to reduce carbon dioxide content of the effluent from hydrogen cation exchangers. Reduces CO_2 to approximately 5–10 ppm but saturates water with air. Also referred to as a decarbonator.
Degasifier, vacuum	Actually a deaerator. Reduces oxygen as well as CO_2 and all other gases to a very low level. Preferred as a means of CO_2 reduction when demineralizing boiler water make-up. Eliminates water pollution and reduces corrosion problems when transferring water through steel equipment. Usually results in longer anion exchange resin life.
Degradation	Physical or chemical reduction of ion exchange properties due to type of service, solution concentration used, heat, or aggressive operating conditions. Some effects are capacity loss, particle size reduction, excessive swelling, or combinations of the above.

Term	Definition
Degree of crosslinking	Effective amount of crosslinking present in an ion exchange resin, normally expressed as an equivalent amount of physical crosslinking agent (e.g., divinylbenzene).
Deionization	Removal of ionizable (soluble) constituents and silica from a solution by ion exchange processing. Normally performed by passing the solution through the hydrogen form of cation exchange resin and through the hydroxide form of an anion exchange resin, either as a two-step operation or as an operation in which a single bed containing a mixture of the two resins is employed.
Deionized water	Water that has had all dissolved ionic constituents removed. Cation and anion exchange resins, when properly used together, will deionize water.
Demineralization	See <i>Deionization</i> .
Density	Weight of an ion exchange material, usually expressed as wet g/L or lb/ft ³ .
Desalination	Removal of dissolved salts from a solution.
Diffusion	Process whereby ions, atoms, and molecules move in a mix. The movement is random, with the net effect being movement from a higher concentration zone to a lower concentration zone until the zones have equalized.
Dissociation	Process of ionization of an electrolyte or salt upon being dissolved in water, forming cations and anions.
Distributor	Piping inside an ion exchange vessel that evenly distributes flow across the resin bed.
Divinylbenzene	Difunctional monomer used to crosslink polymers.
DOWEX™ resins	Ion exchange resins used for treatment of water and other liquids. A trademark of The Dow Chemical Company.
Double pass	Process by which a stream is treated twice in series by ion exchange resins. Normally a cation exchange resin and anion exchange resin are followed by a mixed bed or another cation exchange resin and anion exchange resin step.
Downflow	Operation of an ion exchange column in which the regenerant enters the top of the ion exchange column and is withdrawn from the bottom. This is the conventional direction of water flow in a co-current ion exchange column.
Dry weight capacity	Amount of exchange capacity present in a unit weight of dried resin.
Eductor	Device that draws a solution into the water stream by using a flow of water to create a vacuum.
Effective size	Particle size expressed in millimeters equal to the 90% retention size determined from a particle size analysis.
Efficiency	Measure of the quantity of regenerant required to remove a chemical equivalent weight of contaminant in the influent water. For a sodium softener, this is usually expressed as pounds of salt per kilograin or kg salt per equivalent of hardness removed.
Effluent	The solution that emerges from an ion exchange column or vessel.
Eluate	The solution resulting from an elution process.
Elution	The stripping of sorbed ions from an ion exchange resin by passing solutions containing other ions in relatively high concentrations through the resin column.
Exchange sites	The reactive groups on an ion exchange resin.
Exchanger bed	Ion exchange resin contained in a suitable vessel and supported by material, such as grated gravel, screen-wrapped pipe, or perforated plate, which also acts as a liquid distribution system.
Exhaustion	Step in an ion exchange cycle in which the undesirable ions are removed from the liquid being processed. When the supply of ions on the ion exchange resin that are being exchanged for the ions in the liquid being processed is almost depleted, the resin is said to be exhausted.

Term	Definition
Fast rinse	Portion of the rinse that follows the slow rinse. Usually passed through the ion exchange bed at the service flow rate.
Film diffusion	Movement of ions through the liquid film on the surface of an ion exchange particle.
Fines	Small particles of an ion exchange resin that are undesirable.
Fouling	Any relatively insoluble deposit or film on an ion exchange material that interferes with the ion exchange process.
Free mineral acidity	Due to the presence of acids such as H ₂ SO ₄ , HCl, and nitric acid (HNO ₃), expressed in ppm or mg/L as calcium carbonate.
Freeboard	Space provided above the resin bed in the column to accommodate the expansion of resin particles during backwashing.
Fulvic acid	A high molecular weight polycarboxylic acid often found in surface water supplies. It frequently contributes to organic fouling of ion exchange materials.
Functional group	Atom or group of atoms on an ion exchange resin that gives the resin its specific chemical characteristics.
Gel	Term applied to the bead structure of certain ion exchange resins that have a microporous matrix structure with small pores generally <10 Å. Gel resins offer good operating capacity and regeneration efficiency. Porous gel resins also exhibit good resistance to organic fouling.
Grains per gallon	The concentration of ions in solution usually expressed in terms of calcium carbonate equivalents. One grain per gallon is equal to 17.1 ppm or mg/L.
Greensands	Naturally occurring materials that possess ion exchange properties. Greensand was the first ion exchange material used in softeners.
Hardness, total	Currently defined as the sum of calcium and magnesium concentrations, both expressed as calcium carbonate in ppm or mg/L.
Head loss	See <i>Pressure drop</i> .
Humic acid	High molecular weight polycarboxylic acid found in surface water supplies that contributes to organic fouling in ion exchange materials.
Hydraulic classification	Tendency of small resin particles to rise to the top of the resin bed during a backwash operation and the tendency of large resin particles to settle to the bottom.
Hydrogen cation exchanger	Term used to describe a cation resin regenerated with acid to exchange hydrogen ions (H ⁺) for other cations.
Hydrogen cycle	Cation exchange resin operation in which the regenerated ionic form of the resin is the hydrogen form.
Hydrometer	Instrument used for measuring the relative density (specific gravity) of liquids.
Hydroxide cycle	Anion exchange operation in which the regenerated form of the ion exchange material is the hydroxide form.
Influent	Solution entering an ion exchange column.
Interstitial volume	Space between the particles in an ion exchange resin bed.
Ion exchange	Process by which ionic impurities in water are attached to active groups on and in an ion exchange resin, and more desirable ions are discharged into water.
Ionic strength	Half of the sum of the product of ion concentrations and the square of their charges.
Ionization	Separation of part or all of the solute molecules into positive (cationic) and negative (anionic) ions in a dissociating medium such as water.
Iron	Often present in ground waters in a reduced, soluble form (such as ferrous bicarbonate) in quantities usually ranging from 0.5–10 ppm or mg/L. Iron in solution is susceptible to oxidation, precipitating as a reddish-brown floc when contacted by air under normal well-water conditions.

Term	Definition
Kinetics	Rate at which ions can be exchanged between a solution and a resin. Kinetics is usually impacted by the diffusion rate of solution into the resin, selectivity differences between the ions being exchanged, and the nature of the functional group doing the exchanging.
Layered bed	Two ion exchange materials (e.g., weak and strong base anion resins) with sufficient differences in density and hydraulic characteristics to be layered in the same vessel, in place of two separate vessels.
Leakage (hardness, sodium, silica, etc.)	Caused by incomplete regeneration of an ion exchange bed. Since complete regeneration is usually inefficient, most ion exchange processes operate at one-half to one-third of the total capacity of the ion exchange system.
Macroporous	Term applied to the bead structure of certain ion exchange resins that have a tough, rigid structure with large discrete pores. Macroporous resins offer good resistance to physical, thermal, and osmotic shock and chemical oxidation. Macroporous anion resins also exhibit good resistance to organic fouling.
Macroreticular	See <i>Macroporous</i> .
Membrane	Thin sheet separating different streams, which contains active groups that have a selectivity for anions or cations but not both.
Mixed bed	Use of a mixture of cation and anion resins in the same column to produce water of extremely high quality.
Molality	Number of gram-molecules weight of a solute per kilogram of solvent.
Molarity	Number of gram-molecules weight of a solute per liter of solution.
Monomeric silica	Simplest form of silica, often described as SiO_2 and referred to as dissolved or reactive silica.
Nonionic	Compounds that do not have a net positive or negative charge.
Ohm	Unit of resistance of a solution, often related to the electrolytic concentration.
Operating capacity	Portion of the total exchange capacity of an ion exchange resin bed that is used in a practical ion exchange operation. Commonly expressed in kilograins per cubic foot (kgr/ft^3) or milliequivalents per liter (meq/L).
Operating cycle	Complete ion exchange process consisting of a backwash, regeneration, rinse, and service run.
Organic fouling	Condition where a significant amount of organic molecules remains in the beads following a normal regeneration.
Organic matter	Present in many ground and surface waters. Organic matter may come from natural sources such as swamps and be visible as color. Pollution by industrial wastes and household detergents are other sources of organic matter.
Osmotic shock	Expansion or contraction of resin beads due to volume changes imposed by repeated applications of dilute and concentrated solutions.
Osmotic stability	Ability of an ion exchange material to resist physical degradation due to osmotic shock.
Particle diffusion	Movement of ions within the ion exchange material toward exchange sites.
Permeability	Ability of an ion exchange membrane to pass ions under the influence of an electric current.
pH	Negative logarithm (base 10) of the hydrogen ion concentration in water.
Physical stability	Ability of an ion exchange resin to resist breakage caused by physical manipulation or by volume changes due to either osmotic shock or iteration between two or more ionic forms.
Polar	Molecular property in which the positive and negative electrical charges are permanently separated. Polar molecules ionize in solution and impart electrical conductivity.
Polarity	Molecular property in which the positive and negative electrical charges are permanently separated.

Term	Definition
Polisher	Mixed-bed ion exchange unit usually installed after a two-bed deionizer system to remove the last traces of undesirable ions.
Polydispersed resin	Resin composed of particles of a wide range of particle sizes.
Polymeric silica	Larger molecular weight silica compounds that result from the chemical polymerization of monomeric silica.
Porosity	Used qualitatively to describe that property of an ion exchange resin that allows solutes to diffuse in and out of the resin particle. Porosity is usually used with regard to large ions and molecules such as organic acids. Porosity is directly related to the water content and inversely related to the crosslinkage of a gel resin.
Potable water	Water meeting Health Department standards for use as drinking water. These waters may be hard and may contain considerable salts in solution.
Pressure drop	Loss in liquid pressure resulting from the passage of the solution through the bed of ion exchange resin.
Pretreatment	Includes flocculation, settling, filtration, or any treatment water receives prior to ion exchange.
Process water	Any water mixed with a product, or becoming part of a product, or used to wash a product. These supplies require various kinds of treatment such as clarification and filtration. In many cases ion exchange resins are used to soften, dealkalize, or completely deionize the water.
Quaternary ammonium	Term describing a specific group that imparts a strongly basic exchange ability to some anion exchange resins.
Raw water	Untreated water from wells, surface sources, or the sea.
Reactive silica	See <i>Monomeric silica</i> .
Regenerant	Chemical used to convert an ion exchange resin to the desired ionic form for reuse.
Regeneration	Displacement from the ion exchange resin of the ions removed from the process solution. May be performed either by co-current or counter-current operation. Lower ion leakages are typically obtained with counter-current regeneration at comparable regenerant dosages.
Regeneration efficiency	Measure of the amount of capacity of an ion exchange resin compared to the amount of regenerant applied. This is expressed as a ratio of equivalents of capacity to equivalents of regenerant and is therefore <100%. It is the reciprocal of <i>Stoichiometry</i> .
Regeneration level	Amount of regenerant used per cycle. Commonly expressed in lb/ft ³ of resin or g/L of resin. Also referred to as regeneration dosage.
Reversible	Ability of an ion exchange resin to use variations in component concentrations and selectivity to allow a resin to be regenerated.
Rinse	Passage of water through an ion exchange resin bed to flush out excess regenerant.
Run time	Time between regenerations or the duration of the service cycle.
Salt splitting	Conversion of salts to their corresponding acids or bases by passage through strong acid cation or strong base anion exchange resins, respectively.
Saturated	Maximum amount of a substance that can be dissolved in a solvent.
Saturation level	The level or concentration of a material in a solvent at which the material has reached the limit of its solubility. A material that is at a level or concentration higher than its saturation level tends to precipitate and form deposits.
Scavenger	Polymer matrix or ion exchange material used to specifically remove organic species from the process liquid before the solution is deionized.
Selectivity	Difference in attraction of one ion over another to an ion exchange resin.
Silica	Present in most water supplies. Well waters usually contain silica in solution while surface waters may contain soluble, colloidal, and suspended silica.

Term	Definition
Slow rinse	Portion of the rinse that follows the regenerant solution and is passed through the ion exchange material at the same flow rate as the regenerant.
Sluicing	Method of transporting resin from one tank to another with water. Sluicing is usually used in mixed-bed deionization systems with external regeneration systems.
Sodium form cation resin	Cation exchange resin, regenerated with salt (NaCl). Exchanges sodium ions (Na ⁺) for metal cations (Mg ²⁺ , Ca ²⁺ , etc.), forming sodium salts (sulfates, carbonates, etc.).
Sphericity	Measure of the amount of ion exchange resin beads that are unbroken.
Stability	Capability of a resin to resist chemical and physical degradation.
Stoichiometry	Measure of the quantity of regenerant required compared to the resultant capacity of the ion exchange resin. This is expressed as a ratio of equivalents of regenerant to equivalents of capacity and is therefore >100%. It is the reciprocal of <i>Regeneration efficiency</i> .
Stratified bed	See <i>Layered bed</i> .
Strong acid capacity	Part of the total cation exchange capacity that is capable of converting neutral salts to their corresponding acids. Also referred to as <i>Salt splitting capacity</i> .
Strong acid cation resin	Resins employed in softening and deionization systems. When regenerated with salt, the sodium ions on the resin will effectively exchange for divalent cations such as calcium and magnesium. When regenerated with H ₂ SO ₄ or HCl, the resin will split neutral salts, converting the salt to its corresponding acid. The resin usually receives its exchange capacity from sulfonic groups.
Strong base anion resin	Resins employed in chloride anion dealkalizers and deionization systems. When regenerated with salt, the chloride ions exchange for bicarbonate and sulfate anions. When regenerated with caustic soda, the resin removes both strong and weak acids from cation exchange resin effluent. The resin usually receives its exchange capacity from quaternary ammonium groups.
Strong base capacity	Part of the total anion exchange capacity capable of converting neutral salts to their corresponding bases. Also referred to as <i>Salt splitting capacity</i> .
STY/DVB copolymer	Polymer containing styrene (vinylbenzene) crosslinked with divinylbenzene.
Sulfonic	Term describing a specific group that imparts a strongly acidic exchange ability to some cation resins.
Support media	Graded-particle-size, high-density materials such as gravel, anthrafil, quartz, etc. Used to support the resin bed.
Surface water	Water taken directly from surface sources such as rivers, lakes, and seas.
Swell	Tendency of an ion exchange resin to expand or contract depending on the counterions associated with it.
Tertiary ammonium	Term describing a specific group that imparts a weakly basic exchange ability to some anion resins.
Tertiary effluent	Waste water from a municipal water-treatment plant that has undergone sedimentation, biological treatment, and advanced particle removal steps such as clarification and filtration. See also <i>Waste water</i> .
Throughput	Amount of product water generated during the service cycle.
Total capacity	Maximum exchange ability of an ion exchange resin expressed on a dry weight, wet weight, or wet volume basis.
Train	Single ion exchange system capable of producing the treated water desired, such as a strong acid cation resin bed followed by a strong base anion resin bed, with multiple trains being duplicates of the single system.
Under drain	Piping inside an ion exchange vessel that evenly collects the treated water after it has passed through the resin bed.

Term	Definition
Uniform particle size	Resin that has a very narrow range of particle sizes, normally with a uniformity coefficient of <1.10.
Uniformity coefficient	Volume or weight ratio (>1) of the 40% retention size and the 90% retention size determined from a particle size analysis. See <i>Effective size</i> .
UPCORE™	Packed bed, counter-current regeneration technology in which process flow is downflow and regeneration is upflow after a compaction step. UPCORE (<i>up'kō rā</i>) systems are self-cleaning, eliminating the need for backwash and increasing regeneration efficiency while minimizing leakage. A trademark of The Dow Chemical Company.
Upflow	Operation of an ion exchange column in which the regenerant enters the bottom of the ion exchange column and is withdrawn from the top. Regeneration efficiency and column leakage may be improved by this process.
Valence	Number of positive or negative charges of an ion.
Void volume	See <i>Interstitial volume</i> .
Volume mean diameter	Particle size expressed in microns (µm) or millimeters (mm) equal to the 50% retention size determined from a particle size analysis.
Waste water	Contaminated water that can often be recovered, cleansed of toxic or other undesirable elements, or otherwise purified with ion exchange processes.
Water retention	Amount of water, expressed as a percent of the wet weight, retained within and on the surface of a fully swollen and drained ion exchange material.
Water softening	Exchange of sodium for the hardness in water by ion exchange.
Weak acid cation resin	Used in dealkalization and desalination systems and in conjunction with strong acid cation resins for deionization. When regenerated with acid, the resin will split alkaline salts, converting the salt to carbonic acid. This resin exhibits very high regeneration efficiency. It usually receives its exchange capacity from carboxylic groups.
Weak base anion resin	Used to remove mineral acids from solution. These resins are employed in deionizers when silica removal is not required. When regenerated with soda ash, ammonia, or caustic soda, the resin adsorbs strong acids such as HCl and H ₂ SO ₄ from the cation bed effluent. The resin usually receives its exchange capacity from tertiary amine groups.
Well water	Generally refers to water from a ground water source that has been accessed via a well. When the well is close to surface water, then significant portions of the water obtained may be from the surface water source. See <i>Surface water</i> .
Wet volume capacity	Amount of exchange capacity present in a unit volume of hydrated resin.
Zeolite	Mineral composed of hydrated silicates of aluminum and either sodium or calcium or both. The term is commonly used in connection with water softening by ion exchange (e.g., zeolite softener, hot lime zeolite, etc.).

Table 2. Acronyms and abbreviations common to ion exchange.

Acronym/ Abbreviation	Definition
A&E	architect and engineer
ASTM	American Society for Testing and Materials
AVT	all volatile treatment
BWR	boiling water reactor
CIP	cleaning in place
CP	condensate polishing
Da	dalton
degas	degasifier
demin	demineralization
DVB	divinylbenzene
DWC	dry weight capacity
FB	free base
FMA	free mineral acidity
GAC	granular activated carbon
gpm	gallons per minute
grpg	grains per gallon
H/A	hardness to alkalinity ratio
IX	ion exchange
kgr	kilograins
ME	microscopic examination
OEM	original equipment manufacturer
OF	organic fouling
OS	organic scavenger
ppb	unit of concentration, parts per billion, equal to 1 µg/L
ppm	unit of concentration, parts per million, equal to 1 mg/L
psi	pounds per square inch
psig	pounds per square inch gauge
PWR	pressurized water reactor
RO	reverse osmosis
SAC	strong acid cation
SBA	strong base anion
SBS	sodium bisulfite
SHMP	sodium hexametaphosphate
SMBS	sodium metabisulfite
spec	specification
SSC	salt splitting capacity

Acronym/ Abbreviation	Definition
TBC	total bacteria count
TDS	total dissolved solids, usually expressed as mg/L or ppm
TEA	total exchangeable anion
TEC	total exchange capacity
TH	total hardness
TOC	total organic carbon
TRC	total residual chlorine
TSS	total suspended solids
UPS	uniform particle size
WAC	weak acid cation
WBA	weak base anion
WBC	weak base capacity
WRC	water retention capacity
WUB	whole uncracked beads
WVC	wet volume capacity

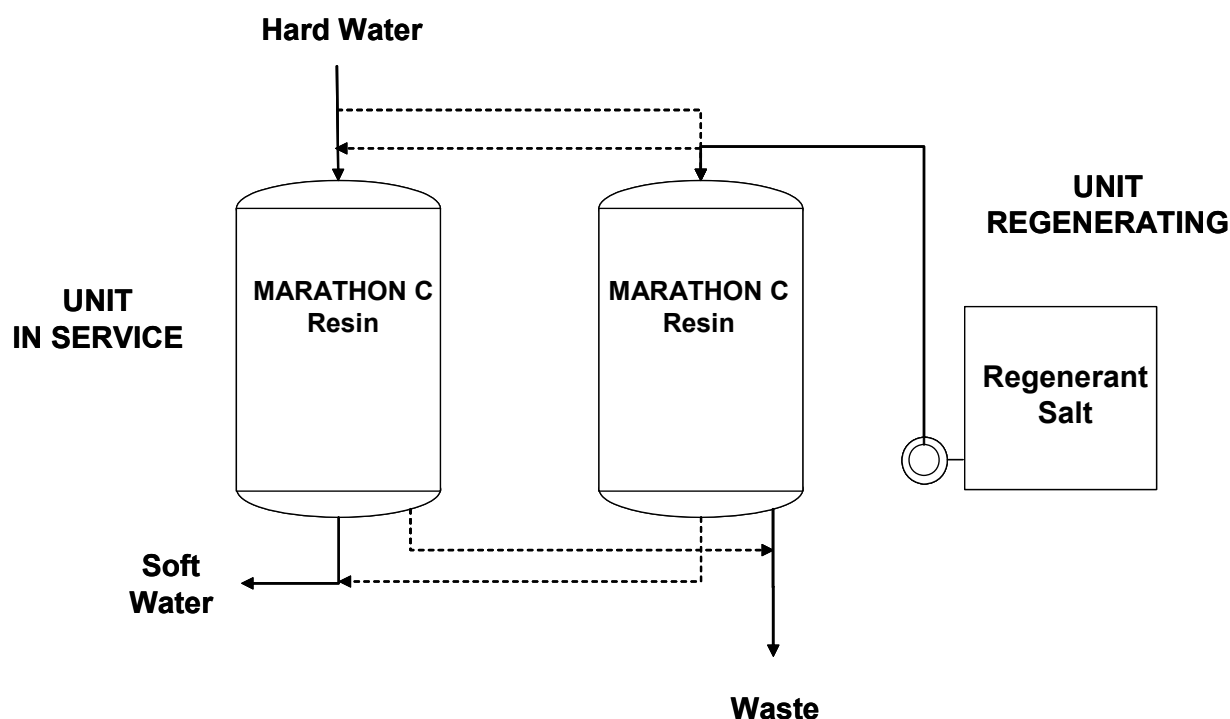
3 SODIUM CYCLE ION EXCHANGE PROCESS (WATER SOFTENING)

3.1 Ion Exchange Resins Specified

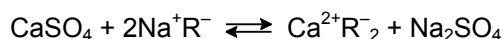
Some resins used in industrial water softening include DOWEX™ MARATHON™ C, DOWEX MARATHON C-10, DOWEX MARATHON MSC resins, and DOWEX strong acid cation resins sold to the home water-softening market. Many of these resins are available in equipment offered by leading equipment manufacturers.

These resins soften hard-water supplies by exchanging the calcium and magnesium salts responsible for the hardness of water for very soluble sodium salts. Only calcium, magnesium, and sodium in the water are important and are affected by the softening process. A flow diagram of the process is shown in Figure 1.

Figure 1. Sodium cycle ion exchange process (water softening, co-current regeneration).



3.2 Typical Reaction and Chemicals Used



where R = DOWEX MARATHON C resin

Ordinary salt (NaCl) is used almost exclusively to regenerate DOWEX MARATHON C resin. Other sources of sodium ion may be used, such as sea water or other sodium salts. The amount of regenerant applied to DOWEX MARATHON C resin determines to a degree the amount of soft water it will deliver. Capacity is also a function of the raw water total dissolved solids (TDS) content and other factors described below.

3.3 Equipment Required

Equipment includes a vessel to accommodate DOWEX™ MARATHON™ C resin, with piping, valves, chemical tank, and accessories properly engineered for economical balance of resin capacity and chemical efficiency, and proper regeneration.

To design co-current or counter-current plants under different operating conditions, correction factors for the specific conditions can be applied as described below.

3.4 Softener Design for Co-current and Counter-current Operation

To design a co-current or counter-current plant, determine the resin operating capacity based on one reference set of operating conditions and then apply correction factors for the specific conditions of the design. The reference conditions are:

- Linear flow of 12 m/h (5 gpm/ft²) or 16 bed volumes/h
- Temperature 68°F (20°C)
- 500 ppm TDS feed
- 30-inch (75-cm) resin bed depth
- 10% NaCl regenerant at 25 min contact time
- Capacity total hardness (TH) endpoint of 3% (15 ppm CaCO₃) for co-current operation.

The particular conditions applying to the softener (e.g. temperature, oxidants) may impact the choice of resin, and these conditions should be considered before proceeding with the design.

3.4.1 Co-current Design

1. From Figure 2 to Figure 4, determine the level of regenerant required for the particular water feed TDS to give an acceptable hardness leakage.

Figure 2. Hardness leakage in co-current operation for DOWEX MARATHON C.

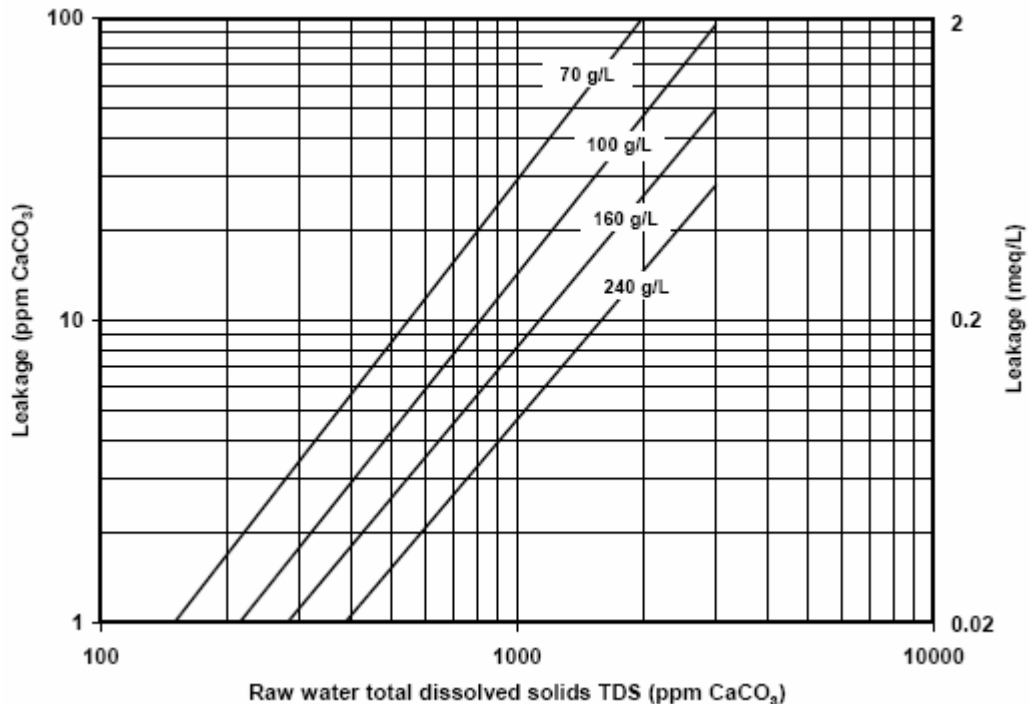


Figure 3. Hardness leakage in co-current operation for DOWEX™ MARATHON™ C-10.

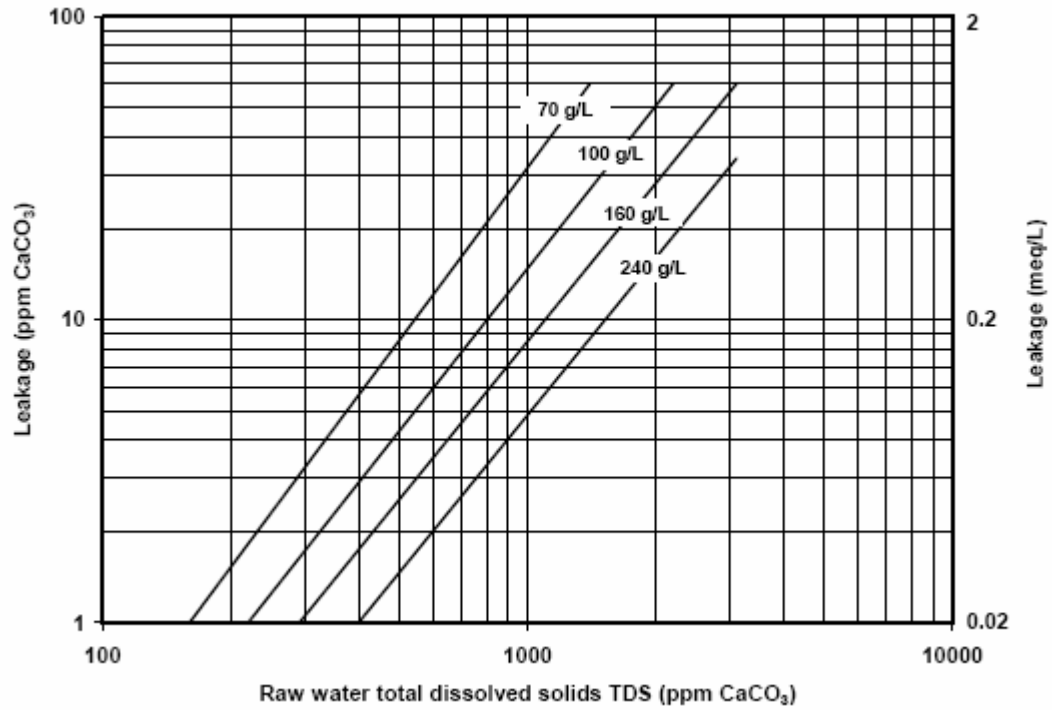
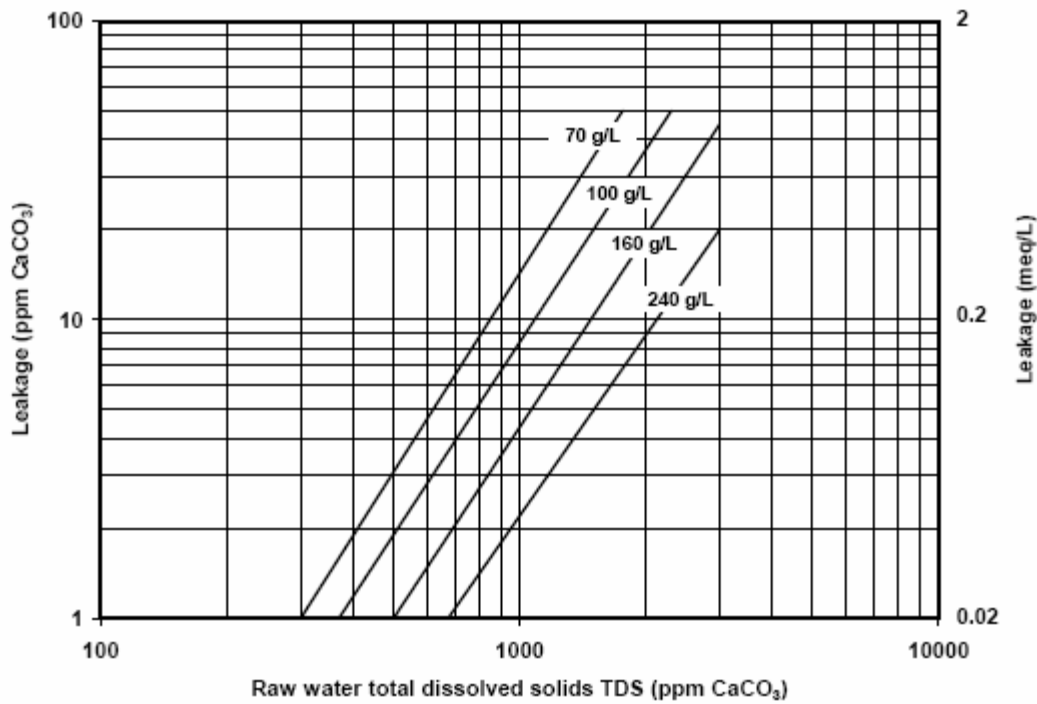
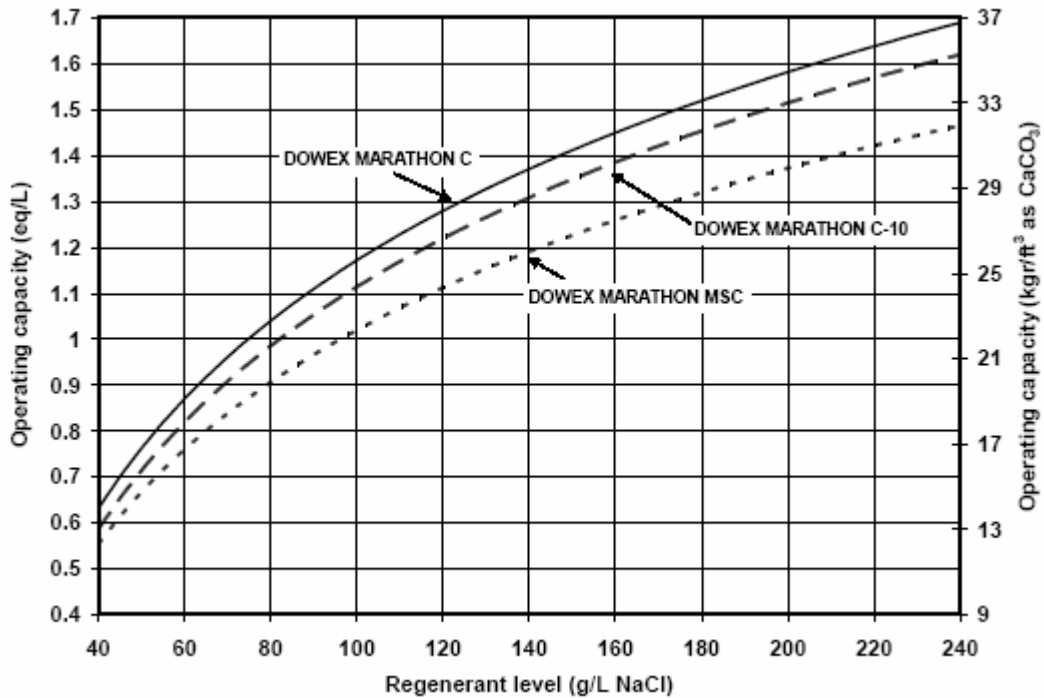


Figure 4. Hardness leakage in co-current operation for DOWEX MARATHON MSC.



2. Use Figure 5 to determine the resin operating capacity at that level of regeneration.

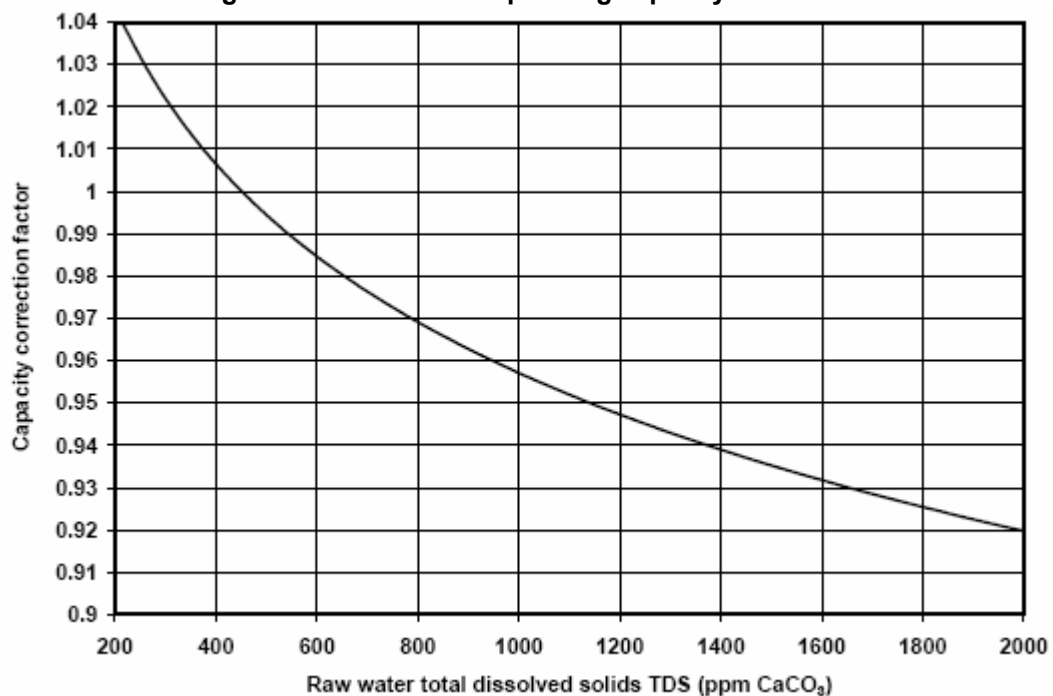
Figure 5. Operating capacity of DOWEX™ MARATHON™ resins for water softening.



To design at other conditions, correction factors should be applied to the operating capacity curve as described below:

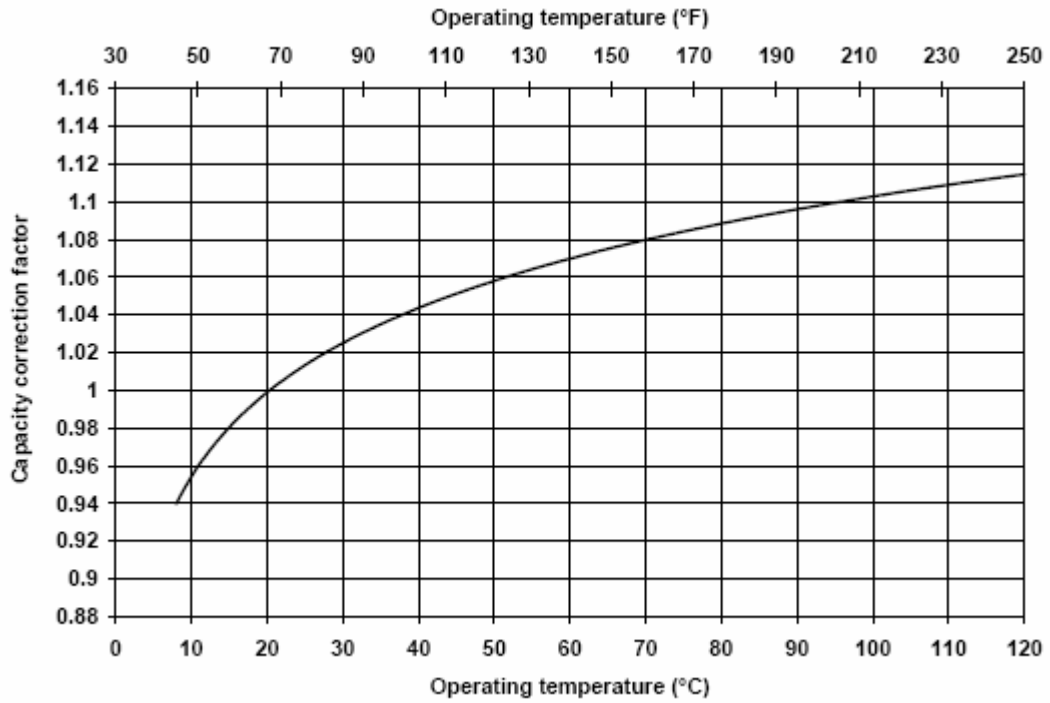
3. Correct the operating capacity for feed water TDS using Figure 6.

Figure 6. Correction of operating capacity for feed TDS.



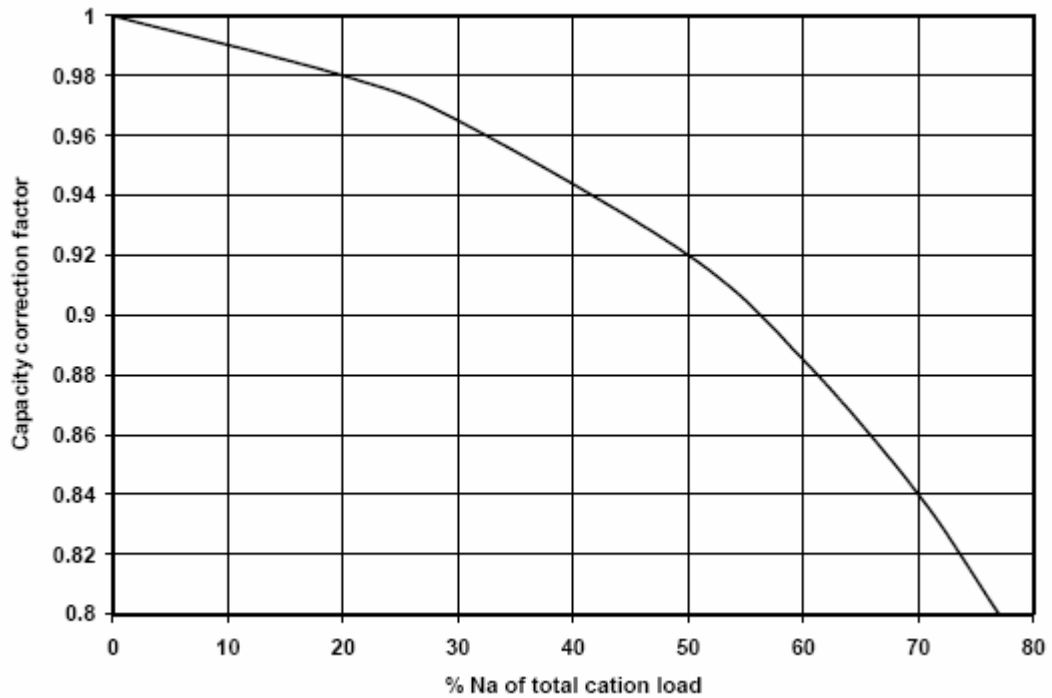
- Correct the operating capacity for feed temperature using Figure 7.

Figure 7. Correction of operating capacity for feed temperature.



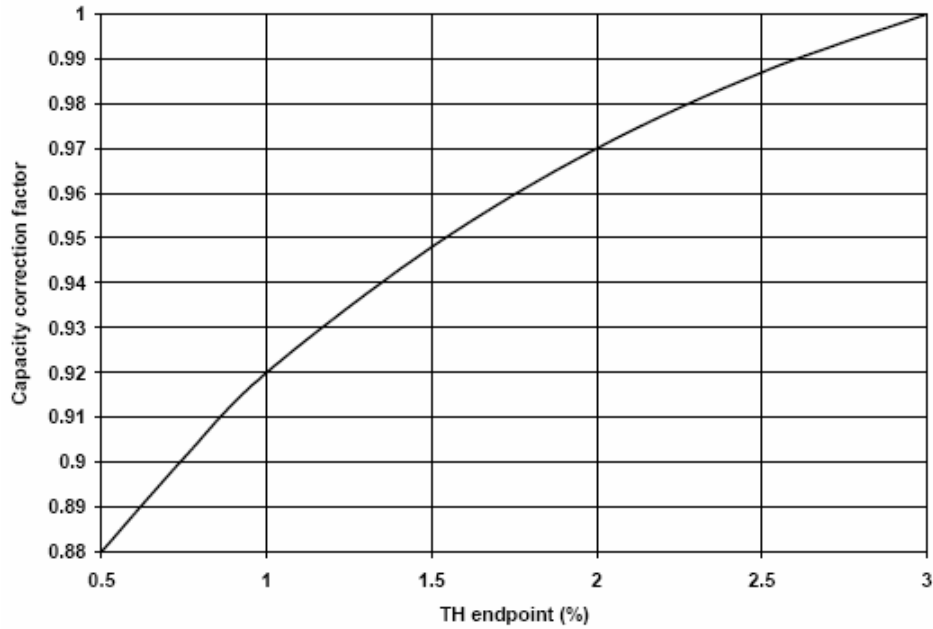
- Correct the operating capacity for %Na/TH in feed using Figure 8.

Figure 8. Correction of operating capacity for %Na in feed.



6. Correct the operating capacity for TH endpoint (if desired) using Figure 9.

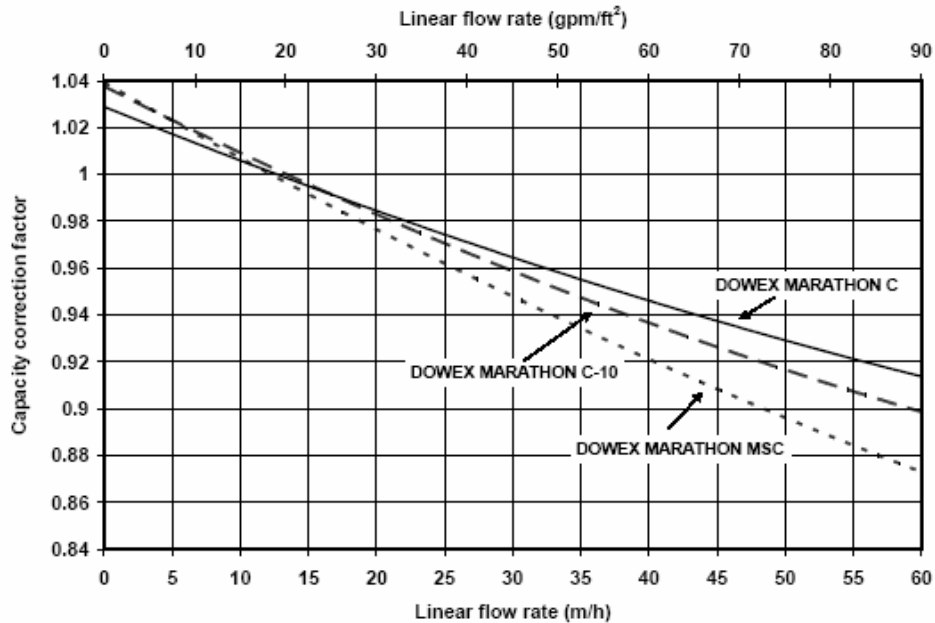
Figure 9. Correction of operating capacity for TH endpoint.



From the calculated resin operating capacity above, apply a capacity safety factor (if desired) and determine the resin volume required to produce the desired plant throughput. Design of the vessel dimensions is described as follows:

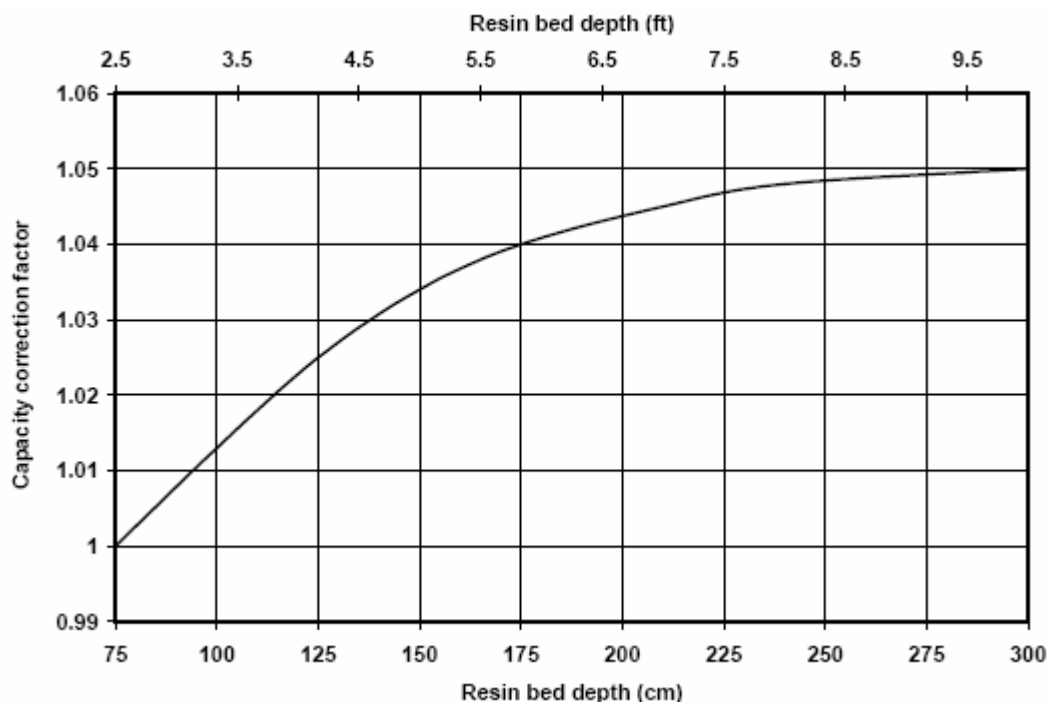
1. Choose a vessel dimension to give a service flow rate between 2–20 gpm/ft² (5 and 50 m/h). With an increase in flow rate there is an increase in hardness leakage, which may be contained within certain limits by reducing service exchange capacity. This operating capacity correction is given in Figure 10. Correct the operating capacity for flow rate and adjust the resin volume accordingly.

Figure 10. Correction of operating capacity for flow rate.



The resin bed height correction is given in Figure 11. Leakage and capacity data presented here are based on resin bed depths of 30 inches (75 cm), the minimum depth recommended. Average leakage for the run is lower for deeper beds due to continually improving water during exhaustion. The capacity correction factors are shown for up to 10-ft (300-cm) beds. Modification of the vessel dimensions should be made by iteration using Figure 10 and Figure 11 until the final design is obtained.

Figure 11. Correction of operating capacity for resin bed depth.



3.4.2 Counter-current Design

Leakage data presented in Figure 2 through Figure 4 are based on co-current operation. In designing counter-current softening systems, leakages are very low (expect <1 ppm CaCO_3), so these figures are not used.

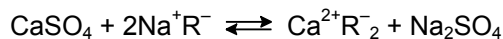
The operating capacities for counter-current systems can be taken as the same as co-current, so Figure 5 and through Figure 11 can be applied using the same methodology. In general, maximum salt efficiency is obtained at lower regeneration levels, while maximum capacity results from higher levels. The designer must balance these considerations.

3.5 Precautions

To ensure consistent performance, supply the water softener with clean water to avoid fouling the resin and equipment. If the water supply is high in iron, stabilize with polyphosphate or remove iron by oxidation and filtration before softening. High levels of residual chlorine should be avoided in order to extend resin life.

4 BRACKISH WATER SOFTENING

There are limits to the water quality that can be obtained by softening with a strong acid cation exchange resin. The hardness leakage is related to the TDS of the water being treated, since the equilibrium of the typical reaction shown in Section 3 and below is shifted to the left as the salt concentration (TDS) increases in the solution. On a practical basis, a 1 ppm hardness leakage level is obtainable with salt-regenerated strong acid resin only at solution concentrations below 5000 ppm TDS.



where $R = \text{DOWEX}^{\text{TM}} \text{MARATHON}^{\text{TM}} \text{C resin}$

Weak acid resins exhibit much higher affinity for hardness ions than do strong acid resins. So much so, in fact, that the ability to remove hardness ions from brackish (high TDS) water becomes practical. Hardness leakages of less than 1 ppm can be obtained at TDS levels as high as 30,000 ppm. This same selectivity, however, makes it impossible to effectively regenerate the resin to the sodium form by using salt as the regenerant. Instead, dilute mineral acid is used to regenerate hardness ions from the weak acid resin. This makes use of the resin's very high affinity for hydrogen ions. Regeneration with dilute mineral acid effectively and efficiently converts the resin to the hydrogen form. Conversion of the resin to the sodium form is then done by neutralization of the hydrogen form with a dilute sodium hydroxide (NaOH) solution.

Regeneration of the weak acid resin to the acid form is most effective when HCl is used. This acid does not form precipitates with the hardness ions. The use of H_2SO_4 is also possible, but great care must be taken to keep calcium sulfate (CaSO_4 , gypsum) from precipitating in and around the resin beads during regeneration. This is best prevented by using a very dilute H_2SO_4 solution and increasing the flow rate of regenerant solution. Note that the best practice and our strong recommendation is to avoid the problems associated with H_2SO_4 regeneration by using HCl.

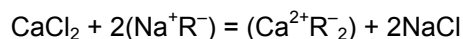
4.1 Ion Exchange Resin Specified

DOWEX MAC-3 weak acid resin is used, usually preceded by a softener using a salt-regenerated strong acid resin as the roughing stage. The resin removes hardness ions from water having a total dissolved solids (TDS) too high for complete hardness removal by strong acid cation resin.

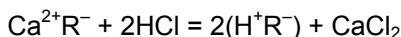
The resin selectively removes calcium and magnesium ions from high TDS water, replacing them with sodium ions. The high selectivity of the resin, which allows this removal, is also the basis for the two-step regeneration requirement. Regeneration requires removal of the hardness ions with mineral acid solution (HCl preferred) and subsequent conversion to the sodium ion by neutralization with a base, such as NaOH.

4.2 Typical Reactions and Chemicals Used

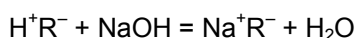
Exhaustion:



Regeneration:



Neutralization:



where $R = \text{DOWEX MAC-3}$

HCl regeneration followed by neutralization with NaOH is strongly recommended. The alkalinity in the water being treated may substitute for NaOH if it exceeds the amount of calcium and magnesium in the water.

4.3.1 Equipment Sizing

Equipment sizing can be done using Dow's CADIX software available at www.dowwatersolutions.com/cadix. Table 4 shows the TDS range where weak acid cation softening is recommended.

Table 4. TDS range for weak acid cation softening.

Feed Water ppm CaCO ₃		
TDS	Hardness	Suggested Process
<2000	<700	Strong Acid Cation Resin Single Bed
700-5000	<2000	Strong Acid Cation Resin Series Bed Counter-current Regeneration
5-10,000	<500	Weak Acid Cation Resin Single Bed
5-10,000	500-2000	Strong Acid-Weak Acid Cation Resin Series Operation
10-50,000	<2000	Weak Acid Cation Resins Series Bed

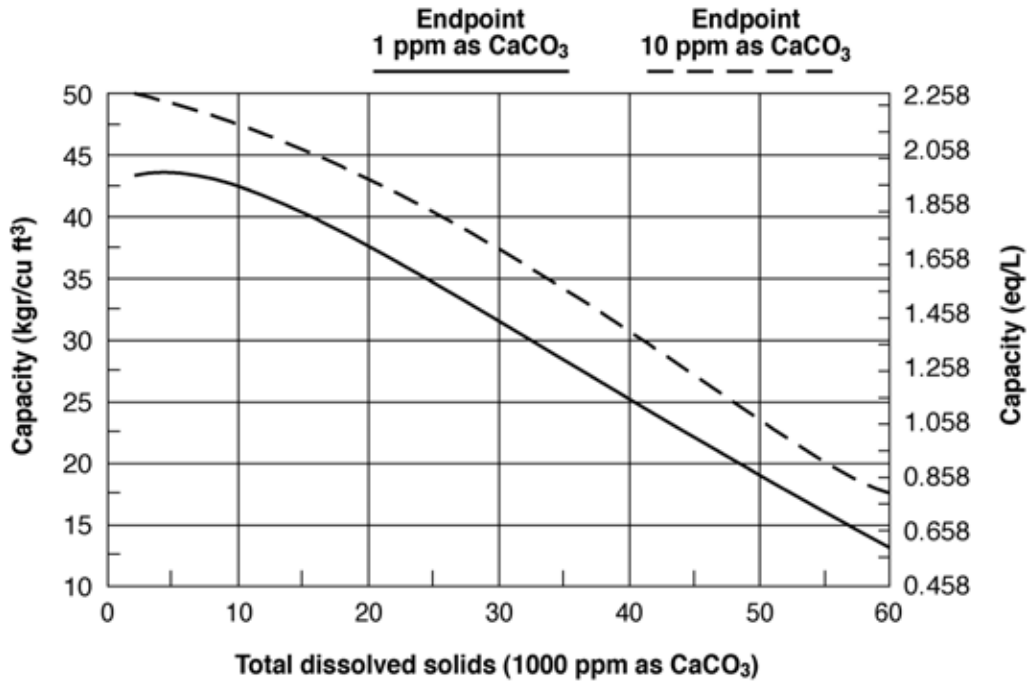
Table 5 illustrates the water quality that can be expected using a weak acid cation resin as a softener in high-TDS waters. The hardness leakage is very low. The dosage of mineral acid to obtain hardness leakage levels of less than 1 ppm is 110% of the theoretical amount of ions loaded on the resin.

Table 5. Results of high TDS water softening using weak acid resin.

Constituent	ppm as	Typical Raw Water	Softened Water
Calcium	CaCO ₃	1000	<1
Magnesium	CaCO ₃	2000	<1
Sodium	CaCO ₃	22000	25000
Total electrolyte	CaCO ₃	25000	25000
Bicarbonate	CaCO ₃	2000	2000
Carbonate	CaCO ₃	0	0
Hydroxide	CaCO ₃	0	0
Sulfate	CaCO ₃	3000	3000
Chloride	CaCO ₃	20000	20000
Nitrate	CaCO ₃	0	0
M Alk	CaCO ₃	2000	2000
P Alk	CaCO ₃	0	0
Carbon dioxide	CaCO ₃	10	10
pH	—	7.2	7.2
TDS	CaCO ₃	25000	25000

Resin operating capacity as a function of total dissolved solids is shown in Figure 13. The sodium form of the resin, when exhausted to the mixed hardness-sodium forms, must be regenerated free of sodium ions to ensure that the hardness ions have been removed. Thus, the 110% requirement is based on the total exhaustion capacity. As a rule of thumb, this is about 6.5 lb HCl/ft³ (104 kg/m³) for stripping the hardness and sodium ions from the resin, and about 7.0 lb NaOH/ft³ (112 kg/m³) for neutralization of the acid form of the resin to the sodium form in preparation for the next cycle.

Figure 13. Brackish (high TDS) softening capacity for DOWEX™ MAC-3 resin.



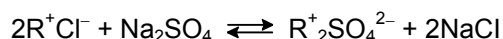
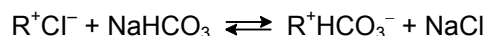
5 DEALKALIZATION: SALT SPLITTING PROCESS

5.1 Ion Exchange Resin Specified

DOWEX™ MARATHON™ A2 Type II strong base anion exchange resin in the chloride form is recommended. For best results, the dealkalizer should be preceded by a water softener using either DOWEX HCR-S or DOWEX MARATHON C strong acid cation resins.

DOWEX MARATHON A2 Type II resin reduces the bicarbonate alkalinity of a water supply by exchanging bicarbonate, carbonate, sulfate, and nitrate anions for chloride anions.

5.2 Typical Reactions and Chemicals Used



where R = DOWEX MARATHON A2 resin

Sodium chloride, NaCl, is used to regenerate DOWEX MARATHON A2 resin. Some caustic soda, NaOH, may be added (usually 1 part NaOH to 9 parts NaCl) to improve capacity and reduce leakage of alkalinity and carbon dioxide by converting bicarbonate to carbonate (Table 6). Calcium carbonate (CaCO₃) and magnesium hydroxide (Mg(OH)₂) precipitated from NaCl by NaOH can cause hardness leakage from the dealkalizer. This regenerant should be filtered for best results.

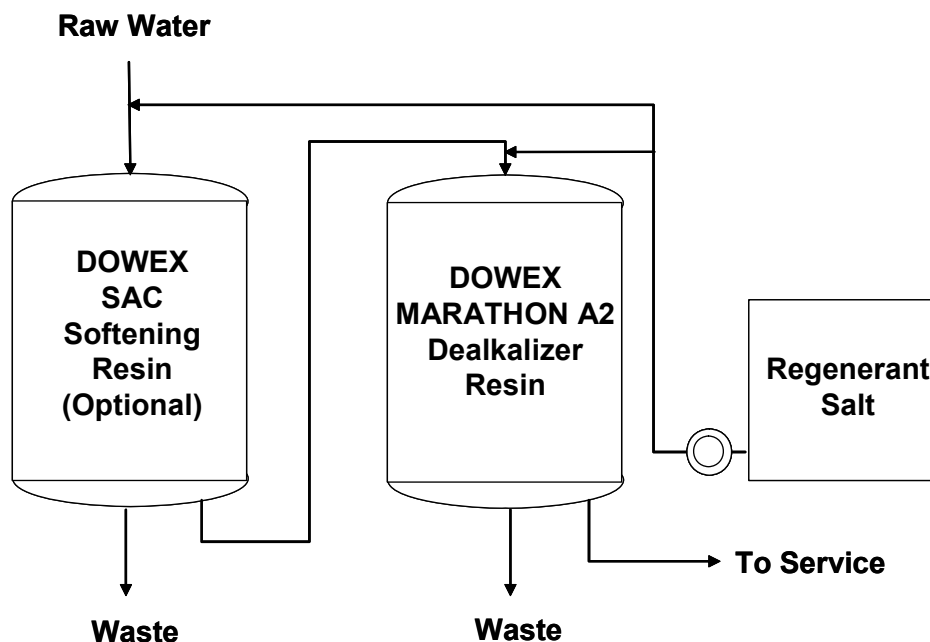
Table 6. Results of dealkalization by the salt splitting process.

Constituent	ppm as	Typical Soft Water	Dealkalized Water	
			NaCl Regeneration	NaCl/NaOH Regeneration
Calcium	CaCO ₃	Nil	Nil	Nil
Magnesium	CaCO ₃	Nil	Nil	Nil
Sodium	CaCO ₃	200	200	200
Total electrolyte	CaCO ₃	200	200	200
Bicarbonate	CaCO ₃	150	30	0
Carbonate	CaCO ₃	0	0	20
Hydroxide	CaCO ₃	0	0	0
Sulfate	CaCO ₃	25	0	0
Chloride	CaCO ₃	25	170	180
Nitrate	CaCO ₃	0	0	0
M Alk	CaCO ₃	150	30	20
P Alk	CaCO ₃	0	0	10
Carbon dioxide	CO ₂	10	20	0
pH	–	7.5	5.5	8.3
Silica	SiO ₂	10	10	10

5.3 Equipment Required

The equipment includes a vessel to accommodate DOWEX MARATHON A2 resin, with piping, valves, chemical tanks, and accessories properly engineered for optimum operation. If a supply of soft water is unavailable, a water softener should be placed ahead of the dealkalizer. The regeneration system may be built to accommodate both the softener and the dealkalizer. Figure 14 is a general flow diagram for this system.

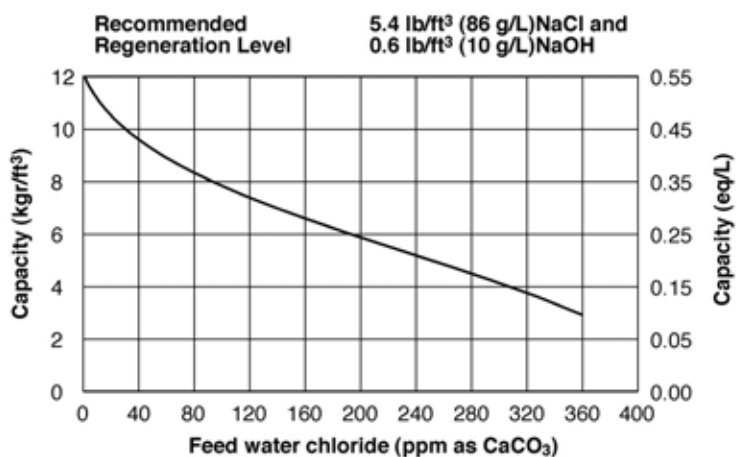
Figure 14. Dealkalization by the salt-splitting process.



5.3.1 Equipment Sizing

1. Determine the total anion content in the feed water as ppm CaCO_3 . Subtract from this value the chloride content of the feed as ppm CaCO_3 . The resulting number is the total exchangeable anion (TEA) content as ppm CaCO_3 , or divide by 17.1 to obtain grains/U.S. gallon (grpg).
2. Determine from Figure 15 the resin capacity for the TEA content as kg/ft^3 at the feed water chloride level. Figure 15 shows the approximate capacity obtained at the recommended regeneration level as a function of the chloride content of the influent water.

Figure 15. Effect of chloride on capacity of DOWEX™ MARATHON™ A2 resin in the chloride cycle.



- Calculate the capacity required to handle the TEA content of the feed for the desired feed rate and cycle length.

$$\frac{\frac{\text{gallons}}{\text{minute}} \times \frac{\text{minutes}}{\text{cycle}} \times \frac{\text{grains}}{\text{gallon}}}{\frac{\text{kilograin} \times 1000}{\text{ft}^3}} = \frac{\frac{\text{grains}}{\text{cycle}}}{\frac{\text{grains}}{\text{ft}^3}} = \frac{\text{ft}^3}{\text{cycle}}$$

- Size the bed to this volume, keeping bed depths ≥ 36 inches (0.91 m).
- Calculate the flow rate per unit volume. If this number is outside the range of 0.5–3.0 gpm/ft³ (4.0–24.0 (m³/h)/m³), modify the cycle length and resin volume to bring it within this range.

Note: These calculations can also be done via CADIX.

5.4 General Advantages

This is the simplest of the dealkalizing processes, and it is especially good for smaller installations and other places where it is desirable to avoid the handling of acid. While it is initially a larger investment than the hydrogen cycle weak acid cation resin process, it is more easily handled by unskilled operators. The procedure lends itself to automated operation with very simple controls.

5.5 Precautions

Water must be clean and free of iron to avoid fouling of the resin and equipment. Operation on hard water can give only marginal results and should be avoided when NaOH is used with NaCl for regeneration (Table 7). See handling precautions relating to NaOH (Section 12.7).

Table 7. Regenerant concentration and flow rate

NaCl	5% at 0.5 gpm/ft ³ (4.0 (m ³ /h)/m ³)
------	---

5.6 Reference Documents

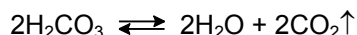
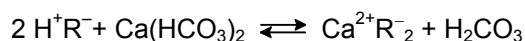
DOWEX™ MARATHON™ A2 Product Information (177-01594)
 DOWEX MARATHON A2 Engineering Information (177-01693)

6 DEALKALIZATION: WEAK ACID CATION RESIN PROCESS

6.1 Ion Exchange Resin Specified

DOWEX™ MAC-3 weak acid cation (WAC) exchange resin is recommended. This resin removes cations and associated alkalinity from water by converting alkaline salts of calcium and magnesium to the corresponding weak acid (dissolved CO₂) and subsequently removing the CO₂ by degasification.

6.2 Typical Reactions and Chemicals Used



where R = DOWEX MAC-3 resin

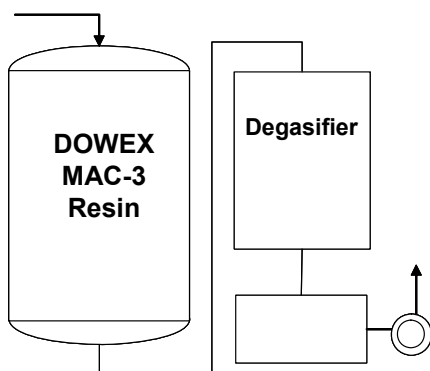
Mineral acids are used to regenerate DOWEX MAC-3 resin. HCl is preferred over H₂SO₄, due to the precipitation problems that can occur with H₂SO₄ and calcium that have concentrated on the resin. If H₂SO₄ is used as the regenerant, flow rates during regeneration must be high enough to prevent this precipitation.

6.3 Equipment Required

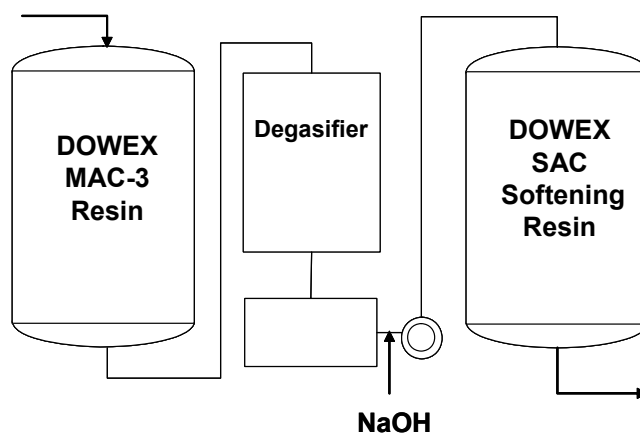
Equipment includes a vessel to accommodate DOWEX MAC-3 resin, with piping, valves, chemical tanks and accessories properly engineered for economical balance of resin capacity and hydraulic properties. This unit is usually followed by a degasifier unless the subsequent use of the product water does not require CO₂ removal (e.g., a cooling tower). This operation is often used in conjunction with a strong acid cation exchange resin as a chemically efficient hydrogen cycle process. Data presented here and in Section 7 can be used together to design such a system. Figure 16 shows the general flow diagrams for these systems.

Figure 16. Dealkalization by the weak acid cation resin process.

DOWEX MAC-3 resin followed by degasifier. Degasifier can often be eliminated in cooling tower applications.



DOWEX MAC-3 resin followed by degasifier, causing dosing, and polishing softener for low-pressure boiler feed make-up.



6.3.1 Equipment Sizing

Use CADIX available at www.dowwatersolutions.com/cadix.

6.4 General Advantages

Partial demineralization is accomplished with appropriate influent waters using a single ion exchange resin that operates at very high regeneration efficiency (near stoichiometric amounts). Alkalinity reduction is accompanied by a corresponding reduction in cations (Table 8). Best results are obtained with hard, alkaline, low-sodium waters.

Table 8. Results of dealkalization by the weak acid cation resin process.

Constituent	ppm as	Typical		
		Raw Water	Weak Acid Resin Effluent	Degasified Effluent
Calcium	CaCO ₃	100	Nil	Nil
Magnesium	CaCO ₃	50	Nil	Nil
Sodium	CaCO ₃	50	50	50
Hydrogen	CaCO ₃	0	0	0
Total electrolyte	CaCO ₃	200	50	50
Bicarbonate	CaCO ₃	150	0	0
Carbonate	CaCO ₃	0	0	0
Hydroxide	CaCO ₃	0	0	0
Sulfate	CaCO ₃	25	25	25
Chloride	CaCO ₃	25	25	25
Nitrate	CaCO ₃	0	0	0
M Alk	CaCO ₃	150	0	0
P Alk	CaCO ₃	0	0	0
Carbon dioxide	CO ₂	10	160	10
pH	—	7.5	2.0	7.5

6.4.1 Precautions

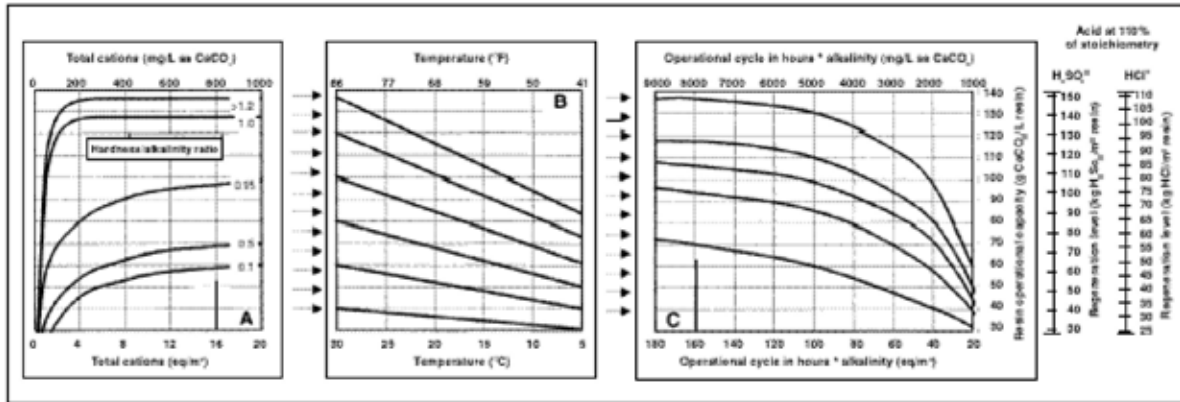
Regenerant concentrations and flow rates must be closely controlled, particularly if H₂SO₄ is used (Table 9). Weak acid cation resins are rate sensitive and operate best under constant conditions. Changes in water temperature, flow rate or composition, hardness and alkalinity levels, as well as TDS content, will change the operating capacity of the resin. These effects must be considered during the design process. Start-up of a weak acid cation resin dealkalizer to be run without mineral acid leakage requires exhaustion of the resin on the first cycle beyond the design endpoint, and then application of the design regenerant level.

Table 9. Regenerant concentration and flow rate

H ₂ SO ₄	0.3% at 1 gpm/ft ³ (8.0 (m ³ /h)/m ³)
H ₂ SO ₄	0.8–1.0% at 4.5 gpm/ft ³ (36.1 (m ³ /h)/m ³)
HCl	5% at 1 gpm/ft ³ (8.0 (m ³ /h)/m ³)

Resin capacity can be determined from Figure 17. Unless the first 15% of the treated effluent is discarded, the average hardness leakage when the hardness to alkalinity ratio (H/A) is >0.8 (as shown in Table 8 where H/A =1) will be approximately 10% of the raw water concentration. Adding a strong acid cation exchanger in the sodium form to remove residual hardness can be justified when the hardness to alkalinity ratio is >0.8.

Figure 17. Co-current operational capacity data.



*Divide by 16.0G to convert from kg acid/m³ resin to lb acid/ft³ resin

6.5 Reference Documents

- DOWEX™ MAC-3 Product Information (177-01603)
- DOWEX MAC-3 Engineering Information (177-01560)

7 DEMINERALIZATION (DEIONIZATION) PROCESS

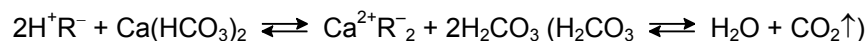
7.1 Ion Exchange Resins Specified

Weak acid cation exchange resin:	DOWEX™ MAC-3
Strong acid cation exchange resins:	DOWEX MARATHON™ C, DOWEX MARATHON C-10, and DOWEX MARATHON MSC
Weak base anion exchange resins:	DOWEX MARATHON WBA and DOWEX MARATHON WBA-2
Strong base anion exchange resins:	DOWEX MARATHON A, DOWEX MARATHON 11, DOWEX MARATHON A2, and DOWEX MARATHON MSA

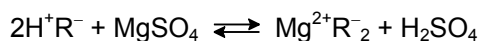
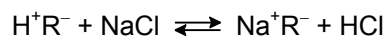
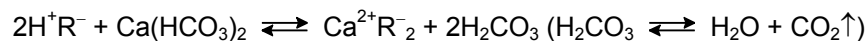
These resins remove cations and anions from water. Complete ion removal is determined by feed water composition, equipment configuration, amounts and types of ion exchange resins and regenerants used, and quality of effluent required.

The process converts all salts of calcium, magnesium, sodium, and other metal cations to their corresponding acids with cation exchange resin(s), then removes these acids with the appropriate anion exchange resin(s). The demineralization operation can be a sequential cation-anion process (single beds or layered beds) or an intimate mixture of cation and anion resins (mixed beds). A degasifier may be inserted prior to the strong base anion resin to remove carbon dioxide and thus reduce NaOH chemical consumption.

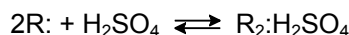
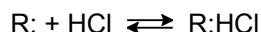
7.2 Typical Reactions and Chemicals Used



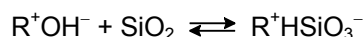
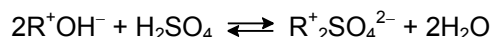
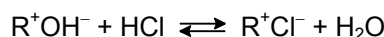
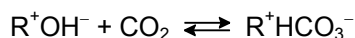
where R = DOWEX MAC-3 resin



where R = DOWEX MARATHON C, DOWEX MARATHON C-10, or DOWEX MARATHON MSC resin



where R = DOWEX MARATHON WBA or DOWEX MARATHON WBA-2 resin



where R = DOWEX MARATHON A, DOWEX MARATHON 11, DOWEX MARATHON A2, or DOWEX MARATHON MSA resin

H₂SO₄ or HCl is usually used for cation resin regeneration at a rate of 2 to 4 ppm for each ppm of cation removed. Caustic soda (NaOH) is used at a rate of 1 to 2 ppm for each ppm of acid (e.g., HCl and H₂SO₄) removed by a weak base anion resin, or 2 to 3 ppm for each ppm of either strong or weak acid anion removed by a strong base anion resin. Mixed beds normally require 15–20% higher regenerant dosages than individual beds.

In Table 10, a typical water sample is analyzed before any treatment and after each of the three main steps in demineralization. The analyses indicate which constituents are removed from the water at each stage of the process.

Table 10. Results of treatment by the demineralization process.

Constituent	ppm as	Typical Raw Water			
		Typical Raw Water	Typical Strong Acid Cation Effluent after Degasification	Typical Weak Base Anion Effluent after Degasification	Typical Strong Base Anion Effluent
Calcium	CaCO ₃	150	Nil	Nil	Nil
Magnesium	CaCO ₃	50	Nil	Nil	Nil
Sodium	CaCO ₃	50	0–5	0–5	0–5
Hydrogen	CaCO ₃	0	100	0	0
Total electrolyte	CaCO ₃	250	100	0–5	0–5
Bicarbonate	CaCO ₃	150	0	0	0
Carbonate	CaCO ₃	0	0	0	0
Hydroxide	CaCO ₃	0	0	0	0–5
Sulfate	CaCO ₃	50	50	0	0
Chloride	CaCO ₃	50	50	0–5	0
Nitrate	CaCO ₃	0	0	0	0
M Alk	CaCO ₃	150	0	0–5	0–5
P Alk	CaCO ₃	0	0	0	0–5
Carbon dioxide	CO ₂	10	5	5	0
pH	—	7.5	2.0	7.0	7–9
Silica	SiO ₂	10	10	10	0–0.1

7.3 Equipment Required

A demineralization system may consist of a number of individual ion exchange units (e.g., a two-step system would involve a cation vessel and an anion vessel) or a single vessel containing a mixture of cation and anion exchange resins (mixed bed). Also required in any demineralization system are appropriate piping, valves, chemical regenerant storage, flow controls, and other accessories properly engineered for economical balance of resin capacity and chemical efficiency. The following illustrations show the basic types of demineralization processes and which of the constituents is removed by each of the demineralizing units.

Table 11. Basic types of demineralizers with DOWEX™ resin used.

Diagram	Constituents Removed			
	Cations (Ca, Mg, Na)	Strong Acids (SO ₄ , Cl, NO ₃)	Weak Acids CO ₂ ^a	SiO ₂
<p>2 BED</p>	MARATHON™ C MARATHON C-10 or MARATHON MSC	MARATHON WBA or MARATHON WBA-2	—	—
<p>2 BED MIXED BED</p>	MARATHON C MARATHON C-10 or MARATHON MSC	MARATHON A MARATHON 11 or MARATHON MSA	MARATHON A MARATHON 11 or MARATHON MSA	MARATHON A MARATHON 11 or MARATHON MSA
<p>3 BED</p>	MARATHON C MARATHON C-10 or MARATHON MSC	MARATHON WBA or MARATHON WBA-2	MARATHON A MARATHON 11 or MARATHON MSA	MARATHON A MARATHON 11 or MARATHON MSA
<p>4 BED</p>	MARATHON C MARATHON C-10 or MARATHON MSC	MARATHON WBA or MARATHON WBA-2	MARATHON A MARATHON 11 or MARATHON MSA	MARATHON A MARATHON 11 or MARATHON MSA
<p>2 BED WITH DEGASIFIER</p>	MARATHON C MARATHON C-10 or MARATHON MSC	MARATHON A2	Degasifier + MARATHON A2	MARATHON A2
<p>3 BED WITH DEGASIFIER</p>	MARATHON C MARATHON C-10 or MARATHON MSC	MARATHON WBA or MARATHON WBA-2	Degasifier + MARATHON A MARATHON 11 or MARATHON MSA	MARATHON A MARATHON 11 or MARATHON MSA
<p>ANION SYSTEM AS IN A-F ABOVE</p>	MAC-3 MARATHON C MARATHON C-10 or MARATHON MSC	As with appropriate anion system shown in A-F above.		

^aCO₂ results from alkalinity converted by DOWEX MARATHON C, MARATHON C-10, OR MARATHON MSC resin.

7.3.1 Equipment Sizing

See Section 11.7.

Note: CADIX can also be used to perform these calculations.

7.4 Product Water Quality

If it is a process water, it is likely that complete removal of carbon dioxide and silica is unnecessary. If so, a weak base anion resin is used. If removal of carbon dioxide and silica is required, a strong base anion resin is chosen. Demineralizers can produce waters with varied quality, depending on the type of system and the water supply. They usually produce water free of suspended solids. Determination of dissolved solids by evaporation will include any organic matter that may be present in the deionized water. Water quality is often measured in terms of the amount of suspended solids, dissolved solids concentration, and conductivity ($\mu\text{S}/\text{cm}$) or resistivity ($\text{M}\Omega\cdot\text{cm}$). Since conductivity is the reciprocal of resistivity, $1 \mu\text{S}/\text{cm}$ is equivalent to $1 \text{M}\Omega\cdot\text{cm}$ and represents approximately 0.5 ppm. A mixed bed unit is required if water purity in excess of $5 \text{M}\Omega\cdot\text{cm}$ is needed. The mixed bed may be the primary unit or a polishing unit following a multiple bed system.

7.5 Product Water Quantity

Usually, if the water demand is less than approximately 50 gpm ($11.4 \text{ m}^3/\text{h}$), the plant will benefit from the simplest piece of equipment at the expense of a higher chemical operating cost. For that reason, it is common to find mixed bed demineralizers widely used for small plant requirements because both the anion and cation resin can be contained in one unit and no degasifier is used. On the other hand, when plant demands exceed 200 gpm, it is almost certain that several units will be built into the demineralizer and one will probably be a degasifier.

7.6 Other Demineralization Techniques

The various ion exchange resin combinations indicated in the flow diagrams in Table 11 represent the majority of system designs employed today. Variations from these standard designs, however, are being increasingly utilized, especially those techniques that demonstrate significant chemical regenerant utilization improvements. Two of these techniques are outlined here.

7.6.1 Counter-current Operation

This term refers to the relative flow directions of the service and regeneration cycles. As opposed to the typical downflow service and regeneration of many systems, counter-current operation is typically downflow service and upflow regeneration. The primary advantage of counter-current operation is that very low leakage can be obtained at moderate regeneration levels, thus minimizing operating and waste disposal costs. Counter-current operation is also advantageous in softening.

7.6.2 Layered Beds

A layered bed of ion exchange resin involves the use of two cation resins or two anion resins in a single unit. A cation layered bed is composed of a weak acid resin upper layer and a strong acid resin lower layer, while an anion layered bed uses either a weak base resin upper layer with a strong base resin lower layer or a strong base resin upper layer and weak base resin lower layer depending on the density of the resins. In general, the use of layered beds allows some of the advantages of weak acid and weak base resins to be realized in the operation of a single cation or anion bed. Improved regenerant efficiencies and, in some cases, improved operating capacities over the corresponding strong acid or strong base units alone are attained. The layered bed concept is made possible by the density and particle size differences between the resins used. Upon exhaustion, the backwashing operation separates the resin layers that may have become partially mixed during service. In order for the full advantages of the weak acid and weak base resins to be realized, good resin separation is important.

7.7 Reference Documents

DOWEX™ MAC-3 Product Information (177-01603)
DOWEX MAC-3 Engineering Information (177-01560)
DOWEX MARATHON™ C Product Information (177-01593)
DOWEX MARATHON C Engineering Information (177-01686)
DOWEX MARATHON C-10 Product Information (177-01800)
DOWEX MARATHON MSC Product Information (177-01786)
DOWEX MARATHON WBA Product Information (177-01592)
DOWEX MARATHON WBA Engineering Information (177-01691)
DOWEX MARATHON WBA-2 Product Information (177-01788)
DOWEX MARATHON A Product Information (177-01595)
DOWEX MARATHON A Engineering Information (177-01687)
DOWEX MARATHON 11 Product Information (177-01585)
DOWEX MARATHON 11 Engineering Information (177-01690)
DOWEX MARATHON A2 Product Information (177-01594)
DOWEX MARATHON A2 Engineering Information (177-01693)
DOWEX MARATHON MSA Product Information (177-01787)
DOWEX MARATHON MSA Engineering Information (177-01725)

8 THE UPCORE™ COUNTER-CURRENT REGENERATION SYSTEM

The UPCORE system from Dow Water Solutions is a modern downflow service, **UP**flow **CO**unter-current **RE**generation packed bed technology for ion exchange demineralizers, water softeners, and other applications. The technology is self-cleaning and can be applied to new plant designs and also to rebuilding and upgrading existing installations. Dow has developed a range of uniform DOWEX™ UPCORE Mono ion exchange resins for this system.

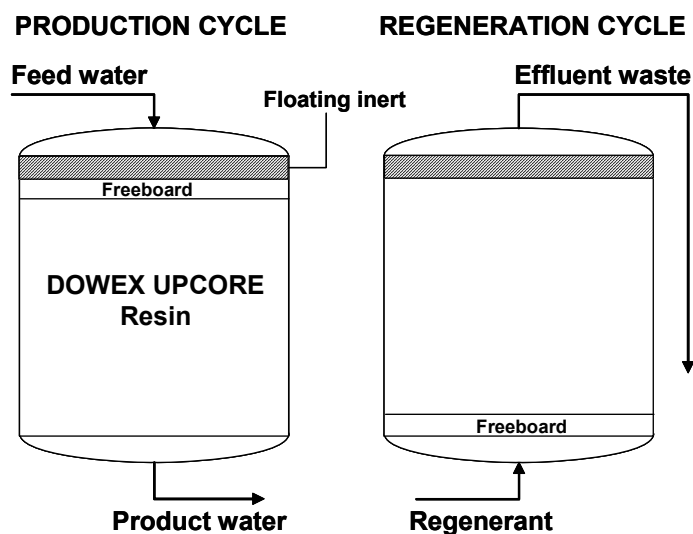
8.1 Process Description

The vessel is almost completely filled with ion exchange resin, and there is a small freeboard above the resin bed to allow for resin movement and swelling. The top collector/distributor system in the vessel is surrounded by a shallow layer of floating inert material that allows free passage of spent regenerants and rinse water as well as resin fines and other suspended solids, while retaining the normal-size resin beads in the vessel. Vessels designed for the UPCORE system are therefore straightforward and inexpensive. If existing co-current resin beds are converted to this counter-current technology, system modifications are minimal and plant capacity can be nearly doubled.

With the UPCORE system, the service (loading) cycle operates downflow, so the settled resin bed is insensitive to fluctuations in feed flow because the bed stays fixed against the bottom distribution system. If feed flow is interrupted, there is no danger that ionic stratification will be disturbed. The highly regenerated polishing zone at the bottom of the bed remains intact and uncontaminated by exhausted beads higher up in the bed.

During upflow regeneration, the resin bed is first lifted as a fixed bed and compacted against the floating inert resin layer with dilution water. Once compacted, the regenerant then passes upflow at a rate sufficient to maintain the resin in the packed state. So the upflow compaction and regeneration steps serve two purposes: cleaning the vessel of resin fines and other particulates and reactivating the ion exchange sites on the resin. No separate backwash step is needed. Suspended solids and resin fines are automatically removed during the compaction step of each regeneration cycle. Figure 18 illustrates service and regeneration cycles with the UPCORE system.

Figure 18. Service and regeneration cycles with UPCORE system.



8.2 Self-Cleaning Ability

Resin beds operated with UPCORE™ technology are self-cleaning. There is no need for backwashing facilities to prevent problems of resin fines or other particle accumulation. Suspended solids in the feed water are filtered out during the service cycle and accumulate at the top surface of the resin bed. At the start of the regeneration compaction step, resin fines and suspended materials (filtered out on the surface during the service cycle) are effectively removed from the resin bed because of a highly efficient hydrodynamic shear effect. During the settling step, particulates migrate upward and accumulate at the top surface of the resin bed. These fines remain at the top of the packed bed during the subsequent downflow service run and are then swept from the bed during the compaction step of the next upflow regeneration cycle. The layer of floating inert material and the correct choice of collector system allow the suspended solids and resin fines to pass through while retaining the normal-size resin beads. This ensures that pressure drop across the bed is kept at a constant level and does not continuously increase as it can in other counter-current designs. Controlling pressure drop reduces the risk of channeling of flow through the bed (which reduces operating capacity) and excessive resin attrition.

Because of the self-cleaning ability, there is no specific need for a separate backwash tank. For more information on suspended solids removal in the UPCORE system, refer to A. Medete paper listed in Section 8.6.

8.3 Regeneration Cycle

Step 1. Compaction: At the end of the service cycle, water flows up from the bottom distributor system, causing the resin bed to compact against the inert material at the top of the vessel. The resin bed is initially compacted against the inert beads by an upflow stream of water. The resin particle size and density, the amount of freeboard, and the water temperature determine the flow rate needed for compaction. It takes only 2 or 3 minutes for the bed to fully compact. The water is normally demineralized (or decationized for the cation unit) to prevent ionic contamination of the polishing zone.

Steps 2 and 3. Injection/displacement: Once compacted, the resin bed remains in place even if the flow rate is reduced. This allows regeneration to take place at the optimum flow rate in terms of regenerant contact time and concentration. The total quantity of regenerant chemical per volume of resin is approximately half as much as the amount that is typically used for co-current designed systems. A displacement or slow rinse cycle follows the regeneration step of the UPCORE system. The flow of displacement rinse water is in the upflow direction at a rate equal to that used during regeneration. Upflow displacement rinse follows, and in the final step, the bed is allowed to settle.

Step 4. Settling: After the displacement rinse is completed, the flow is stopped and the resin bed is allowed to fall freely. It takes between 5 and 10 minutes for the compacted bed to settle. During settling, the bed falls to the bottom of the vessel layer by layer. Most importantly, the polishing zone is not disturbed by the settling phase.

As the freeboard moves upward through the resin bed, a classification of the resin takes place and any resin fines are kept in suspension. This settling results in a loosening of the bed and allows the resin fines to move with the freeboard and rise to the top, where they are removed in the next compaction step. Carryover of resin fines to the next vessel during the service cycle is thus prevented.

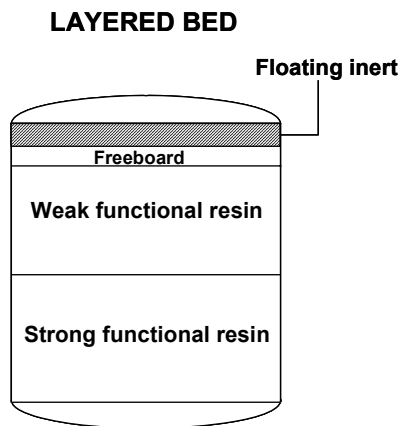
Step 5. Fast final rinse: The regeneration cycle is completed with a fast final rinse or the recirculation of rinse water between the cation and anion resin beds. In the fast final rinse step, water flows down from the top of the vessel at a rate equal to the service flow. The water for the final rinse step can be filtered for cation resins; however, it should be decationized or demineralized for anion resins. To save service water, the final rinse can also be recirculated from the cation to the anion vessel at the service cycle flow rate.

8.4 UPCORE™ and the Layered Bed Anion Option

A layered bed anion configuration is a highly cost-effective way to take advantage of the high exchange capacity of the weak base anion resin to remove free mineral acidity and high molecular weight dissolved organic species. This top layer of weak base resin serves to protect and optimize the capacity and service life of the strong base anion resin for silica removal. Only a single vessel is needed, and the vessel can be designed without a middle plate (Figure 19) because the separation of the resins is ensured by the difference in the particle size distribution and resin density. The weak base naturally floats on top of the strong base resin.

Furthermore, the UPCORE system can be installed in layered bed configurations without major modification to existing vessels, and it is possible to readily optimize the ratio of layered resin volumes in the event of changes in the raw water supply source.

Figure 19. Vessel design without a middle plate.



8.5 Comparison with other Regeneration Systems

Ion exchange regeneration technology has developed over the years from the early co-current regenerated systems to counter-current block systems and counter-current packed bed technology, including the Dow UPCORE system. The purpose of this review is to describe the different technologies and to compare their characteristics and performance.

8.5.1 Co-current Regeneration System

This is the simplest system where a resin is regenerated in the same downwards direction as the service flow (Table 12). The vessel has a large freeboard to allow expansion of the resin bed when backwashing is carried out to remove suspended solids and resin fines. Co-current regeneration systems will generally produce water of much lower quality than counter-current systems, with typical leakage values approximately 10 times higher.

Table 12. Characteristics of co-current regeneration system.

Advantages	Disadvantages
Proven process	High chemical cost
Reliable	Lower water quality
Easy resin cleaning	Lower productivity

8.5.2 Counter-current Regeneration Systems

In these systems, the regenerant is applied in the opposite direction to the service flow. This has the advantage of providing better water quality (lower ionic leakage), higher chemical efficiency, and reduced waste water. In order to obtain low leakage levels from a counter-current regenerated resin system, the contaminating ions must be kept from contacting the resin in the effluent end of the column during regeneration and rinse. Conditions that would disrupt the resin bed configuration must be avoided. Backwash frequency also must be minimized.

Block systems and packed beds are the main types of counter-current systems:

Blocked systems: These systems include air hold down, water hold down, and inert mass blocked. The service flow is downwards and regeneration is upflow (Table 13). To avoid disturbance of the resin polishing zone at the bottom of the vessel, the resin bed is held down (blocked) by air pressure, water flow, or an inert mass in the top part of the vessel. The regenerant passes up through the resin and out of a collector system in the middle part of the vessel.

Table 13. Characteristics of blocked counter-current regeneration systems.

Advantages	Disadvantages
High chemical efficiency	High capital cost
Excellent water quality	Complex regeneration
In situ backwash	Sensitive system (intermediate distributor)
	Backwash required every 10-15 cycles requiring double regenerations

Upflow service packed bed systems: These systems may be upflow service with downflow regeneration or downflow service with upflow regeneration (Table 14).

Table 14. Characteristics of upflow counter-current regeneration systems.

Advantages	Disadvantages
Optimized chemical efficiency	Sensitive to flow rate
Excellent water quality	Risk of fines carry over
High productivity	Intermediate plate needed for layered beds
	Suspended solids accumulate in the resin bed
	External backwash operation required
	Extra capital cost for backwash vessels

8.5.3 UPCORE™ Packed Bed System

This system has upflow regeneration and downflow service. The UPCORE system offers all the advantages of counter-current regeneration technology in addition to:

- Simple construction and control
- Self-cleaning mechanism
- Insensitivity to production flow variations and stops
- No risk of carry-over of resin fines
- Layered bed anion design without the need for a separating nozzle plate
- Economically more suitable for co-current retrofits

Converting a co-current system to UPCORE™ offers the following advantages:

- Reduce regenerant chemical costs up to 55%
- Nearly double the plant capacity
- Almost 50% less system downtime
- Better water quality ($< 2 \mu\text{S/cm}$)
- Effluent volume reduction of up to 50%
- Less regeneration time and expense
- Service water consumption savings of up to 50%

8.6 Reference Documents

Medete, A., Proceedings of IEX 2000, Cambridge, UK, July 2000, p. 69.

9 ION EXCHANGE RESIN OPERATIONAL INFORMATION

9.1 Storage and Handling of Ion Exchange Resins

9.1.1 Storage of New, Unused Resin

Standard demineralizing and softening resins experience minimal change in chemical properties over a 2-year shelf life. Storing anion resins in the hydroxide form longer than 1 year is not recommended.

Resins should be stored in their original, unopened packaging in a cool, dry area. An indoor storage facility with climate control between 32–90°F (0–30°C) should be used for the best results.

Storage temperatures above 90°F (30°C) can cause premature loss of capacity for anion resins, particularly those stored in the hydroxide form. Although cation resins can withstand higher temperatures, up to 120°F (50°C), it is best to store all resins under similar conditions. Storage temperatures below 32°F (0°C) can cause resin freezing, and temperatures below 0°F (–18°C) should be avoided. Tests of DOWEX resins under repeated freeze-thaw cycles show that bead damage can occur, so frozen resin must be thawed before safe loading can take place. Frozen resin should be thawed out completely under room-temperature conditions before loading and use.

Reference Document: Tech Facts 177-01750 Storage of Used Resin

As with new resins, used resins should be stored under climate-controlled conditions, where feasible, to maximize the life of the resins.

Additionally, care should be taken that resins are not exposed to air because they will dry out and shrink. When rehydrated, these resins are susceptible to bead breakage due to rapid reswelling of the resin beads. If resin beads are allowed to become dry, they should be hydrated with a saturated NaCl solution. The high osmotic pressure will minimize the rapid reswelling. The salt can then be removed by successive dilutions to prevent rapid change in osmotic pressures and resulting bead breakage.

Biological growth problems can be caused by inactivity of used resin during extended storage. In order to minimize the potential for biofouling, inactive systems should be stored in a biostatic solution such as concentrated NaCl. This complete exhaustion is acceptable for most demineralizer applications but undesirable for very high purity applications. In addition to minimizing biogrowth, the concentrated brine solution will prevent freezing. The recommended procedure is as follows:

1. After exhaustion and a thorough backwash, the resin is ready for lay-up.
2. Apply a 15–25% NaCl solution to the bed and fill the vessel so that no air is present. The salt solution will minimize biogrowth.
3. Upon reactivation of the vessel, the resin will need to be rehydrated by successive washes of less concentrated salt to minimize osmotic shock.
4. Prior to service, the beds must undergo a double or triple regeneration.

Reference Document: Tech Facts 177-01750

9.1.2 Safety Aspects on Handling

Ion exchange resins are generally not classified as hazardous materials, although resins in the hydrogen or hydroxide form are irritating to the eyes. A certain amount of attention should be paid during storage, handling, and processing of the resins. Material Safety Data Sheets (MSDS) are available from The Dow Chemical Company.

When sampling and installing, resin can emerge with considerable force in some cases. Care should also be taken to clean up spills of ion exchange resins because the small beads are very slippery when stepped on.

9.2 Loading/Unloading Resins

Loading and unloading ion exchange resins from vessels can be done in a variety of ways, depending on the equipment design and procedures developed at the site. One simple means of transferring resin is through the use of eduction systems.

9.2.1 Preliminary Inspection

1. Before loading the resins, make a detailed inspection of the empty vessel.
2. Remove all debris of previous resins or foreign material.
3. Clean up distributors and inspect all laterals, splash-plates, and nozzles for damage or plugging.
4. Inspect the rubber lining, if present, for integrity, and perform a spark test, if possible.
5. Whenever possible, check the pressure loss of the empty vessel at nominal flow rate and observe the flow patterns for uniformity.

9.2.2 Loading Procedure for Single-Bed Ion Exchange Vessels

For co-current and block systems:

1. Fill vessel with sufficient water (approximately 1/3 vessel height) to allow settling and avoid resin damage.
2. Load the ion exchange resin by pouring it from the top or by the use of a vacuum eductor.
3. Backwash the resins for 30 min, according to the manufacturer's recommended flow rates. Backwash expansion as a function of flow, temperature, and ionic form is available on the individual datasheets for DOWEX™ resins.
4. Close vessel and carry out double regeneration.

Note: Weak base anion resins should be stored in solution overnight to wet- the resins prior to backwash. Alternatively, if an overnight soak is not feasible, the bed can be operated for one cycle before a backwash is performed. This will allow the resin to be wetted during operation, but care should be taken that a backwash is not performed on unwetted resin, as resin loss will occur.

For packed-bed, counter-current regeneration systems, the procedure is the same as above with the following modifications:

1. The freeboard should be calculated on the basis of the total resin bed height, taking the volume of the resins in the most swollen form. For a strong acid cation, this is the fully regenerated hydrogen form; for strong base anions, the fully regenerated hydroxide form; and for weak base anions, the exhausted form.
2. Add approximately half of the resin and backwash as above.
3. Add the floating inert resin and then load the remaining resin on top.

Reference Document: Tech Facts 177-01756

9.2.3 Loading Procedure for Layered-Bed Anion Resins

For co-current and block systems:

1. Fill vessel with sufficient water (approximately 1/3 vessel height) to allow settling and avoid resin damage.
2. Load strong base anion resin in the chlorine form.
3. Backwash at 2.5–3.5 gpm/ft² (6–8 m/h) for 30 min.
4. With 3 ft (1 m) of water above the strong base anion, load weak base anion resin and soak overnight to ensure wetting of the resin. Backwash at 0.5–0.75 gpm/ft² (1.5–2 m/h) for 30 min.
5. Alternatively, if an overnight soak is not feasible, the bed can be operated for one cycle before a backwash is performed. This will allow the resin to be wetted during operation, but care should be taken that a backwash is not performed on unwetted resin, as resin loss will occur.
6. Close vessel and carry out double regeneration on both resin components.

For packed-bed, counter-current regeneration systems, the procedure is the same as above with the following modifications:

1. The freeboard should be 5% of the total resin bed height, taking the volume of the resins in the most swollen form. For the strong base anion, this is the fully regenerated hydroxide form, and for the weak base anion, the exhausted form.
2. Before adding the weak base resin, add the floating inert resin on top of the strong base anion and then load the weak base resin on top.

Reference Document: Tech Facts 177-01763

9.2.4 Loading Procedure for Regenerable Mixed-Bed Resins

These procedures are specifically designed for equipment which is internally regenerated, with an interface collector between the cation and anion layers.

1. Fill vessel with sufficient water (approximately 1/3 vessel height) to allow settling and avoid resin damage.
2. Load cation resin to about 2 in. (5 cm) below final desired level.
3. Backwash cation at 5–6 gpm/ft² (12–15 m/h) for 30 min.
4. Settle and drain bed to 2–4 in. (5–10 cm) above resin surface and fill remaining cation resins up to the level of the central collector (if in the hydrogen form) or 1–2 in. (3–5 cm) below if in the sodium form. Carry out a second backwash for 10 min and settle. Ensure that the resin surface is even and at the correct level.
5. With 3 ft (1 m) of water above the cation resin, load anion resin. Backwash at 2 gpm/ft² (5 m/h) for 5 min.
6. If anion resin is in the chloride form or cation resin is in the sodium form, carry out double regeneration on both resin components.
7. Rinse resins with flow from top and bottom, with removal of rinse water through the central collector, for 30 min.
8. Reduce water level to about 2 in. (5 cm) above the resin bed and air mix for 15–20 min.

Reference Document: Tech Facts 177-01757

9.2.5 Start-up Operation

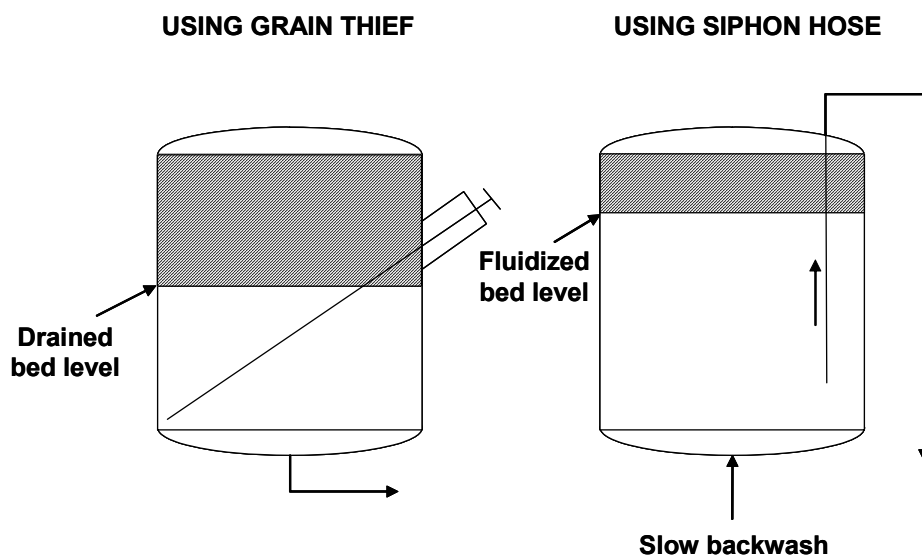
Start the run and monitor rinse down until the specified conductivity, silica, and TOC (if necessary) are achieved.

For regenerable mixed bed, resin clumping may still be present if the required water quality is not reached. To eliminate this, the mixed bed should be run for a minimum of 5 h and then a further 15-min air mix should be carried out at the end of the service run before backwashing to optimize resin mixing. Do not try to separate new or freshly regenerated resins.

9.3 Resin Sampling

A representative sample of ion exchange resins in vessels is necessary for accurate resin analyses. Ideally, a sample is taken throughout the vessel and mixed well to represent the overall bed. Several devices have been developed and used over the years to get such a core sample (Figure 20).

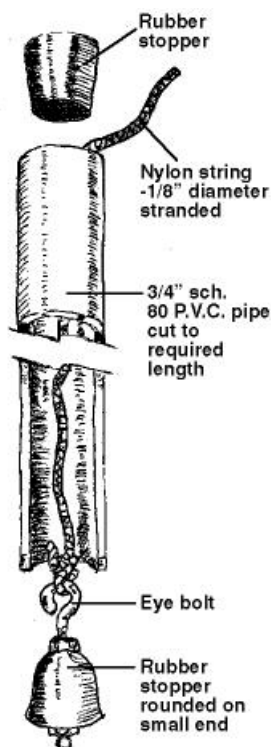
Figure 20. Examples of devices for obtaining a core sample.



An example procedure to obtain a representative sample of a resin bed from the top of the bed to the bottom with minimum equipment expense is as follows:

1. Build the device as shown in Figure 21. It is important that the lower stopper be rounded or it will not seat properly. A rubber ball may be substituted in place of the stopper, but its diameter must be larger than the pipe diameter. Other required equipment:
 - Clean 2–3 gal (approximately 10-L) plastic bucket
 - Plastic 1 qt (1-L) sample jars
 - Plastic storage bags for secondary leak containment

Figure 21. Example of device for obtaining a sample from top to bottom of a resin bed.



2. Open access to the resin vessel. This is a good time also to measure the resin depth and inspect the upper distributors. It is not always necessary to remove the manway. If there is a nozzle larger than 2 in. (5 cm), it can be used for this procedure.
3. Drain the excess water in the vessel to resin level. Make sure that no free acid or caustic is present. If necessary, rinse the resin to ensure the resins are at neutral pH.
4. Allow the lower stopper to extend 6 in. (15 cm) from the bottom of the polyvinyl chloride (PVC) pipe. Use the upper stopper to hold the string in this position.
5. Using a slow up-and-down motion, insert the device into the resin bed slowly. This must be done slowly to allow the resin level to equalize in the pipe. Inserting the device too fast will result in a sample of only the bottom portion of the bed.
6. When the device hits bottom, pull it back 2–3 in. (5–8 cm) and pull the string to seat the lower stopper. Pushing down on the pipe will aid in seating the stopper. Stretch the string tight and insert the upper stopper to hold it.
7. Remove the device from the bed and lower the bottom end of the pipe to a person on the floor. Remove the upper stopper. Remove the lower stopper and allow the resin to discharge into the bucket.
8. Pour deionized water in the top of the pipe to rinse the resin out of the pipe. Repeat the procedure as many times as required to obtain approximately 1 qt (1 L) of resin. Pour collected resin into 1 qt (1 L) plastic sample bottles. Seal the sample bottles with tape and place in plastic storage bags for secondary leak containment prior to packaging.
9. Proper labeling is essential. If resins are to be shipped for testing, label the bottle with company name, plant name, contact name and phone number, resin name, and bed identification and number. Also indicate whether the sample is regenerated or exhausted.
10. Send the resin samples to your resin testing supplier. Remember to include system information as well as which tests should be performed on the resin. For questions about Dow’s resin testing services, please contact your Dow representative and ask about DIRECTORSM Services.

Reference Document: Tech Facts 177-01758

9.4 Analytical Testing of Ion Exchange Resins

Dow Water Solutions tests new and used ion exchange resins under the DIRECTOR Services program. Table 15 lists the analyses available.

Table 15. Analyses available from Dow Water Solutions.

Standard Characteristics	Identification of Fouling	Dynamic Performance
Total exchange capacity	Organic fouling	Anion resin kinetic response
Total exchange capacity as received (TEC as received)	Calcium fouling	Weak base operating capacity
Strong base (salt-splitting) capacity (SSC)	Iron fouling	Weak base rinse volume
Strong base (salt-splitting) capacity as received (SSC as received)	—	—
Weak base capacity (WBC)	—	—
Water retention capacity (WRC)	—	—
Water retention capacity as received (WRC as received)	—	—
Microscopic bead examination	—	—
Particle size distribution	—	—

Reference Document: Service Information 177-01767

9.5 Backwash of an Ion Exchange Resin Bed

If suspended solids in the feed stream are not completely removed by pretreatment, the ion exchange resin bed will act as a filter during the service cycle. As solids accumulate at the top of the bed and move

down into the bed, water can begin to channel through the resin bed, causing a portion of the bed to be unused, ultimately resulting in a lower bed capacity. For this reason, the resin bed is backwashed prior to regeneration to remove the filtered solids and reclassify the bed.

The backwash flow rate must be sufficient to expand the resin bed and remove the particulate without losing resin from the top of bed. When the backwash flow is controlled at the backwash inlet, pressure is sometimes released within the resin bed, causing the evolution of dissolved gases in and around the resin particles. These gases tend to adhere to the resin particles and float them from the column. This problem is alleviated by keeping the column under pressure during backwash.

In locations where water temperature fluctuates seasonally, water viscosity will change with temperature, increasing as the temperature drops, thus affecting the expansion of the resin bed during the backwash operation. Failure to adjust flow rates of the backwash operation with temperature fluctuations can result in either insufficient backwash or loss of resin. Backwash flow rates as a function of temperature are given in the individual datasheets and engineering brochures for DOWEX™ resins.

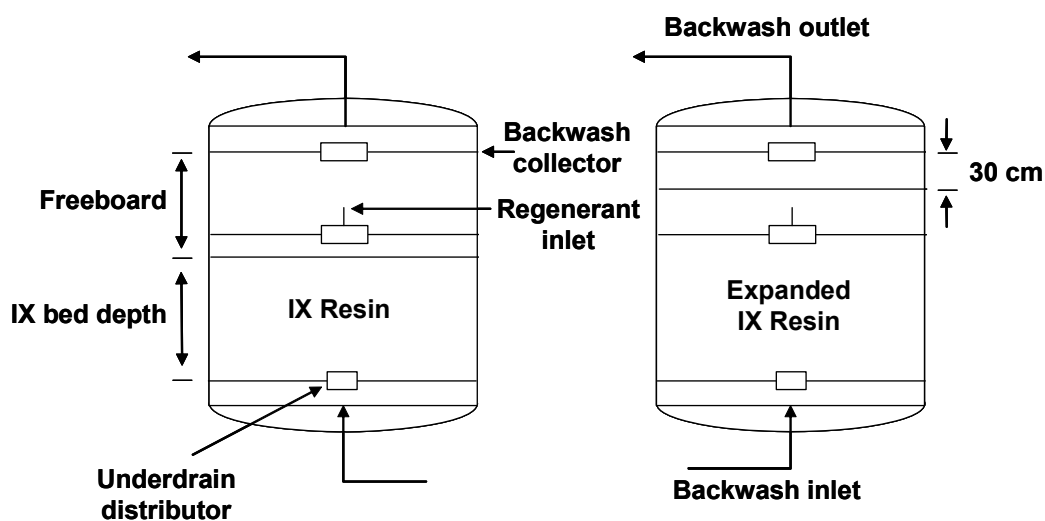
The percent expansion for an ion exchange vessel can be calculated using the formula below:

$$\% \text{Expansion} = \frac{\text{Fluidized Height}}{\text{Settled Bed Depth}} \times 100$$

Backwash recommendations are as follows:

1. Expand the resin bed with a uniform flow of water sufficient to wash out particulates:
 - 80–100% bed expansion for conventional polydispersed resins
 - 60–80% bed expansion for uniform particle sized resins
2. Continue flow for two to three displacements of the unit freeboard volume.
3. Position the backwash expansion outlet distributor at the recommended expansion point plus 12 in. (30 cm).
4. Maintain constant backwash water temperature year round, or adjust the backwash flow rate according to the fluctuating water temperature.
5. Use degassed backwash water or operate the backwash under pressure.
6. For mixed beds, the backwash flow should be sufficient to expand the cation resin a minimum of 20% for proper removal of particulate from the mixed bed.

Figure 22. Diagram of backwash procedure.



Reference Document: Tech Facts 177-01753

9.6 Resin Stability and Factors

Ion exchange resins are manufactured for extended use. There are, however, a number of factors that can impact resin life. Major factors are described in the following sections.

9.6.1 Temperature

All ion exchange resins have a recommended maximum operating temperature as indicated in their product datasheets. Operation of ion exchange resins at elevated temperatures can cause degradation of the functional sites and loss of ion exchange capacity. For DOWEX™ resins, the following guidelines have been established to minimize the chances of premature degradation (Table 16 through Table 18).

Table 16. Guidelines for strong acid cation resins.

Resin Type	Na Form Maximum	H Form Maximum
8% gel	250°F (120°C)	250°F (120°C)
10% gel	265°F (130°C)	265°F (130°C)
Macroporous	300°F (150°C)	300°F (150°C)

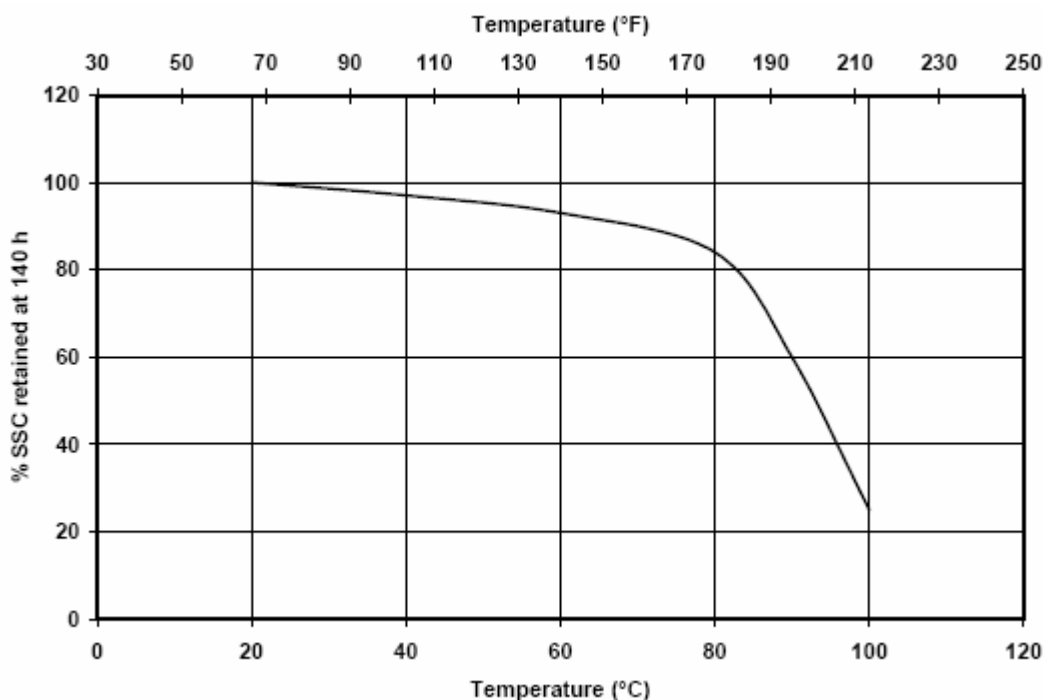
Table 17. Guidelines for strong base anion resins.

Resin Type	Cl Form Maximum	OH Form Maximum
Type 1	212°F (100°C)	140°F (60°C)
Type 2	160°F (70°C)	95°F (35°C)
Acrylics	120°F (50°C)	95°F (35°C)

Table 18. Guidelines for weak functionality resins.

Resin Type	Maximum
Weak base anion	212°F (100°C)
Weak acid cation	250°F (120°C)

These temperature maxima are intended only as guides. Thus, a temperature limitation does not mean that the resin will be unstable above and stable below this temperature. It should also be recognized that thermal degradation is proportional to the product of time and temperature. Thus, an occasional excursion for a brief time to a temperature above the maximum may result in little or no loss in performance. When exposed to higher than the recommended temperature, however, the resin will often lose its functional groups, which will result in loss of capacity and reduced resin life (Figure 23).

Figure 23. Type 1 strong base anion resin: salt splitting capacity loss vs. temperature.

Reference Document: Tech Facts 177-01751

9.6.2 Oxidation

Exposing an ion exchange resin to a highly oxidative environment can shorten resin life by attacking the polymer crosslinks, which weakens the bead structure, or by chemically attacking the functional groups. One of the most common oxidants encountered in water treatment is free chlorine (Cl_2). Hydrogen peroxide (H_2O_2), nitric acid (HNO_3), chromic acid (H_2CrO_4), and HCl can also cause resin deterioration. Dissolved oxygen by itself does not usually cause any significant decline in performance, unless heavy metals and/or elevated temperatures are also present to accelerate degradation, particularly with anion exchange resins.

When a strong base anion resin experiences chemical attack, the polymer chain usually remains intact, but the quaternary ammonium strong functional group (trimethylamine for type 1 anion resins) splits off. Alternately, the strong base functional groups are converted to weak base tertiary amine groups, and the resin becomes bifunctional, meaning it has both strong base and weak base capacity. The decline in strong base (salt splitting) capacity may not be noted until more than 25% of the capacity has been converted.

Although weak base anion resins are more stable than strong base anion resins, they can oxidize and form weak acid groups. When this occurs, the resin tends to retain sodium and requires a greater than normal volume of rinse water following regeneration.

Cation exchange resins are more thermally stable than anion exchange resins. Chemical attack on a cation exchange resin usually results in the destruction of the polymer crosslinks, resulting in an increase in water retention capacity and a decrease in the total wet volume exchange capacity. Although it is not possible to accurately predict resin life when other factors are considered, the following guidelines for feed water chlorine levels will maximize the life of cation resins (Table 19).

Table 19. Recommended maximum free chlorine levels (ppm as Cl₂).

Feed Temperature °F (°C)	Gel Standard Crosslink	Gel High Crosslink	Macroporous
40–50 (5–10)	0.3	0.5	1.0
50–60 (10–15)	0.2	0.3	0.8
60–70 (15–20)	0.1	0.2	0.6
70–85 (20–30)	< 0.1	0.1	0.5
>85 (>30)	Absent	< 0.1	< 0.5

When strong acid cation resins are operated in higher chlorine environments, shorter resin life will be expected. The effect of free Cl₂ is additive, so the reduction in resin lifetime should be proportional to the increase in the level of chlorine in the feed. For example, if a standard gel cation treating water at 40–50°F (10–15°C) has a lifetime of 10 years with the recommended <0.2 ppm free Cl₂ in the feed, the lifetime would be reduced to about 6 years if the level of free Cl₂ were to increase 5 times to 1 ppm.

Reference Document: Tech Facts 177-01754

9.6.3 Fouling

Irreversible sorption or the precipitation of a foulant within resin particles can cause deterioration of resin performance. The fouling of anion exchange resins due to the irreversible sorption of high molecular weight organic acids is a well-known problem. Extensive experience in deionization has demonstrated that it is better to prevent fouling by removing the foulant before the water flows through the resin beds, rather than try to clean the foulant from the resin. Where fouling conditions are likely, proper resin selection can minimize resin fouling. Although fouling rarely occurs with cation exchange resins, difficulties due to the presence of cationic polyelectrolytes in an influent have been known to occur. Precipitation of inorganic materials, e.g. CaSO₄, can sometimes cause operating difficulties with cation exchange resins. See Section 10.

Silica fouling: Silica (SiO₂) exists in water as a weak acid. In the ionic form, silica can be removed by strong base anion exchange resins operated in the hydroxide cycle. Silica can exist as a single unit, (reactive silica) and as a polymer (colloidal silica). Colloidal silica exhibits virtually no charged ionic character and cannot be removed by the ionic process of ion exchange. Ion exchange resins do provide some colloidal silica reduction through the filtration mechanism, but they are not very efficient at this process.

Silica is a problem for high-pressure boilers, causing precipitation on the blades, which reduces efficiency. Both types of silica, colloidal and reactive, can cause this problem.

Both reverse osmosis and ultrafiltration are effective in removing colloidal silica. FILMTEC™ reverse osmosis membranes offer the additional advantage of substantial reduction (98%+) of reactive silica as well. Coagulation techniques in clarifiers can be very effective at removing colloidal silica.

Dem mineralizers with weak and strong base anion units can experience silica fouling because of the use of waste caustic from the strong base anion vessel to regenerate the weak base anion resin during thoroughfare regeneration. To avoid this, most of the impurities from the strong base anion resin are dumped to the drain before the thoroughfare begins (generally, the first third of the regenerant). To be confident that the right amount is dumped, an elution study can be performed.

Layered bed configurations with weak and strong base anions in the same vessel generally operate with lower caustic concentrations and more uniform flow rates, so they tend to be less prone to silica precipitation.

Reference Document: Tech Facts 177-01762, 177-01764

9.6.4 Osmotic Shock

The alternative exposure of resins to high and low concentrations of electrolytes can cause resin bead cracking and splitting due to the alternate contraction and expansion of the bead. Over time, there may be significant reduction in particle size and an increase in resin fines, causing increased pressure drop across the resin bed during system operation and subsequent resin losses during backwash and regeneration. The resistance that a particular ion exchange resin has to osmotic shock can be determined by subjecting the resin to repeated cycles of high and low concentrations of electrolytes, such as NaOH and H₂SO₄.

Ion exchange resin particle size is an important factor related to osmotic shock. Smaller beads, particularly those which pass a number 30 sieve (smaller than approximately 600 µm) are more resistant to breakage than larger particles.

9.6.5 Mechanical Attrition

The physical stability of most currently used ion exchange resins is adequate to prevent attrition losses in column operations. Bead breakage due to mechanical attrition can occur when the resin is subjected to unusual mechanical forces, such as a crushing valve, a pump impeller, or an abrasive action during the movement of resin particles from one vessel to another. The broken beads will maintain the same operating capacity as whole perfect beads, but they are more prone to fluidization during backwash, and may be lost. In addition, the small fragments will fill the void spaces between the whole resin beads, resulting in increased pressure drop across the bed. Large beads are more subject to mechanical attrition than smaller ones.

9.6.6 Radiation

Since ion exchange resins are organic polymers, they can be affected by radiation. Generally, cation exchange resins are adequately stable for almost all reasonable applications involving radioactivity. Radiation damage shows up as a de-crosslinking of the resin. Anion exchange resins are less stable although generally adequate for use in radiation fields.

9.7 Useful Life Remaining on Ion Exchange Resin

The degradation mechanism for cation resins is de-crosslinking of the polymer matrix, leading to an increase in swell and water retention capacity. The approximate useful life of cation exchange resins may therefore be evaluated by comparing the water retention capacity to the original resin. Anion resins degrade by loss of total capacity and strong base (salt splitting) capacity, so the useful life can be assessed by comparison of the remaining salt-splitting capacity with that of the original resin. Figure 24 and Figure 25 show these relationships.

Figure 24. Approximation of useful life of in-use cation exchange resins.
(based on water retention capacity)

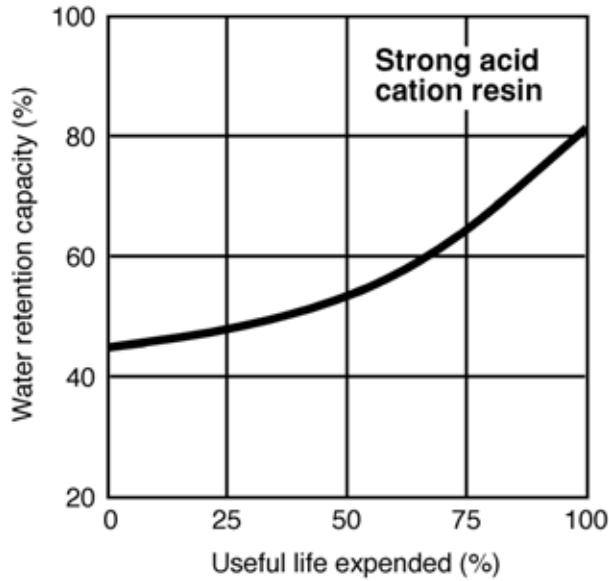
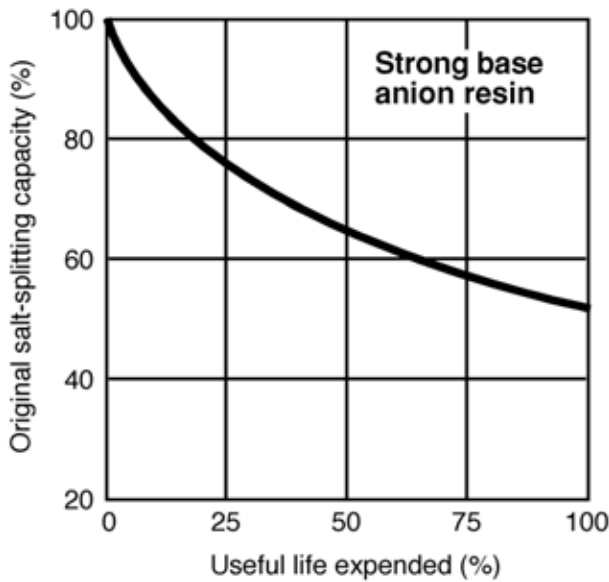


Figure 25. Approximation of useful life of in-use anion exchange resins.
(based on remaining salt splitting capacity)



10 ION EXCHANGE CLEANING PROCEDURES

10.1.1 Removal of Iron and Manganese from Cation Resins

Iron has a complex chemistry and may be present as inorganic precipitates (oxides/hydroxides), as cationic species, or as organometallic complexes. In water-treatment applications, iron is generally converted to the less-soluble Fe (III) form within the resin bed. Manganese also may be present as inorganic precipitates. Three possible cleaning procedures are described:

Air brushing: This is used in condensate polishing and other water-treatment applications such as make-up demineralization to remove insoluble, particulate iron (crud).

1. Exhaust the resin.
2. Air-brush the bed and then backwash for 30 min.
3. Regenerate the resin as normal.

If the particulates are large, backwashing may not be effective in removing them. In this case, the solids can be driven down to the bottom of the bed and removed through the screen/drain using the following procedure:

1. Air-brush the bed for 30 s at a rate of approximately four volumes air per min per volume resin and then drain the bed for 30 s, adding more water at the top.
2. Repeat step 1 about 10–20 times.
3. Regenerate the resin as normal.

If soluble iron is also present, air-brushing should be followed by acid treatment.

HCl treatment: This is used to remove crud and soluble contaminants. If possible, the acid injection in step 2 and the displacement step 4 should be made upflow into the resin bed to move the bed and increase contacting. If only downflow injection is possible, a normal backwash should be made first to loosen the bed prior to the treatment.

1. Exhaust the resin and backwash.
2. Pass two bed volumes of 10% HCl solution with a contact time of 30 min.
3. Leave to soak for 2–4 h.
4. Displace with two to three bed volumes of water.
5. Rinse out with three to five bed volumes of deionized water fast rinse (downflow).

Note: HCl is very corrosive and can cause severe burns on contact. Avoid inhalation of the fumes and provide adequate ventilation when handling the acid. Refer to the manufacturer's safety information. The acid can also cause problems with materials of construction, so ensure that the acid is compatible with the plant equipment before use.

Reference Document: Tech Facts 177-01852

Reducing agent treatment: This treatment uses a reducing agent (sodium dithionite, $\text{Na}_2\text{S}_2\text{O}_4$) to convert Fe(III) to the more soluble Fe(II). It is used in water softening and other applications, where acid can damage the materials of construction. If possible, steps 2, 4, and 6 should be made upflow into the resin bed to increase contact. If only downflow injection is possible, a normal backwash should be made first to loosen the bed prior to the treatment. Do not use air-brushing to agitate the resin bed because this will impair the reducing agent performance.

1. Exhaust the resin and backwash.
2. Pass one bed volume of 5% $\text{Na}_2\text{S}_2\text{O}_4$ solution with a contact time of 30 min.
3. Leave to soak for 2 h.
4. Pass one bed volume of 5% $\text{Na}_2\text{S}_2\text{O}_4$ solution with a contact time of 30 min.
5. Leave to soak for up to 24 h if possible.
6. Displace with two to three bed volumes of water.
7. Rinse out with three to five bed volumes of deionized water fast rinse.
8. Double regenerate the resin (same NaCl concentration, double time).

10.1.2 Removal of Barium, Strontium, and Calcium Sulfates from Cation Resins

Precipitation of BaSO₄, SrSO₄, and CaSO₄ into a cation resin bed is a potential problem with H₂SO₄ regeneration. Removal of the calcium with HCl is only partially effective because the solubility of CaSO₄ in this media is also relatively low. A more effective treatment is to use a complexing agent for calcium removal:

1. Carry out the normal regeneration sequence for the cation.
2. Pass upflow one bed volume of 10% sodium citrate over 20–30 min.
3. Leave to soak overnight with occasional air injection if possible to facilitate contact of the citrate with the resin.
4. Displace/rinse the citrate downflow with minimum five bed volumes of deionized water.
5. Backwash the resin and then carry out a double regeneration (same acid concentration, double injection time).

Reference Document: Tech Facts 177-01832

10.1.3 Removal of Iron from Anion Resins

Two possible cleaning procedures are as follows: **Acid Wash with HCl at high concentration:** The acid concentration should be increased gradually to avoid excessive osmotic stress to the resin:

1. Exhaust the resin.
2. Pass upflow one bed volume of 5% HCl solution with a contact time of 30 min.
3. Pass upflow one bed volume of 10% HCl solution with a contact time of 30 min.
4. Leave to soak for 2–4 h.
5. Displace upflow with two to three bed volumes of water.
6. Rinse out with three to five bed volumes of deionized water fast rinse (downflow).
7. Double regenerate the resin (same NaOH concentration, double time).

Reducing agent treatment: The same procedure can be used as for cation resins described above (Section 10.1.1).

Reference Document: Tech Facts 177-01846

10.1.4 Removal of Calcium and Magnesium from Anion Resins

Calcium fouling can occur on anion resins if raw filtered water is used as the dilution source for the NaOH regenerant instead of decationized, softened, or deionized water. If calcium (and magnesium) are present in the NaOH, then they are likely to precipitate with the bicarbonates/carbonates that are being driven off of the exchange sites. The result is extremely prolonged rinse times, which render the ion exchange process inoperable.

Calcium can also be deposited during brine cleaning of mixed bed anions (especially for primary working mixed beds), when a NaCl/NaOH mixture is introduced to remove organic fouling. If the cation component of the mixed bed is not regenerated prior to the brine treatment, the formation of Ca(OH)₂ and Mg(OH)₂ can occur because the alkaline brine mixture is often prepared by introducing NaOH to the mixed bed vessel and adding salt pellets via the top manway. Therefore, it is critical to first regenerate the cation resin. The acid concentration should be increased gradually to avoid excessive osmotic stress to the resin:

1. Exhaust the resin.
2. Backwash the resin for approximately 15 min, with air injection if necessary.
3. Pass upflow one bed volume of 2% HCl solution with a contact time of 30 min.
4. Pass upflow one bed volume of 10% HCl solution.
5. Leave to soak 4–16 h with occasional air injection to facilitate contacting of the acid with the resin.
6. Displace/rinse the acid downflow with minimum five bed volumes of deionized water.
7. Backwash the resin and then carry out a double regeneration (same caustic concentration, double injection time).

Reference Document: Tech Facts 177-01833

10.1.5 Removal of Silica and Organics from Anion Resins

If silica and organic levels in the feed water are high, it is advisable to carry out regular brine treatments with hot caustic soda, if possible, as part of a preventative maintenance program, because heavily fouled resins may not be completely restored with this treatment. An alternative is to install an organic filter as pretreatment to the demineralization line:

1. Exhaust the resin.
2. Try to warm the resin bed by recirculating warm water (approximately 120°F (50°C) if possible).
3. Pass upflow one bed volume of 10% NaCl + 1% NaOH solution at 1.2–2.0 gpm/ft² (3–5 m/h).
4. Leave to soak for 4–16 h.
5. Displace upflow with one bed volume of water, leave for 4 h.
6. Displace upflow with two to three bed volumes of water.
7. Rinse out with three to five bed volumes of deionized water fast rinse (downflow).
8. Double regenerate the resin (same NaOH concentration, double time).

Expect the first run to give an earlier conductivity break.

Note: Cation effluent or soft water must be used for the solution's make-up and rinse. Hot solutions will increase the efficiency of the clean-up and regeneration. Recirculation of the cleaning solution, for the contact time specified, will also increase the efficiency of the clean-up. For silica fouling alone, warm (95°F/35°C) or hot (120°F/50°C) caustic is effective.

Reference Document: Tech Facts 177-01843

10.1.6 Removal of Biological Growth from Ion Exchange Resins

Ion exchange resins in continuous operation are subjected to extreme changes in pH during regeneration. As a result, biological growth is not a common problem in most demineralizers. Most biological growth problems are caused by inactivity of the resin during extended storage. In order to minimize the potential for biofouling, inactive systems should be stored in a biostatic solution such as 15–25% NaCl.

In cases where biological growth has occurred, an extended air scour followed by double regeneration may be able to restore the resins to a usable condition. If this procedure is not successful, there are two other procedures that can be used. Oxidative damage can occur from each type of treatment, so it is important to control the concentration, temperature, and contact time of the chemical.

Peracetic acid and hydrogen peroxide treatments: Peracetic acid (CH₃COOOH) has a wide-band action for removing microorganisms and is an effective treatment for both cation and anion exchange resins. H₂O₂ is less effective and requires a higher concentration:

1. Put resin into exhausted form.
2. Prepare peracetic acid solution of 0.2% concentration or 2% H₂O₂.
3. For anion resins, apply 57 g peracetic acid/ft³ resin (2 g/L) by passing one bed volume of the solution at ambient temperature through the resin bed during a 30–60 min contact time. Measure the peracetic acid or residual H₂O₂ in the effluent and stop when it reaches a level of approximately 10% of the inlet concentration.
4. For cation resins, 57–113 g peracetic acid/ft³ resin (2–4 g/L) can be applied using one to two bed volumes of the 0.2% solution over 30–60 min.
5. Rinse out with four bed volumes of deionized water over a period of about 1 h, until no peracetic acid is detectable in effluent.
6. Make a double regeneration of the resin.

Chlorine treatment: Sodium hypochlorite ($\text{NaOCl}\cdot 5\text{H}_2\text{O}$ or bleach) cleaning is a very intense treatment for sterilizing and removing organic contaminants on cation exchange resins. Note that chlorine can be explosive under certain conditions.

The recommended procedure for cation resins is as follows:

1. Regenerate the resin (hydrogen form). If the resin has iron or other metal contamination, pretreat with about two bed volumes of 10% HCl solution.
2. Ensure that the resin is completely exhausted by treating with brine solution (for strong acid cation resins) or caustic (for weak acid cation resins) because any residual H^+ on the resin can lead to the generation of free Cl_2 . Take care to allow for resin swelling.
3. Use a sodium hypochlorite solution of 0.10% concentration (1000 ppm).
4. Apply 143 g free Cl_2/ft^3 (5 g/L) resin by passing two bed volumes of the NaOCl solution at ambient temperature down through the resin bed with a 30–45 minute contact time. Allow the resin to soak in the solution for 1–2 h.
5. Rinse out with one to two bed volumes of deionized water.
6. For the most effective treatment, apply more solution, repeating step 4. Perform a final rinse with three to four bed volumes of deionized water (until no Cl_2 is detectable in effluent).

The recommended procedure for anion resins is as follows:

1. Put resin into exhausted (Cl) form. If the resin has iron or other metal contamination, pretreat with about two bed volumes of 10% HCl solution.
2. Use a sodium hypochlorite solution of 0.05% concentration (500 ppm).
3. Apply 57 g free Cl_2/ft^3 (2 g/L) resin by passing two bed volumes of the NaOCl solution at ambient temperature through the resin bed with a 30–45 minute contact time. Measure the effluent and stop if free Cl_2 reaches a level of about 10% of the inlet concentration.
4. Rinse out with three to four bed volumes of deionized water (until no Cl_2 is detectable in effluent).

Reference Document: Tech Facts 177-01744

10.2 Ion Exchange Troubleshooting

The three prime problem areas are system loss of throughput capacity, failure to produce specified water quality, and increased pressure drop.

Table 20. System loss of throughput capacity.

Symptom	Possible Causes	Remedies
Loss of throughput capacity	Faulty or inaccurate measurement system (flow meter, conductivity meter, etc.)	Check measurement system. Repair or replace if necessary.
	Inappropriate rinse water quality	Use softened water for cation resins, decationized water for anion resin, demineralized water for mixed-bed resin
	Long rinse down	See "Resin degradation/fouling" below.
	Change in water composition/increase in influent TDS	Obtain a current water analysis to confirm (the computer design program CADIX has this functionality), then increase regeneration level or evaluate potential for upgrading system to UPCORE™
	Early breakthrough due to decreased water quality	See Table 21. Failure to produce specified water quality.
	Low flow rate due to pressure drop increase	See Table 22. Increased pressure drop.
	Resin loss	Measure resin bed depth, in the same form that the resin was supplied. Add more resin as required. If a sudden high loss of resin occurs, check vessel and distribution system for leaks
	Inadequate regeneration	Check for correct resin contact time, flow rates, and concentration
	Leaking/by-pass of regenerant valves	Check and adjust all valves.
	Resin degradation/fouling	Take sample and confirm with resin analysis, clean or replace resin as appropriate. See Section 9.4 and Section 10.

Table 21. Failure to produce specified water quality.

Symptom	Possible Causes	Remedies
High conductivity/ leakage of target ions	Faulty or inaccurate measurement system (conductivity meter, etc.)	Check measurement system. Repair or replace if necessary.
	Valve leakage	Check and adjust all valves.
	Inadequate regeneration	Check for correct resin contact time, flow rates, and concentration
	Internal distributor blocked	Repair/clean distributor.
	Flow rate above normal	Reduce flow or change to larger bead resin.
	Channeling	See high pressure drop causes
	Low service water flow rate	Increase service water flow rate to minimum operating guidelines to prevent channeling
	Resin degradation/fouling	Take sample and confirm with resin analysis, clean or replace resin as appropriate. See Section 9.4 and Section 10.
	Poor regenerant quality	See guidelines for regenerant quality.
Hardness leakage from cation resins	CaSO ₄ precipitation	Clean and check acid injection concentrations or implement step-wise regeneration.
CO ₂ leakage from weak anion resins	Faulty degasifier for systems with strong base anion	Measure pH from weak base anion unit. If pH <4 and CO ₂ is present in effluent, check/repair degasifier function.
Silica leakage from weak base anion	Silica precipitation	In high silica waters, regenerant from strong base anion resin must be initially dumped before applying to weak base anion.
CO ₂ leakage from strong anion resins	Faulty degasifier	Measure pH from weak base anion unit. If pH <9 and CO ₂ is present in effluent, check and repair degasifier function.
Silica leakage from strong base anion resins	Presence of colloidal silica	Review pretreatment and modify as appropriate.
Silica leakage from strong base anion resins	High feed water temperature	Adjust regenerant conditions or operating conditions to compensate.
	Low regeneration temperature or lack of bed preheating	Adjust regenerant conditions or operating conditions to compensate.
Low pH, high conductivity, silica leakage from anion resins	Organic fouling, loss of strong base capacity	Take sample and confirm with resin analysis, clean or replace resin as appropriate.
Sodium leakage, high pH, silica leakage from anion resins	Premature sodium break from cation	Check cation for calcium sulfate precipitation and regeneration sequence.
Sodium leakage, high pH from anion resins	Strong acid cation resin incursion (cross contamination)	Investigate cause (e.g. broken strainers or traps). Replace anion.

Table 22. Increased pressure drop.

Symptom	Possible Causes	Remedies
Increased pressure drop/restricted flow	Valve(s) partially closed	Check and adjust all valves.
	Internal distributor blocked	Repair/clean distributor.
	Flow rate above normal	Reduce flow or change to larger bead resin.
	Low feed water temperature	Reduce flow or change to larger bead resin.
	Increased amount of suspended solids in the influent	Increase backwash time and frequency.
	Fouling, precipitation, or biogrowth in resin bed	Take sample and confirm with resin analysis, clean or replace resin as appropriate. See Section 9.4 and Section 10.
	Compacted bed	Extended backwash or air brush during backwash.
	Resin fines	Increase backwash rate to expand bed to a point 6–12 inches (15–30 cm) below the outlet header. Remove or change backwash outlet screens.
	Resin oxidative damage	Take sample and confirm with resin analysis and replace resin.
	Inappropriate resin choice	Replace with correct resin type.
	Broken under drain or resin sub-fill system	Inspect and repair.
	Excessive resin volume in vessel	Re-adjust volume according to guidelines.

11 DESIGNING AN ION EXCHANGE SYSTEM

An entire ion exchange water treatment system consists of a pretreatment section, the ion exchange section, and an ion exchange polishing section, which is usually a mixed bed. This section gives general information on designing the ion exchange and polishing sections using DOWEX™ ion exchange resins.

Ion exchange system performance is typically characterized by three parameters: volume treated per cycle (or throughput), water quality, and chemical consumption (efficiency). The goal of the designer of an ion exchange system is to ensure that the correct water quality and quantity is delivered with optimized regenerant consumption and capital cost. The optimum design depends on the relative importance of these parameters. Each is described in this section. Dow offers the CADIX (Computer Aided Design of Ion eXchange) computer program to aid designers.

11.1 Product Water Requirements

The required water quality will help define the regeneration system, plant configuration, and resin choice. For high-quality water, a counter-current regeneration system should be used, which should provide a water quality of $<0.5 \text{ M}\Omega\cdot\text{cm}$ ($2 \mu\text{S}/\text{cm}$) and residual silica of 20 to 50 ppb as SiO_2 , with a typical endpoint of $1 \text{ M}\Omega\cdot\text{cm}$ ($4 \mu\text{S}/\text{cm}$) conductivity or a maximum endpoint value of 0.3 mg/L SiO_2 above the average silica leakage. Co-current regeneration systems will typically give leakages about 10 times higher than counter-current systems. Details of different regeneration systems are described in Section 8 The UPCORE™ Counter-Current Regeneration System.

A polishing mixed bed will be required if the product water specification is below that achievable from the demineralization plant alone or if a higher degree of safety is required to ensure water quality. The mixed-bed outlet water should be about $0.025 \text{ M}\Omega\cdot\text{cm}$ ($0.10 \mu\text{S}/\text{cm}$) at 75°F (25°C) and 10 to 20 ppb as SiO_2 .

11.2 Feed Water Composition and Contaminants

Feed water composition and temperature are usually given parameters. These parameters and the product water requirements influence the choice of system configuration. See Section 11.3.

The level of feed water contaminants depends on the efficiency of the pretreatment, and specific raw-water quality requirements will define the necessity of a pretreatment. Suspended solids, oils, organic matter, and certain inorganic substances (e.g. Fe, Mn) in the raw water must be limited to ensure trouble-free plant performance. Flocculation problems can also affect the resins, and chlorine will oxidatively degrade the resins. Should the resins become fouled, there are a number of cleaning procedures described in Section 10.2.

11.3 Selection of Layout and Resin Types (Configuration)

The plant configuration will depend on the feed water composition, the water quality required, and the economics of operation. The following general guidelines are given to help with configuration and resin selection. Because of the improved performance of the uniform DOWEX MARATHON™ resins, these resins are recommended over standard (polydispersed) resins. The uniform DOWEX UPCORE Mono resins are designed for plants using the UPCORE system.

Strong acid cation resin: This resin is used for water softening in the sodium cycle (see Section 3 Sodium Cycle Ion Exchange Process (Water Softening)) and for demineralization when the temporary hardness in the feed is $<40\%$. For small plants and with HCl as regenerant, a strong acid cation resin also offers a simple effective solution on waters with $>40\%$ temporary hardness. DOWEX MARATHON C is the resin of choice for most applications. DOWEX UPCORE Mono C-600 is the resin of choice for UPCORE systems (see Section 8 The UPCORE™ Counter-Current Regeneration System).

Weak acid cation resin: This resin is used as a single resin for dealkalization in the hydrogen cycle (Section 5 Dealkalization: Salt Splitting Process) and for brackish water softening in sodium cycle (Section 4 Brackish Water Softening). In demineralization, the use of a weak acid cation prior to a strong cation is preferred with feed waters containing a high proportion of temporary hardness ($>40\%$) and low

free mineral acidity (FMA). This configuration has advantages in terms of regeneration efficiency and operating capacity.

With H₂SO₄ regeneration, two separate cation columns should be used in order to allow acid dilution at the weak acid resin inlet. For counter-current regeneration, a double compartment, layered bed cation with a facility for acid dilution at the WAC inlet can be used, but it is more complex to operate. Selected resins are DOWEX™ MAC-3 or DOWEX UPCORE™ MAC-3 for UPCORE systems.

Strong base anion resin type 1: A type 1 strong base anion as a single resin is particularly recommended for treating low FMA water with high silica and where low silica leakage is required (about 20 ppb in counter-current operation). The resin can be regenerated at up to 122°F (50°C) for more effective silica removal. DOWEX MARATHON™ A is designed for general demineralization. DOWEX UPCORE Mono A500 or DOWEX UPCORE Mono A625 are recommended for UPCORE systems.

Strong base anion resin type 2: A type 2 strong base anion resin is well suited for small plants because of its excellent regeneration efficiencies for water compositions where CO₂ and SiO₂ are <30% of the total feed anions. Type 2 anion resins have much better operating capacity and regeneration efficiency than type 1, but they are limited to lower temperature operation (<95°F/35°C caustic treatment) and have a higher SiO₂ leakage (about 50 ppb in counter-current operation). DOWEX MARATHON A2 is the resin of choice for general demineralization. DOWEX UPCORE Mono A2-500 is recommended for the UPCORE system.

Weak base anion resin: This type of resin is used as a single resin to obtain partially deionized water without removal of CO₂ and SiO₂. For complete demineralization, the combination of weak base and strong base anion resins is an excellent choice for larger plants because it provides optimum operation costs. The weak base has very high regeneration efficiency and provides additional capacity to the system. The weak and strong anion resin combination is well suited to treat waters with low alkalinity or degassed feed when the FMA (Cl + NO₃ + SO₄) is typically >60% of the total anions.

Weak base anion resins are particularly effective at handling natural organics, which are usually high molecular weight, weakly acidic compounds that affect both weak base and strong base anion resins. In a weak base/strong base anion configuration, some of the organics will pass through the weak to the strong base. The design should therefore account for SBA organic loading at the end of the cycle because the resin will require additional NaOH to desorb the organics. There are important differences in loading capacity or reversibility to organics between different anion resin types.

The weak and strong anion resins can either be designed in two separate vessels or for counter-current regeneration in one vessel with or without a separation nozzle plate. For separated anions, DOWEX MARATHON WBA and DOWEX MARATHON A are recommended. DOWEX MARATHON WBA and DOWEX MARATHON A LB are designed to be used together as a layered bed in a single column without a nozzle plate. For UPCORE systems, the resins are DOWEX UPCORE Mono WB-500 and DOWEX UPCORE Mono A-500 or DOWEX UPCORE Mono A-625.

11.4 Chemical Efficiencies for Different Resin Configurations

Because of differences in the regenerability of strong and weak functionalized resins, the configurations described in Section 11.3 above will have different chemical efficiencies. The chemical efficiency of regeneration (also known as stoichiometry) for an ion exchange resin is defined as:

$$\text{Chemical efficiency} = \frac{\text{Amount regenerant chemical added (eq/L)}}{\text{Resin operating capacity obtained (eq/L)}} \times 100\%$$

Because the resin usage of the regenerant chemical is non-ideal, the chemical efficiency is always >100%. Therefore, the efficiency becomes worse as the value increases. Table 23 gives typical regeneration efficiencies for different resin types and combinations in co-current and counter-current regeneration systems.

Table 23. Typical regeneration efficiencies for different resin types and combinations.

Resin Type/Configuration	Regeneration System	Typical Regeneration Efficiency (%)
Strong acid cation	Co-current HCl	200–250
	Counter-current HCl	120–150
	Co-current H ₂ SO ₄	250–300
	Counter-current H ₂ SO ₄	150–200
Weak acid cation		105–115
Weak acid + strong acid cation		105–115
Strong base anion type 1	Co-current	250–300
	Counter-current	140–220
Strong base anion type 2	Co-current	150–200
	Counter-current	125–140
Weak base anion		120–150
Layered bed anion		120–130

11.5 Atmospheric Degasifier

The decision to install an atmospheric degasifier is principally economic. Removing carbon dioxide before it reaches the anion resins will reduce NaOH chemical consumption, and this should be balanced against the cost of the degasifier. Generally, the economic balance is not in favor of a degasifier for small plants (up to approximately 45 gpm or 10 m³/h). For larger plants, if the total CO₂ is greater than 50–100 ppm (mg/L), the payback time for a degasifier should be short.

Atmospheric degasifiers usually reduce residual CO₂ down to 5 ppm (mg/L). A residual value of 10 ppm (mg/L) CO₂ is recommended as a safety margin for design.

A vacuum degasifier is used for systems requiring very low levels of residual CO₂. This reduces the CO₂ to below 1 ppm (mg/L).

11.6 Resin Operating Capacities and Regenerant Levels

In co-current operation, the product water quality requirements will define the minimum levels of acid and caustic regenerant to be used. The regenerant levels and the feed water composition will then define the resin operating capacity. Although high regenerant levels result in increased capacity and lower ionic leakages, the chemical efficiency of the system (Section 11.4) becomes worse.

Ionic leakage and operating capacity curves are available as a function of feed composition and regenerant levels in the engineering brochures for DOWEX™ resin or from the CADIX computer design program.

As a guide, Table 24 gives an overview of typical regeneration levels for single resin columns used in co-current and counter-current regeneration systems with the corresponding resin operating capacities.

Table 24. Typical regeneration level ranges for single resin columns.

Regeneration System	Regenerant Level		Typical Operating Capacity	
	(lb/ft ³)	(g/L)	(kgr/ft ³)	(eq/L)
Co-current regeneration				
HCl	5–7.5	80–120	17.5–26	0.8–1.2
H ₂ SO ₄	9.5–12.5	150–200	11–17.5	0.5–0.8
NaOH	5–7.5	80–120	8.5–13	0.4–0.6
Counter-current regeneration				
HCl	2.5–3.5	40–55	17.5–26	0.8–1.2
H ₂ SO ₄	3.75–5	60–80	11–17.5	0.5–0.8
NaOH	2–2.8	30–45	8.5–13	0.4–0.6

The choice between HCl and H₂SO₄ is principally economic. HCl is a trouble-free regenerant with high efficiency. H₂SO₄ is less efficient and has lower operating capacity, particularly if stepwise regeneration is required in high hardness waters to avoid CaSO₄ precipitation. Guidelines for amounts and concentrations of H₂SO₄ in stepwise regeneration are given in Table 25.

Table 25. Guidelines for amounts and concentrations of H₂SO₄ in stepwise regeneration.

Calcium in Feed Water (%)	Amount and Concentration of H ₂ SO ₄
Ca <15	3%
15 < Ca <50	1/3 at 1.5% and 2/3 at 3.0%
50 < Ca <70	1/2 at 1.5% and 1/2 at 3.0%
Ca >70	1% or use HCl

The specifications on the purity of the regeneration chemicals must ensure trouble-free operation of the ion exchange resins after regeneration. Recommendations on the quality of regeneration chemicals are provided in Section 12.

A safety factor should be applied to operating capacity figures to compensate for non-ideal operating conditions and resin aging on a working plant. Typical safety margins are 5% for cation resins and 10% for anion resins. Once the operating capacity has been determined, the required resin volume can be calculated from the throughput (volume treated per cycle) as follows:

$$\text{Resin volume (L)} = \frac{\text{Feed salinity (eq/m}^3\text{)} \times \text{Throughput (m}^3\text{)}}{\text{Resin operating capacity (eq/L)}}$$

The resin volume then allows design of the vessel sizing.

11.7 Vessel Sizing

The vessels should be made from typical, well-known materials of construction such as rubber-lined carbon steel or fiberglass. The vessel should have distribution/collector systems that give good distribution of fluids during all phases of the operation. For this reason, a maximum vessel diameter of 11.5 ft (3.5 m) is recommended. Installation of sight-glasses is advised in order to check resin levels and separation in the case of layered beds and mixed beds.

The design of the vessels should give a maximum resin bed depth, while limiting the pressure drop across the resin bed to approximately 14.7 psi (1 bar). The optimum column diameter must be a balance between the resin bed height, the ratio of resin height to diameter (H/D), and the linear velocity. H/D should be in the range 2/3 to 3/2.

Vessel sizing should be adjusted to allow for resin expansion if backwashing is performed (80–100% of the settled resin bed height). Resin swelling during service, the minimum bed height requirements, and service and regenerant flow rates are listed in Table 26. These values are offered as guidelines only and should not be regarded as exclusive. Some applications may function outside of the guidelines. Typical resin bed depth is 4 ft (1.2 m) for co-current and block regeneration systems and 6.5 ft (2 m) for counter-current packed bed systems.

Table 26. Design guidelines for operating DOWEX™ resins.

Parameter	Guideline
Swelling	
Strong acid cation Na → H	5–8%
Weak acid cation H → Ca	15–20%
Strong base anion Cl → OH	15–25%
Weak base anion free base (FB) → HCl	15–25%
Bed depth, minimum	
Co-current single resin	2.6 ft (800 mm)
Counter-current single resin	4 ft (1200 mm)
Layered bed strong base anion resin	2.6 ft (800 mm)
Layered bed weak base anion resin	2 ft (600 mm)
Backwash flow rate	
Strong acid cation	4–10 gpm/ft ² (10–25 m/h)
Weak acid cation	4–8 gpm/ft ² (10–20 m/h)
Strong base anion	2–6 gpm/ft ² (5–15 m/h)
Weak base anion	1.2–4 gpm/ft ² (3–10 m/h)
Flow rates	
Service/fast rinse	2–24 gpm/ft ² (5–60 m/h)
Service/condensate polishing	30–60 gpm/ft ² (75–150 m/h)
Co-current regeneration/displacement rinse	0.4–4 gpm/ft ² (1–10 m/h)
Counter-current regeneration/displacement rinse	2–8 gpm/ft ² (5–20 m/h)
Total rinse requirements	
Strong acid cation	2–6 bed volumes
Weak acid cation	3–6 bed volumes
Strong base anion	3–6 bed volumes
Weak base anion	2–4 bed volumes

11.8 Number of Lines

Based on the flow rate and throughput required, the number of lines operating at the same time needs to be defined. The simplest layout with 2 lines (1 in operation, 1 in standby) can be used in most cases. With large plants (>1800 gpm or 400 m³/h), however, it may be more appropriate to have 3 lines (2 x 50% in parallel, 1 in standby) to reduce system redundancy, optimize flow conditions, and reduce vessel sizing. In designing an ion exchange system, it is important to ensure that there is enough time for the standby lines to complete regeneration before they are required to go back on-line. The optimum number of lines with minimum redundancy can be calculated using the following formula:

$$\text{number of lines} = \frac{\text{run length (throughput)(h)} + \text{regeneration time (h)}}{\text{regeneration time (h)}}$$

If the equation predicts a non-integer result, the number should be rounded down to obtain the optimum number of lines. For example, a 10-h run length with a 3-h regeneration time gives a ratio of 4.3, so the number of lines with minimum redundancy would be 4.

11.9 Mixed Bed Design Considerations

Below are some general guidelines for designing a working mixed bed downstream of a demineralization plant:

- Resin volume ratio of cation to anion should be in the range 40:60 to 60:40.
- Flow rate of 20–40 bed volumes per hour.
- Regenerant levels of 0.8–1.0 lb HCl/ft³ (80–100 g/L) or 1.2–1.6 lb H₂SO₄/ft³ (120–160 g/L) cation and 0.8–1.0 lb NaOH/ft³ (80–100 g/L) anion.
- Maximum service run length <4 weeks.
- Maximum silica loading <1.0 g SiO₂/L anion resin at end-of-cycle.
- Minimum cation resin bed depth of 1.5 ft (450 mm).

12 USEFUL GRAPHS, TABLES, AND OTHER INFORMATION

12.1 Particle Size Distribution

Test methods to establish and/or express the size distribution of DOWEX™ Gaussian (conventional) ion exchange resins are based on the “U.S.A. Standard Series” of sieves. Table 27 gives the main characteristics of sieves of interest to the analysis of bead size distributions.

Table 27. Main characteristics of sieves for bead size distribution analysis.

U.S. Standard Mesh Number	Nominal Sieve Opening mm	Opening Tolerance $\pm \mu\text{m}$	Nominal Wire Diameter mm
10	2.00	70	0.900
12	1.68	60	0.810
14	1.41	50	0.725
16	1.19	45	0.650
18	1.00	40	0.580
20	0.841	35	0.510
25	0.707	30	0.450
30	0.595	25	0.390
35	0.500	20	0.340
40	0.420	19	0.290
45	0.354	16	0.247
50	0.297	14	0.215
60	0.250	12	0.180
70	0.210	10	0.152
80	0.178	9	0.131
100	0.150	8	0.110
120	0.125	7	0.091
140	0.104	6	0.076
170	0.089	5	0.064
200	0.074	5	0.053
230	0.064	4	0.044
270	0.053	4	0.037
325	0.043	3	0.030
400	0.038	3	0.025

Due to the narrow particle size distribution of DOWEX uniform particle sized (UPS) resins, the conventional method of using U.S.A. Standard Sieves does not provide sufficiently detailed information to describe the particle distribution effectively.

The particle size distribution for DOWEX UPS resins is therefore given as a mean particle size covering a specified range and a uniformity coefficient which is <1.1 . In addition, upper and/or lower maximum limits may be given, which are expressed as a percentage. Table 28 gives an example.

Table 28. Recommended particle size ranges for DOWEX™ MONOSPHERE™ 650C.

Parameter	DOWEX MONOSPHERE 650C
Mean particle size	650 ± 50 µm
Uniformity coefficient, max	1.1
Greater than 840 µm (20 mesh), max	5%
Less than 300 µm (50 mesh), max	0.5%

This resin therefore has a mean particle size between 600 and 700 µm with 90% of the beads within ±100 µm of the mean. No more than 0.2% of the bead population is below 300 µm.

12.2 Conversion of U.S. and S.I. Units

To convert non-metric units to S.I. units, multiply by the factors given; to convert S.I. units to the non-metric unit, divide by the factor given.

Table 29. List of conversion factors for U.S. and S.I. units.

from → to ←	to from	multiply by divide by	from → to ←	to from	multiply by divide by
LENGTH			PRESSURE DROP		
inch (in.)	meter (m)	0.0254	psi/ft	kPa/m	22.62
foot (ft)	meter (m)	0.3048	VISCOSITY		
yard (yd)	meter (m)	0.9144	poise	Pascal-second (Pa·s)	0.1
AREA			FLOW RATE		
in ²	m ²	0.0006452	gal/min = gpm	m ³ /h	0.227
ft ²	m ²	0.0929	gal/min = gpm	L/s	0.063
yd ²	m ²	0.8361	gal/day = gpd	m ³ /day	0.003785
VOLUME			gal/day = gpd	L/h	0.158
in ³	liter (L)	0.01639	million gal/day = mgd	m ³ /h	157.73
ft ³	liter (L)	28.32	gal/day = gpd	m ³ /day	3785
yd ³	liter (L)	764.6	Imp gpm	m ³ /h	0.273
Imp. gallon (U.K.)	liter (L)	4.546	FLOW VELOCITY		
U.S. gallon (gal)	liter (L)	3.785	gpm/ft ²	m/h	2.445
MASS			gpd/ft ²	L/m ² h	1.70
grain (gr)	gram (g)	0.0648	SERVICE FLOW RATE		
ounce	gram (g)	28.35	gpm/ft ³	(m ³ /h)/m ³	8.02
pound (lb)	gram (g)	453.6	RINSE VOLUME		
PRESSURE			gal/ft ³	L/L	0.134
atmosphere (atm)	kiloPascal (kPa)	101.3	CHEMICAL DOSAGE		
bar	kiloPascal (kPa)	100.0	lb/ft ³	g/L	103
lb/ft ²	kiloPascal (kPa)	0.04788			
lb/in ² (psi)	bar	0.069			
lb/in ² (psi)	kiloPascal (kPa)	6.895			

12.3 Conversion of Concentration Units of Ionic Species

The following table gives multiplication factors for the conversion of concentration units of ionic species given as gram of the ion per liter (g/L) into equivalent per liter (eq/L) or of gram of CaCO₃ equivalents per liter (g CaCO₃/L).

Table 30. List of conversion factors for concentration units of ionic species.

Compound	Formula	Ionic Weight	Equivalent Weight	Conversion to ^a	
				g CaCO ₃ /L	eq/L
POSITIVE IONS					
Aluminum	Al ³⁺	27.0	9.0	5.56	0.111
Ammonium	NH ₄ ⁺	18.0	18.0	2.78	0.0556
Barium	Ba ²⁺	137.4	68.7	0.73	0.0146
Calcium	Ca ²⁺	40.1	20.0	2.50	0.0500
Copper	Cu ²⁺	63.6	31.8	1.57	0.0314
Hydrogen	H ⁺	1.0	1.0	50.0	1.0000
Ferrous iron	Fe ²⁺	55.8	27.9	1.79	0.0358
Ferric iron	Fe ³⁺	55.8	18.6	2.69	0.0538
Magnesium	Mg ²⁺	24.3	12.2	4.10	0.0820
Manganese	Mn ²⁺	54.9	27.5	1.82	0.0364
Potassium	K ⁺	39.1	39.1	1.28	0.0256
Sodium	Na ⁺	23.0	23.0	2.18	0.0435
NEGATIVE IONS					
Bicarbonate	HCO ₃ ⁻	61.0	61.0	0.82	0.0164
Carbonate	CO ₃ ²⁻	60.0	30.0	1.67	0.0333
Chloride	Cl ⁻	35.5	35.5	1.41	0.0282
Fluoride	F ⁻	19.0	19.0	2.63	0.0526
Iodide	I ⁻	129	129	0.39	0.0079
Hydroxide	OH ⁻	17.0	17.0	2.94	0.0588
Nitrate	NO ₃ ⁻	62.0	62.0	0.81	0.0161
Phosphate (tribasic)	PO ₄ ³⁻	95.0	31.7	1.58	0.0315
Phosphate (dibasic)	HPO ₄ ²⁻	90	48.0	1.04	0.0208
Phosphate (monobasic)	H ₂ PO ₄ ⁻	97.0	97.0	0.52	0.0103
Sulfate	SO ₄ ²⁻	91	48.0	1.04	0.0208
Bisulfate	HSO ₄ ⁻	97.1	97.1	0.52	0.0103
Sulfite	SO ₃ ²⁻	80.1	40.0	1.25	0.0250
Bisulfite	HSO ₃ ⁻	81.1	81.1	0.62	0.0123
Sulfide	S ²⁻	32.1	10	3.13	0.0625
NEUTRAL					
Carbon dioxide	CO ₂	44.0	44.0	1.14	0.0227
Silica	SiO ₂	60.0	60.0	0.83	0.0167
Ammonia	NH ₃	17.0	17.0	2.94	0.0588

^aCalculations based on conversion to monovalent species

Concentrations of ionic species in water have been expressed in different units in different countries. Concentrations should normally be expressed in one of the following ways:

- As grams (g), milligrams ($\text{mg} = 10^{-3} \text{ g}$) or micrograms ($\mu\text{g} = 10^{-6} \text{ g}$) of the (ionic) species per liter (L) or cubic meter (m^3) of water.
- As equivalents (eq) or milliequivalents ($\text{meq} = 10^{-3} \text{ eq}$) of the ionic species per liter (L) or cubic meter (m^3) of water.

Still widely used concentration units are:

- kilograins of CaCO_3 per cubic foot (kgr/ft^3)
- 1 French degree = 1 part CaCO_3 per 100,000 parts of water
- 1 German degree = 1 part CaO per 100,000 parts of water
- grains CaCO_3 /gallon (U. S.)
- ppm CaCO_3
- 1 English degree (Clark) = 1 grain CaCO_3 per (British) Imperial gallon of water

Table 31 gives the conversion factors for commonly encountered units to milliequivalents/liter (meq/L) and $\text{mg CaCO}_3/\text{L}$. Multiply by the conversion factor to obtain $\text{mg CaCO}_3/\text{L}$ or meq/L. Divide by the conversion factor to obtain the different units from numbers expressed as $\text{mg CaCO}_3/\text{L}$ or meq/L.

Table 31. List of conversion factors for common units to meq/L and $\text{mg CaCO}_3/\text{L}$.

Unit	$\text{mg CaCO}_3/\text{L}$	meq/L
kgr/ft^3	2288	45.8
1 grain/U.S. gallon	17.1	0.342
ppm CaCO_3	1.0	0.020
1 English degree	14.3	0.285
1 French degree	10.0	0.200
1 German degree	17.9	0.357

12.4 Calcium Carbonate (CaCO₃) Equivalent of Common SubstancesTable 32. List of conversion factors for CaCO₃ equivalents.

Compounds	Formula	Molecular Weight	Equivalent Weight	Multiply by	
				Substance to CaCO ₃ equivalent	CaCO ₃ equivalent to Substance
Aluminum sulfate (anhydrous)	Al ₂ (SO ₄) ₃	342.1	57.0	0.88	1.14
Aluminum hydroxide	Al(OH) ₃	78.0	26.0	1.92	0.52
Aluminum oxide (alumina)	Al ₂ O ₃	101.9	17.0	2.94	0.34
Sodium aluminate	Na ₂ Al ₂ O ₄	163.9	27.3	1.83	0.55
Barium sulfate	BaSO ₄	233.4	116.7	0.43	2.33
Calcium bicarbonate	Ca(HCO ₃) ₂	162.1	81.1	0.62	1.62
Calcium carbonate	CaCO ₃	100.1	50.0	1.00	1.00
Calcium chloride	CaCl ₂	111.0	55.5	0.90	1.11
Calcium hydroxide	Ca(OH) ₂	74.1	37.1	1.35	0.74
Calcium oxide	CaO	56.1	28.0	1.79	0.56
Calcium sulfate (anhydrous)	CaSO ₄	136.1	68.1	0.74	1.36
Calcium sulfate (gypsum)	CaSO ₄ •2H ₂ O	172.2	86.1	0.58	1.72
Calcium phosphate	Ca ₃ (PO ₄) ₂	310.3	51.7	0.97	1.03
Ferrous sulfate (anhydrous)	FeSO ₄	151.9	76.0	0.66	1.52
Ferric sulfate	Fe ₂ (SO ₄) ₃	399.9	66.7	0.75	1.33
Magnesium oxide	MgO	40.3	20.2	2.48	0.40
Magnesium bicarbonate	Mg(HCO ₃) ₂	146.3	73.2	0.68	1.46
Magnesium carbonate	MgCO ₃	84.3	42.2	1.19	0.84
Magnesium chloride	MgCl ₂	95.2	47.6	1.05	0.95
Magnesium hydroxide	Mg(OH) ₂	58.3	29.2	1.71	0.58
Magnesium phosphate	Mg ₃ (PO ₄) ₂	262.9	43.8	1.14	0.88
Magnesium sulfate (anhydrous)	MgSO ₄	120.4	60.2	0.83	1.20
Magnesium sulfate (Epsom salts)	MgSO ₄ •7H ₂ O	246.5	123.3	0.41	2.47
Manganese chloride	MnCl ₂	125.8	62.9	0.80	1.26
Manganese hydroxide	Mn(OH) ₂	89.0	44.4	1.13	0.89
Potassium iodine	KI	166.0	166.0	0.30	3.32
Silver chloride	AgCl	143.3	143.3	0.35	2.87
Silver nitrate	AgNO ₃	169.9	169.9	0.29	3.40
Silica	SiO ₂	60.1	30.0	1.67	0.60
Sodium bicarbonate	NaHCO ₃	84.0	84.0	0.60	1.68
Sodium carbonate	Na ₂ CO ₃	106.0	53.0	0.94	1.06
Sodium chloride	NaCl	58.5	58.5	0.85	1.17
Sodium hydroxide	NaOH	40.0	40.0	1.25	0.80
Sodium nitrate	NaNO ₃	85.0	85.0	0.59	1.70
Tri-sodium phosphate	Na ₃ PO ₄ •12H ₂ O	380.2	126.7	0.40	2.53
Tri-sodium phos. (anhydrous)	Na ₃ PO ₄	164.0	54.7	0.91	1.09
Disodium phoshate	Na ₂ HPO ₄ •12H ₂ O	358.2	119.4	0.42	2.39
Disodium phos. (anhydrous)	Na ₂ HPO ₄	142.0	47.3	1.06	0.95
Monosodium phosphate	NaH ₂ PO ₄ •H ₂ O	138.1	46.0	1.09	0.92
Monosodium phos. (anhydrous)	NaH ₂ PO ₄	120.0	40.0	1.25	0.80
Sodium metaphosphate	NaPO ₃	102.0	34.0	1.47	0.68
Sodium sulfate	Na ₂ SO ₄	142.1	71.0	0.70	1.42
Sodium sulfite	Na ₂ SO ₃	126.1	63.0	0.79	1.26

12.5 Conversion of Temperature Units

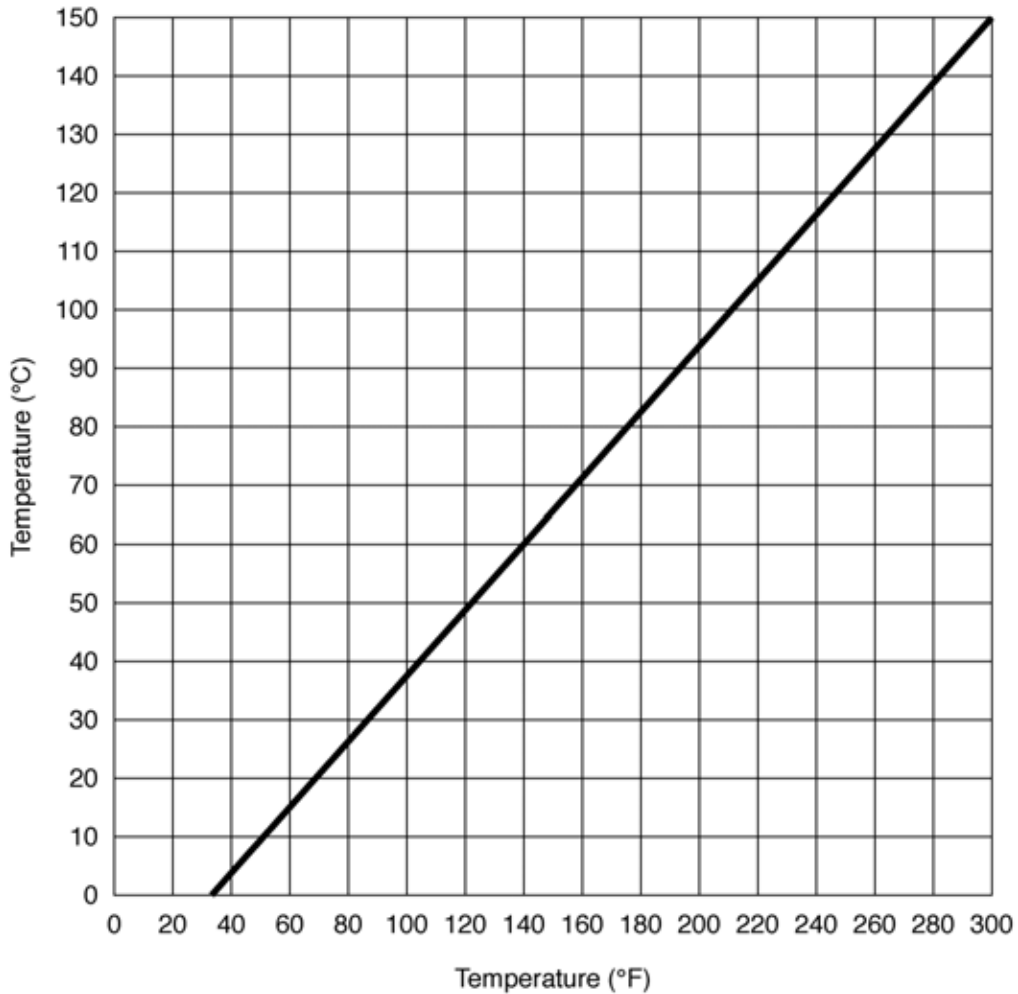
Conversion of temperature units between °C and °F can be made graphically using the grid below or by mathematical conversion using following equations:

degrees Celsius (°C) to degrees Fahrenheit (°F): $(9/5 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$

degrees Fahrenheit (°F) to degrees Celsius (°C): $5/9 (^\circ\text{F} - 32) = ^\circ\text{C}$

The S.I. unit is °C.

Figure 26. Graph for converting between °C and °F.



12.6 Conductance vs. Total Dissolved Solids

Figure 27. Graph for converting between conductance and dissolved solids.

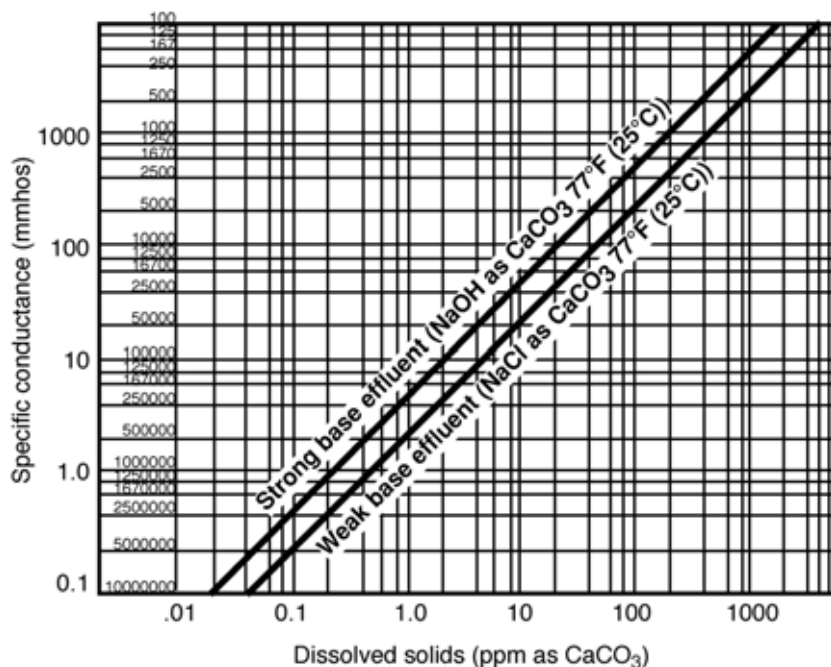
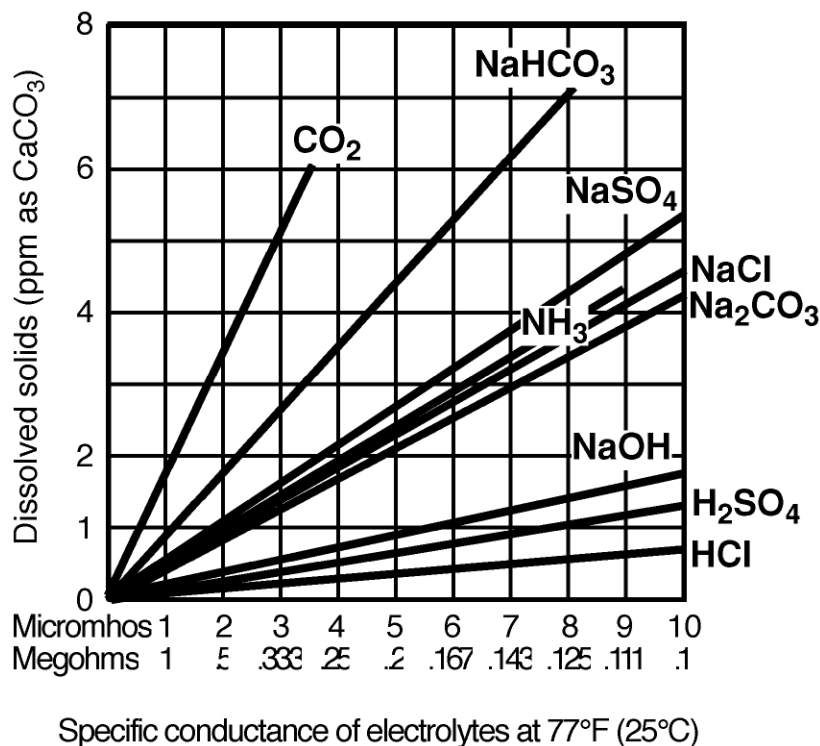


Figure 28. Relationship between dissolved solids and conductance in demineralization operations.



12.7 Handling Regenerant Chemicals

12.7.1 General Precautions

Sufficient precautions should be taken when handling, transporting, or disposing of acidic or basic regenerants. Even after dilution to their operational concentrations or in the waste after regeneration, harmful amounts of acid or base can be present. Adequate personal protection should be provided when using these chemicals, and the manufacturer's guidelines for handling these products should be carefully followed.

The specifications for and purity of the regenerant chemicals must ensure trouble-free operation of the ion exchange resin after regeneration. Therefore, the chemicals must be free of suspended materials or other materials that may be precipitated and/or absorbed by the resin. They should also be free of ionic species other than the active regeneration agents. The presence of these ionic species decreases regeneration efficiency and/or increases leakage of these species during the operational cycle. For example, NaOH containing 2% NaCl will reduce the efficiency by 5 to 10% and cause higher Cl leakage from the strongly basic anion exchange resin. In counter-current operations where low leakage levels are required, regenerants should contain minimal levels of impurities.

Recommendations on the quality of regeneration chemicals are given below. The recommended qualities should prove sufficient for all ion exchange resin applications, and under certain conditions regenerant quantity can be reduced by using spent regenerant from previous regeneration. Figures for impurity levels are based on 100% regeneration chemical.

Hydrochloric acid (HCl, muriatic acid): Both as a gas and in solution, HCl is very corrosive and can cause severe burns on contact. Mucous membranes of the eyes and the upper respiratory tract are especially sensitive to high atmospheric concentrations of HCl. Avoid inhalation of the fumes and provide adequate ventilation when handling the acid.

Table 33. Recommended impurity levels for HCl.

Impurity	Recommended Maximum Level
Fe	0.01%
Other metals, total	10 ppm (mg/L)
Organic matter	0.01%
H ₂ SO ₄ , as SO ₃	0.4%
Oxidants (HNO ₃ , Cl ₂)	5 ppm (mg/L)
Suspended matter as turbidity	~0
Inhibitors	None

Sulfuric acid (H₂SO₄): H₂SO₄ is very dangerous when improperly handled. Concentrated solutions are rapidly destructive to human tissues, producing severe burns. Contact with eyes can cause severe damage and blindness. Inhaling vapors from hot or concentrated acid may be harmful. Swallowing may cause severe injury or death.

Table 34. Recommended impurity levels for H₂SO₄.

Impurity	Recommended Maximum Level
Fe	50 ppm (mg/L)
Nitrogen compounds	20 ppm (mg/L)
As	0.2 ppm (mg/L)
Organic matter	0.01%
Suspended matter as turbidity	~ 0
Inhibitors	None
Other heavy metals	20 ppm (mg/L)

Sodium hydroxide (NaOH, caustic soda): NaOH can cause severe burns on contact with skin or eyes or when taken internally. Great care must be taken when handling the anhydrous material or when preparing or handling NaOH solutions.

Mercury-cell grade NaOH or rayon-cell grade NaOH (purified diaphragm cell) will normally meet the specifications below. Regular diaphragm-cell grade NaOH can contain over 2% NaCl and over 0.1% (1000 mg/L) NaClO₃.

Table 35. Recommended impurity levels for NaOH.

Impurity	Recommended Maximum Level
NaOH	49 - 51%
NaCl	1.0%
NaClO ₃	1,000 ppm (mg/L)
Na ₂ CO ₃	0.2%
Fe	5 ppm (mg/L)
Heavy metals (total)	5 ppm (mg/L)
SiO ₂	50 ppm (mg/L)
Na ₂ SO ₄	250 ppm (mg/L)

Ammonia (NH₃): Ammonia gas or fumes from concentrated solutions can cause serious irritation to eyes and the respiratory tract. Avoid inhalation and provide adequate ventilation when handling ammonia solutions. Ammonia is mostly offered as a solution in water, containing 20 to 30 wt % NH₃. Impurities are normally minimal and cause no potential problem for the regeneration of weak base anion exchange resins.

Sodium chloride (NaCl, salt): NaCl does not require special handling precautions.

Table 36. Recommended impurity levels for NaCl.

Impurity	Recommended Maximum Level
SO ₄ ²⁻	1%
Mg ³⁺ Ca ²⁺	0.5%

12.8 Concentration and Density of Regenerant Solutions

Table 37. Concentration and density of HCl solutions.

g HCl/100 g Solution Weight %	Concentration			Density	
	g HCl/L	eq/L	lb/gal	kg/L	° Baumé
0.5	5.01	0.137	0.042	1.001	0.5
1	10.03	0.274	0.084	1.003	0.7
1.5	15.09	0.413	0.13	1.006	1.0
2	20.16	0.552	0.17	1.008	1.3
2.5	25.28	0.692	0.22	1.011	1.7
3	30.39	0.833	0.25	1.013	2.0
3.5	35.53	0.973	0.30	1.015	2.3
4	40.72	1.12	0.34	1.018	2.7
5	51.15	1.40	0.43	1.023	3.3
6	61.68	1.69	0.50	1.028	4.0
7	72.31	1.98	0.60	1.033	4.7
8	83.04	2.28	0.69	1.038	5.4
9	93.87	2.57	0.78	1.043	1
10	104.8	2.87	0.87	1.048	7
12	127.0	3.48	1.04	1.058	8.0
14	149.5	4.10	1.22	1.068	9.3
16	172.5	4.73	1.46	1.078	10.5
18	195.8	5.37	1.65	1.088	11.8
20	219.6	6.01	1.83	1.098	13.0
22	243.8	6.70	2.0	1.108	14.2
24	268.6	7.36	2.2	1.119	15.4
26	293.5	8.04	2.5	1.129	15
28	318.9	8.74	2.68	1.139	17.7
30	344.7	9.44	2.88	1.149	18.7
32	370.9	10.16	3.07	1.159	19.8
34	397.5	10.89	3.26	1.169	21.0
36	424.4	11.63	3.45	1.179	22.0
38	451.8	12.38	3.63	1.189	23.0
40	479.2	13.13	3.8	1.198	24.0

Table 38. Concentration and density of H₂SO₄ solutions.

g H ₂ SO ₄ /100g Solution Weight %	Concentration			Density	
	g H ₂ SO ₄ /L	eq/L	lb/gal	kg/L	° Baumé
0.5	5.01	0.102	0.042	1.002	0.6
1	10.05	0.205	0.084	1.005	0.9
1.5	15.12	0.309	0.127	1.008	1.3
2	20.24	0.413	0.169	1.012	1.9
3	30.54	0.623	0.255	1.018	2.8
4	41.00	0.837	0.342	1.025	3.6
5	51.60	1.05	0.43	1.032	4.6
6	62.34	1.27	0.52	1.039	5.5
7	73.15	1.49	0.61	1.045	5
8	84.16	1.72	0.70	1.052	7.3
9	95.31	1.95	0.80	1.059	8.1
10	106	2.18	0.89	1.066	9.0
12	129.6	2.64	1.07	1.080	10.8
14	153.3	3.13	1.24	1.095	12.6
16	177.4	3.62	1.52	1.109	14.3
18	202.5	4.13	1.71	1.125	10
20	228.0	4.65	1.90	1.140	17.7
30	365.7	7.46	2.9	1.219	20
35	439.6	8.97	4.2	1.256	29.7
40	521.2	10.6	5.0	1.303	33.5
45	607.1	12.4	5.8	1.349	37.4
50	697.5	14.2	6.5	1.395	41.1
55	794.8	12	7.5	1.445	44.5
60	899.4	18.4	8.4	1.499	48.1
65	1010	20.6	9.2	1.553	51.4
70	1127	23.0	9.9	1.610	54.7
75	1252	25.5	11.1	1.669	57.9
80	1382	28.2	11.9	1.727	60.8
85	1511	30.8	12.6	1.777	63.4
90	1634	33.3	13.3	1.815	64.9
92	1678	34.2	14.0	1.824	65.3
94	1720	35.1	14.4	1.830	65.6
96	1763	30	14.7	1.868	66.7
98	1799	37	15.0	1.906	68.1
100	1831	37.4	15.3	1.944	69.4

Table 39. Concentration and density of NaOH solutions.

g NaOH/100g Solution wt %	Concentration			Density	
	g NaOH/L	eq/L	lb/gal	kg/L	° Baumé
0.5	5.02	0.126	0.042	1.004	0.8
1	10.10	0.253	0.084	1.010	1.5
1.5	15.2	0.381	0.13	1.015	2.3
2	20.4	0.510	0.17	1.021	3.0
2.5	25.7	0.641	0.22	1.026	3.7
3	31.0	0.774	0.26	1.032	4.6
3.5	33	0.907	0.30	1.038	5.4
4	41.7	1.04	0.35	1.043	5.9
5	52.7	1.32	0.44	1.054	7.3
6	63.9	1.60	0.53	1.065	8.9
7	75.3	1.88	0.63	1.076	10.1
8	89	2.17	0.73	1.087	11.5
9	98.8	2.47	0.825	1.098	12.9
10	110.9	2.77	0.925	1.109	14.2
12	135.7	3.39	1.1	1.131	17
14	161.4	4.03	1.4	1.153	19.2
16	188.0	4.70	1.65	1.175	21.6
18	215.5	5.39	1.9	1.197	23.9
20	243.8	6.11	2.1	1.219	20
30	398.3	9.96	3.65	1.328	35.8
40	571.9	14.3	5.0	1.430	43.5
50	762.7	19.1	6.37	1.525	49.8

Table 40. Concentration and density of NH₃ solutions.

g NH ₃ /100g Solution Weight %	Concentration			Density	
	g NH ₃ /L	eq/L	lb/gal	kg/L	° Baumé
1	9.94	0.58	0.083	0.994	10.9
2	19.8	1.16	0.17	0.990	11.5
3	29.6	1.74	0.25	0.985	12.2
4	39.2	2.30	0.33	0.981	12.8
5	48.8	2.87	0.41	0.977	13.3
6	58.4	3.43	0.49	0.973	13.9
7	67.8	3.98	0.57	0.969	14.4
8	77.2	4.53	0.64	0.965	15.1
9	85	5.08	0.73	0.961	15.7
10	95.8	5.62	0.82	0.958	16
12	114.0	6.69	1.0	0.950	17.3
14	132.0	7.75	1.25	0.943	18.5
16	149.8	8.80	1.3	0.936	19.5
18	167.3	9.82	1.5	0.929	20.6
20	184.6	10.8	1.7	0.923	21.7
24	218.4	12.8	1.9	0.910	23.9
28	251.4	14.8	2.1	0.898	25.3
32	282.6	16	2.4	0.883	28.6

Table 41. Concentration and density of NaCl solutions.

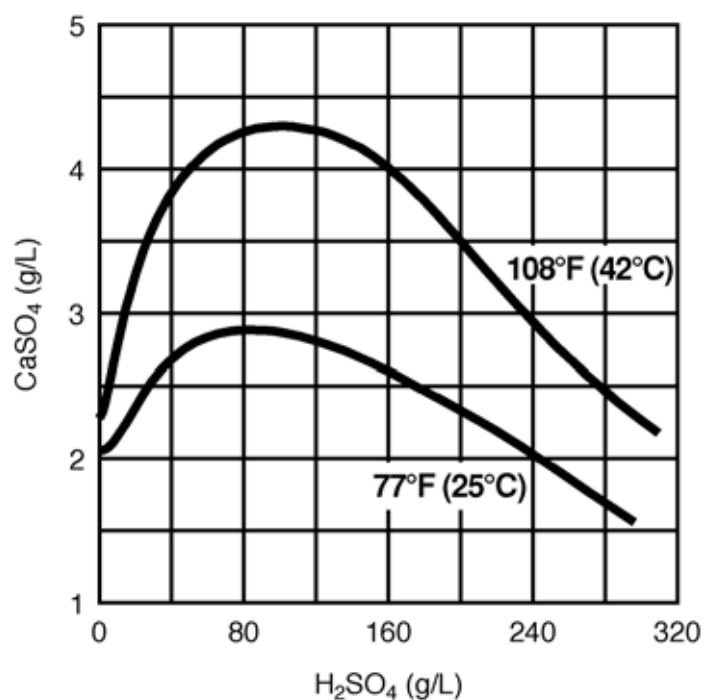
g NaCl/100g Solution Weight %	Concentration			Density	
	g NaCl/L	eq/L	lb/gal	kg/L	° Baumé
1	10.1	0.172	0.08	1.005	0.9
2	20.2	0.346	0.17	1.013	2.0
3	30.6	0.523	0.25	1.020	3.0
4	41.1	0.703	0.34	1.027	3.9
5	51.7	0.885	0.44	1.034	4.8
6	62.5	1.07	0.53	1.041	5.8
7	73.4	1.26	0.62	1.049	9
8	84.5	1.45	0.71	1.056	7.7
9	95.7	1.64	0.80	1.063	8.6
10	107.1	1.83	0.89	1.071	9.6
12	130.3	2.23	1.09	1.086	11.5
14	154.1	2.64	1.29	1.101	13.4
16	178.6	3.06	1.49	1.116	15.2
18	203.7	3.49	1.70	1.132	19
20	229.6	3.93	1.92	1.148	18.6
22	251	4.38	2.1	1.164	20.5
24	283.3	4.85	2.35	1.180	22.1
26	311.3	5.33	2.59	1.197	23.8

Table 42. Concentration and density of Na₂CO₃ solutions.

g Na ₂ CO ₃ /100 g Solution Weight %	Concentration			Density	
	g Na ₂ CO ₃ /L	eq/L	lb/gal	kg/L	° Baumé
1	10.1	0.191	0.084	1.009	1.4
2	20.4	0.385	0.17	1.019	2.8
3	30.9	0.583	0.26	1.029	4.3
4	41.6	0.785	0.35	1.040	5.6
5	52.5	0.991	0.44	1.050	7.0
6	63.6	1.20	0.53	1.061	8.4
7	75.0	1.42	0.63	1.071	9.8
8	85	1.63	0.72	1.082	11.0
9	98.3	1.85	0.82	1.092	12.4
10	110.3	2.08	0.92	1.103	13.6
12	134.9	2.55	1.13	1.124	16
14	160.5	3.03	1.34	1.146	18.4
16	187.0	3.53	1.53	1.169	21.0
18	214.7	4.05	1.70	1.193	23.4

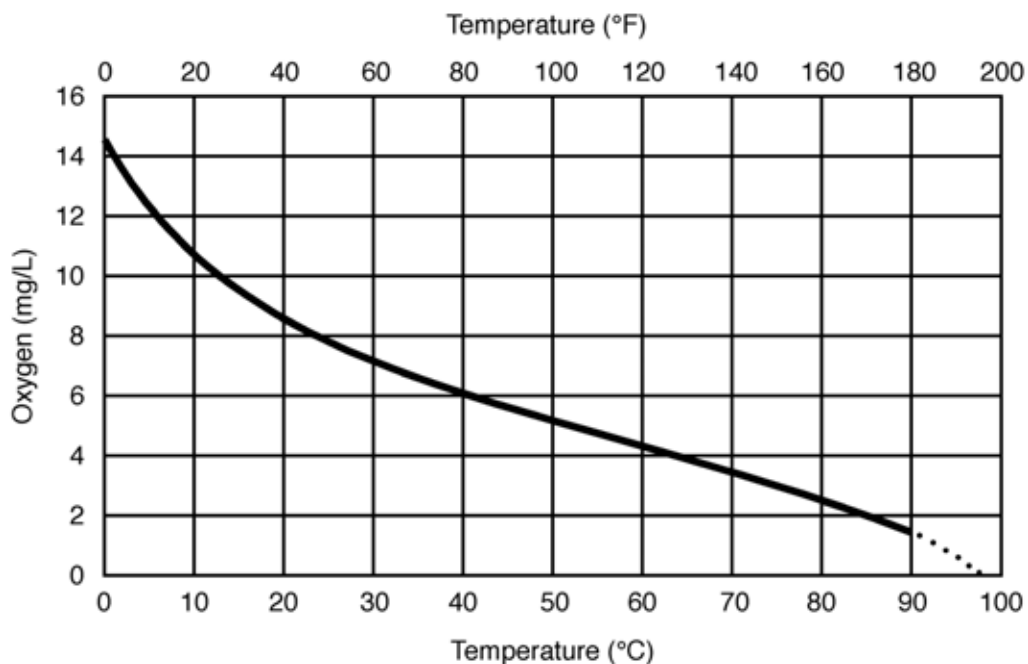
12.9 Solubility of CaSO₄

CaSO₄ is only very slightly soluble in water and dilute H₂SO₄. CaSO₄ precipitation should be prevented in an ion exchange bed, where it may occur when H₂SO₄ is used to regenerate a cation exchange resin. Precipitation can be avoided by step-wise regeneration as discussed in Section 11.6.

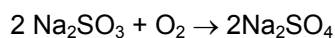
Figure 29. Solubility of CaSO₄ in solutions of H₂SO₄ in water.

12.10 Removal of Oxygen

Figure 30. Solubility of oxygen in water as a function of temperature.



Dissolved oxygen can be reduced by using sodium sulfite according to following reaction:



Based on this equation, a minimum of 7.87 mg Na_2SO_3 is necessary per mg dissolved oxygen. Table 43 shows levels of Na_2SO_3 required to remove different amounts of dissolved oxygen.

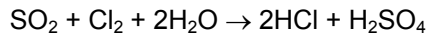
Table 43. Levels of sodium sulfite required to remove dissolved oxygen.

Dissolved Oxygen		Na_2SO_3 (theoretical amount)	
cm^3/L^a	mg/L	mg/L	lb/1000 gal
0.1	0.14	1.1	0.0094
0.2	0.29	2.3	0.019
0.3	0.43	3.4	0.028
0.4	0.57	4.5	0.038
0.5	0.72	5.6	0.047
1.0	1.4	11.3	0.094
2.0	2.9	22.5	0.19
5.0	7.2	56.3	0.47
10.0	14.3	112.5	0.94

^a1 cm^3 dissolved oxygen per liter = 1.43 mg/L
1 mg dissolved oxygen per liter = 0.698 cm^3/L

12.11 Removal of Chlorine

Chlorine is a strong oxidant and may readily degrade ion exchange resins. Chlorine levels in water can be reduced using sulfur dioxide or sodium sulfite according to following reactions.



The minimum amount of reducing agent is: 1.78 g of Na_2SO_3

or 0.91 g of SO_2

This leads to the following amounts of reducing agents to add per 1000 L of water for the given chlorine levels:

Table 44. Amount of reducing agent to add for given chlorine level.

Cl ₂ mg/L	Na ₂ SO ₃ (theoretical amount)		SO ₂ (theoretical amount)	
	g/1000 L	lb/1000 gal	g / 1000 L	lb/1000 gal
0.1	0.18	0.0015	0.09	0.00075
0.5	0.89	0.0075	0.45	0.0038
1	1.78	0.015	0.91	0.0075
2	3.56	0.030	1.82	0.015
3	5.34	0.045	2.73	0.0225
4	7.12	0.06	3.64	0.03
5	8.90	0.075	4.55	0.038
10	17.80	0.15	9.10	0.075

12.12 Tank Dimensions and Capacities

Table 45. Tank dimensions and capacities, vertical cylindrical, in U.S. and S.I. units.

Diameter in ft	Cubic feet per foot depth or Area in ft ²	U.S. gal per foot of depth	Diameter in m	m ³ per m depth or Area in m ²
1 ft 0 in.	0.79	5.87	0.3	0.07
1 ft 1 in.	0.92	6.89	0.4	0.13
1 ft 2 in.	1.07	8.00	0.5	0.2
1 ft 3 in.	1.23	9.18	0.6	0.28
1 ft 4 in.	1.40	10.44	0.7	0.39
1 ft 5 in.	1.58	11.79	0.8	0.50
1 ft 6 in.	1.77	13.22	0.9	0.64
1 ft 7 in.	1.97	14.73	1.0	0.79
1 ft 8 in.	2.18	16.32	1.1	0.95
1 ft 9 in.	2.41	17.99	1.2	1.13
1 ft 10 in.	2.64	19.75	1.3	1.33
1 ft 11 in.	2.89	21.58	1.4	1.54
2 ft 0 in.	3.14	23.50	1.5	1.77
2 ft 6 in.	4.91	36.72	1.6	2.01
3 ft 0 in.	7.07	52.88	1.7	2.27
3 ft 6 in.	9.62	71.97	1.8	2.54
4 ft 0 in.	12.57	94.0	1.9	2.84
4 ft 6 in.	15.90	119.0	2.0	3.14
5 ft 0 in.	19.63	146.9	2.1	3.46
5 ft 6 in.	23.76	177.7	2.2	3.80
6 ft 0 in.	28.27	211.5	2.3	4.16
6 ft 6 in.	33.18	248.2	2.4	4.52
7 ft 0 in.	38.48	287.9	2.5	4.91
7 ft 6 in.	44.18	330.5	2.6	5.31
8 ft 0 in.	50.27	376.0	2.7	5.73
8 ft 6 in.	56.75	424.5	2.8	6.16
9 ft 0 in.	63.62	475.9	2.9	6.61
9 ft 6 in.	70.88	530.2	3.0	7.07
10 ft 0 in.	78.54	587.5	3.2	8.04
10 ft 6 in.	86.59	647.7	3.4	9.08
11 ft 0 in.	95.03	710.9	3.6	10.2
11 ft 6 in.	103.9	777.0	3.8	11.3
12 ft 0 in.	113.1	846.0	4.0	12.6
12 ft 6 in.	122.7	918.0	4.2	13.9
13 ft 0 in.	132.7	992.9	4.4	15.2
13 ft 6 in.	143.1	1071.	4.6	16.6
14 ft 0 in.	153.9	1152.	4.8	18.1
14 ft 6 in.	165.1	1235.	5.0	19.6
15 ft 0 in.	176.7	1322.	5.2	21.2

12.13 Other Information

A typical cubic foot of standard ion exchange resin contains approximately 300 million beads. That is one bead per person living in the United States. One liter contains approximately 10 million beads.

Volume of a sphere: $V = 4/3\pi r^3$, where: r = radius

Surface area of a sphere: $A = 4\pi r^2$

Area of a circle: $A = \pi r^2$

How much is 1 part per billion? You win the lottery of \$10 million and find a penny on the way to the bank. The penny is one part per billion (1 ppb).

DOWEX™ MARATHON™ C sodium form has 2.0 eq/L capacity. Therefore a cubic foot of DOWEX MARATHON C sodium contains 2.87 lb of sodium ions. One liter contains 46 g of sodium ions. If the resin were in the barium form, it would contain 8.57 lb of barium ions at full loading (137 g/L resin).

A standard 5 ft³ fiber drum weighs 15 lb (6.8 kg) and is 30 in. (76 cm) high with a 20.5-in. (52-cm) diameter.

A standard wood pallet weighs approximately 30 lb (13.6 kg).

At 20°C:

1 cubic foot of water weighs 62.4 lb

1 gallon of water weighs 8.33 lb

1 cubic centimeter of water weighs 1 gram

1 liter of water weighs 1 kilogram

1 cubic meter of water weighs 1 metric ton

1 metric ton = 2240 lb

For a column with a diameter of:

1 in. diameter = 154 mL of resin per foot of height

2 in. diameter = 617 mL of resin per foot of height

3 cm diameter = 7 mL of resin per cm of height

4 cm diameter = 12.6 mL of resin per cm of height

1 gpm is 525,600 gal per year

1 gpm for one year with 1 ppm is 4.31 lb per year

100 m³/h is 876,000 m³ per year

100 m³/h for one year with 1 ppm is 876 kg per year

13 BIBLIOGRAPHY

There are many references available that describe ion exchange resin technology, applications, and test procedures. Some are included in various sections of this manual; others are listed below.

Applebaum, Samuel B., *Demineralization by Ion Exchange*, Academic Press Inc., New York, NY, 1968. ISBN 0-12-058950-8.

Dickert, Charles, "Ion Exchange," *Kirk-Othmer Encyclopedia of Chemical Technology*, Volume 14, John Wiley & Sons, New York, NY, 1995.

Dorfner, Konrad, *Ion Exchangers*, Walter de Gruyter & Co., Berlin, Germany, 1991. ISBN 3-11-010341-9.

Naden, D. and Streat, M., *Ion Exchange Technology*, Ellis Horwood Limited, Chichester, Great Britain, 1984. ISBN 0-85312-770-0.

Owens, Dean L., *Practical Principles of Ion Exchange Water Treatment*, Tall Oaks Publishing, Inc., Voorhees, NJ, 1985. ISBN 0-927188-00-7.

Simon, George P., *Ion Exchange Training Manual*, Van Nostrand Reinhold, New York, NY, 1991. ISBN 0-442-00652-7.

Ion Exchange Troubleshooting, Dow Water Solutions website www.dowwatersolutions.com.

14 INDEX**A**

Abbreviations · 9
Acronyms · 9
Air brushing · 57
Analysis · *See* Resin analysis
Anion exchange · 8
Anion resins · 58–59
Attrition, mechanical · *See* Mechanical attrition

B

Backwash · 42, 50
Barium sulfate · 58
Bibliography · 90
Biological growth · 46, 59
Brackish water softening · 26–29

C

CADIX software · 28, 32, 34, 39, 64, 66
Calcium · 58
Calcium sulfate · 58, 85
Capacity
 exchange · 43, 52
 operating · 22–25, 29, 39, 42, 66
 tank · 88
Carbon dioxide · 39
Cation exchange · 7
Cation resins · 57–58
Chlorine · 25, 53, 54, 60, 87
Cleaning procedures · 57–60
Co-current regeneration · 20
 UPCORE system · 43
Co-flow regeneration · *See* Co-current regeneration
Conversion
 calcium carbonate equivalents · 75
 conductance vs TDS · 77
 ionic concentration units · 73
 temperature units · 76
 U.S. and S.I. units · 72
Counter-current regeneration · 25, 39
 UPCORE system · 44
Counter-flow regeneration · *See* Counter-current regeneration

D

Dealkalization · 30–35
Degasifier · 36, 66
Deionization · *See* Demineralization
Demineralization · 36–40
Design, system · 20, 64, 67, 68
 brackish water softening · 27
 dealkalization · 30

DIRECTOR services · 50
DOWEX MAC-3 ion exchange resin · 26
DOWEX resins · 8
DOWEX UPCORE Mono resins · 41

E

Exchange capacity · *See* Capacity, exchange

F

Feed water
 composition · 64
 contaminants · 64
FILMTEC reverse osmosis membranes · 54
Fouling · 54

H

Hydrogen cycle ion exchange · 7

I

Iron · 25, 57, 58

L

Layered beds · 36, 39, 43
Layout · 64
Life, operating · 55
Loading/unloading, resins · 47

M

Magnesium · 58
Manganese · 57
MARATHON resins · 8
Mechanical attrition · 42, 55
Mixed beds · 36, 37, 39, 69
Mono ion exchange resins · *See* DOWEX UPCORE Mono resins
MONOSPHERE resins · 8

O

Operating capacity · *See* Capacity, operating
Operational information · 46
Organics · 59
Osmotic shock · 55
Oxidants · 53
Oxidation · 53
Oxygen · 86

P

Packed beds · 44
Particle size distribution · 70
Product water requirements · 64

R

Radiation · 55
Regeneration
 chemicals · 66–69, 80–85
 conditions · 66–69
 efficiency · 34, 65
Resin analysis · 50
Resin selection · 8, 64

S

Safe handling
 regenerant chemicals · 78
 resins · 46
Salt-splitting process · 30–32
Sampling · 48
Silica · 39, 54, 59
Sizing, vessel · 67
Sodium cycle ion exchange · 7, 19–25
Softening · *See* Sodium cycle ion exchange
Solutions, concentration and density · 80

Stability · 52–56
 temperature · 52
Storage, resins · 46
Strontium sulfate · 58
System design · *See* Design, system

T

Tank capacity · *See* Capacity, tank
Terms · 9
Troubleshooting
 increased pressure drop · 63
 throughput capacity · 61
 water quality · 62

U

Uniform particle size resins · 8
UPCORE system · 41
 regeneration cycle · 42
 self-cleaning · 42

W

Water softening · *See* Sodium cycle ion exchange
Weak acid cation resin · 33–35

Dow Water Solutions Offices.
For more information call Dow Water Solutions:

Dow Europe

Dow Customer Information Group
Dow Water Solutions
Prins Boudewijnlaan 41
B-2650 Edegem
Belgium
Tel. +32 3 450 2240
Tel. +800 3 694 6367 †
Fax +32 3 450 2815

[Contact the Customer Information Group](#)

Dow Pacific

Customer Information Group – Dow
Water Solutions
All countries except Indonesia and
Vietnam:
Toll free phone:
Toll free fax:

All countries:

Tel. +60 3 7958 3392
Fax +60 3 7958 5598

[Contact the Customer Information Group](#)

Dow North America

The Dow Chemical Company
Dow Water Solutions
Customer Information Group
P.O. Box 1206
Midland, MI 48641-1206
USA
Tel. 1-800-447-4369
Fax (989) 832-1465

[Contact the Customer Information Group](#)

Dow Japan

Dow Chemical Japan Ltd.
Dow Water Solutions
Tennoz Central Tower
2-24 Higashi Shinagawa 2-chome
Shinagawa-ku, Tokyo 140-8617
Japan

Tel. +81 3 5460 2100
Fax +81 3 5460 6246

[Contact the Customer Information Group](#)

Dow Latin America

Dow Quimica S.A.
Dow Water Solutions
Rua Alexandre Dumas, 1671
Sao Paulo – SP – Brazil
CEP 04717-903

Tel. 55-11-5188 9277
Fax 55-11-5188 9919

[Contact the Customer Information Group](#)

Internet

www.dowwatersolutions.com

Dow China

Dow Chemical (China) Investment
Company Ltd.
Dow Water Solutions
23/F, One Corporate Avenue
No. 222, Hu Bin Road
Shanghai 200021
China

Tel. +86 21 2301 9000
Fax +86 21 5383 5505

[Contact the Customer Information Group](#)

†Toll-free telephone number for the following countries: Austria, Belgium, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom

Warning: Oxidizing agents such as nitric acid attack organic ion exchange resins under certain conditions. This could lead to anything from slight resin degradation to a violent exothermic reaction (explosion). Before using strong oxidizing agents, consult sources knowledgeable in handling such materials.

Notice: No freedom from any patent owned by Seller or others is to be inferred. Because use conditions and applicable laws may differ from one location to another and may change with time, Customer is responsible for determining whether products and the information in this document are appropriate for Customer's use and for ensuring that Customer's workplace and disposal practices are in compliance with applicable laws and other governmental enactments. Seller assumes no obligation or liability for the information in this document. NO WARRANTIES ARE GIVEN; ALL IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ARE EXPRESSLY EXCLUDED.

