Designing Ion Exchange Systems

Part IV: Troubleshooting DI Systems

By C. F. Michaud

Even a well-designed and built DI system must be well maintained. The ability to recognize and correct demineralizer problems is equally as important as being able to design and build the system.

Servicing DI equipment is somewhat akin to servicing a complex electronic device. Having few, if any, moving parts, a deionizer running at peak performance and one that is not will look the same and sound the same. What's more, the starting point water does not undergo any obvious transformation that makes it distinguishable from the product water. It is even difficult to tell when a valve is open or closed, a pump is operating, or a line is pressurized. We must rely on instrumentation, logic and luck.

Over the past 10 years, I have received thousands of calls regarding DI performance. With rare exception, the problems have fallen into two categories: 1) mechanical problems (including instrumentation) and 2) misapplication. In short, properly designed equipment with properly selected resins will work - every time. I will try to qualify that statement.

DI equipment consists of mechanical equipment (tanks, valves, pumps, pipes and feed water), chemical equipment (resins, regenerants) and instrumentation. From day to day, only the feed water, regenerants and instrumentation change. These changes are small and not always in the same direction or wrong direction. Mechanical changes are generally abrupt. Their functions are "yes" and "no". A valve opens and closes. A pipe leaks or it doesn't.

Over its life, a resin degrades. This degradation is gradual. It is not even perceptible from day to day or even month to month. A measurable change in effluent water quality from one day to the next or a sudden change in quality is more apt to be a mechanical, instrument or regenerant problem than a resin problem. In fact, the chances of it actually being a resin problem are far less than 1%.

I make this statement in hopes of conveying a simple rule for troubleshooting. Problem solving requires an anchor position, a given benchmark around which all other variables and influences may be evaluated. Of all the things that can go wrong, resin is the least likely.

*Therefore, the first rule of DI troubleshooting is: **"Don't blame the resin."***

Logical Approach to Problem Solving

As with all problem solving, the best approach in solving DI problems is to first establish where you are before charting where you want to go. Have you properly defined the problem and documented all assumptions? Things are not always as they appear to be. Keep in mind that instruments go out of calibration, water analyses change and never make assumptions!

Over the years, many problems have arisen that could be termed as "classics". The following examples help demonstrate some of the frustrations frequently shared by troubleshooters and service reps. I have taken liberties with these descriptions to avoid revealing the "victims".

Case #1 - The Missed Approach

To avoid the complexity of stepwise sulfuric acid regeneration of a cation, a customer installed a softener ahead of a demin unit to remove the calcium. He installed regenerated forms of cation and anion and start up went smoothly. After the first regeneration, he was unable to obtain sufficiently low conductivity readings to bring the unit on-line again: His effluent was high pH, and he suspected a caustic rinse problem had developed with the anion unit. Increasing the rinse did not help. He tried a brine squeeze thinking organics may be to blame. No amount of fiddling with the anion regen procedure helped. He changed out the under-drains, adding underbedding to the system for improved distribution and minimizing hideout. The situation worsened. Thinking he may have inadvertently hit the original anion (hydroxide form) with hard water, he tried an acid rinse followed by a double regen.

The solution to this problem was simple - disconnect the softener. The high conductivity and high pH were indeed caused by sodium hydroxide. However, the sodium was coming from the cation - not the anion. The softener changed the feed to 100% sodium. The penalty was very high (10 - 15%) sodium leakage. This leakage was converted to sodium hydroxide in the SBA unit. Regeneration of the cation was then carried out with a 2% sulfuric acid without fear of $CaSO_4$ precipitation.

Case #2 - You Short-Shipped My Resin!

Needing to fill 20 1.8 ft^3 exchange tanks with mixed bed resin, the customer ordered 36 ft^3 of product. He filled each tank in sequence and ran out of resin with about two tanks to go. Noting that the drums of resin were not filled to the top, he claimed he was shorted about 10%.

There is a common misconception about ion exchange resin. Customers feel a cubic foot of resin should completely fill a one cubic foot space. This is not true! Resins are measured (and rated) by resin manufacturers as a backwashed volume in a one inch column only a few inches deep. This is to provide a reproducible volume measurement not subject to intermixing, compression and settling. These "shrinkages" can amount to 10% or more. The customer had actually overfilled his first 18 tanks.

Case #3 - Short Capacities

Wishing to avoid the hassles of having to multiple regenerate new resins on rebedding a small demin system, the customer ordered regenerated forms of both cation and anion resins. Start up was smooth, quality was fine, and the first runs were longer than expected. However, the next run was short. The third, although improved, was still shorter than the "original" design. A quick check of the water analysis showed no significant changes. He questioned the resin.

This customer had under-filled his vessels. Regenerated forms of SAC and SBA resins are more highly swollen than "salt" forms. To purchase an equivalent capacity of H^+ and OH^- form resins would require purchasing 106% of the cation and 116% of the anion requirements due to the swelling. Keep in mind that new resins purchased in regenerated form are much more highly regenerated than any field regeneration scheme will achieve. First runs may exceed the norm by 30 - 50%. This also causes an overrun situation resulting in a very short second run. Normal capacities usually return on the third cycle.

Case #4 - The Non-Silica Fouled Anion

Under pressure to decrease silica leakage and increase the per cycle throughput, the customer increased his anion regenerant level by 2 lbs/ft^3. The anion quality was generally better but the system was still being taken off-line due to silica break, not conductivity break. Further increases in caustic did not help much with respect to silica. He noted that after the initial silica break, his exchange tanks would frequently return to quality when he brought them back to the shop for testing. He was using Type II SBA.

His problem turned out to be his cation. Premature sodium break (due to under-filling the cation bottles) was causing the early sodium break (which is converted to NaOH in the anion) to regenerate a slight amount of silica off the bottom of the anion bed. Once the sodium/silica equilibrium was reached, the silica leakage would drop off (back at the shop). Assuring adequate cation levels can reduce this tendency, particularly with Type II's. We recommend Type I's for critical silica applications.

Case #5 - No Nukes is Good Nukes

Hoping to eliminate resin "taste", a water vending machine service company purchased "nuclear" grade mixed bed resins - having it on good authority that nuclear grade resins were "ultra-pure". They still complained of taste problems.

"Nuclear" grade resins are very high in purity from the standpoint of ionic species such as metals and chlorides left on the resin. They are very highly converted, and they do produce a very high quality water. However, nuclear grade resins are not "conditioned" from the stand point of residual organics which are the real factors contributing to taste from resin. A better recommendation would be to use a "semiconductor" grade of resin (cycled for low TOC) and follow this with a granular carbon filter.

These problems occurred primarily as a result of a misunderstanding on the working mechanisms of various resins. This helps to underscore rule #2 for the DI Troubleshooter.

*The second rule of DI troubleshooting is: **"Don't blame the resin"***

Conclusion

A Troubleshooting Guide is included as part of this article. Its purpose is to provide a working guide to suggest possible causes and solutions for a variety of symptoms.

Solving the persistent demin problem may require looking at two or more related events. The trick is to first determine exactly what you are observing. Poor quality is a result - not a cause. Find out the cause, and the solution will follow.

Resin manufacturers do not test their products for each type of field application. However, they do test each batch for physical and capacity properties to assure quality. If it looks right and tests right, it should work right. This brings us to rule #3.

*The third rule of DI Troubleshooting is **"Don't blame the resin."***

DI Troubleshooting Guide

Problem	Source	Cause	Remedy
Low Resin Capacity	1. Channeling of bed	1. Poor resin classification	1. Backwash to reclassify
		2. Blockage of distributors	2. Check distributors, screens
		3. Entrained air	3. Backwash
		4. Bed deposits	4. See below
		5. Excessive flow rates	5. Check controllers, limit restrictors
		6. Inadequate regenerant distribution	6. Check regen distributors & flow rates
		7. Low flow rates	7. Maintain minimum 2.5 gpm/ft.^{2} Use recirculation if necessary
	2. Bed deposits	1. $CaSo_4$ precipitation	1. HCl treatment. Use low conc. H_2SO_4 in regen
		2. Iron fouling	2. HCl or $Na_2S_2O_4$ treatment
		3. Oil fouling	3. Surfactant/alkali wash
		4. Bacteria fouling	4. Mild NaOCl treatment, backwash
		5. Silt, mud, clay, etc.	5. Harder backwash
		6. Silica fouling	6. Warm NaOH treatment and rinse
	3. Hills & valleys in bed	1. Blockage of distributors	1. Check distributors, screens
		2. Excessive flow rates	2. Check controllers, limit restrictors
		3. Shifting of bed support	3. Probe bed support, backwash to level
		4. Too violent a backwash	4. Adjust backwash flow, correct for temperature
	4. Changes in influent	1. Higher TDS	1. Shorten service cycle, increase regen
		2. Excessive flow rates	2. Aim for 1-2 gpm/ft.^{3}
		3. Lower inlet temperature	3. Low temp means low flow rates
		4. Change in influent makeup	4. Shorten service cycle or increase regen
		5. High influent temperatures	5. Prolonged contact above 120° F can cause permanent loss of SBA capacity.
	5. Inadequate regeneration	1. Clogged chemical lines	1. Check day tanks, valves, ejectors, spec. gravity of regen
		2. Lower regen strength	2. Analyze regenerant chemical
		3. Too short a regen cycle	3. Check timers, sequencers
		4. Inadequate slow rinse	4. Check timers, sequencers
		5. Wrong regenerant	5. Analyze regenerant chemical

DI Troubleshooting Guide

Problem	Source	Cause	Remedy
	6. Low resin volume	1. Resin loss to oxidation 2. Excessive backwash	1. Treat influent with residual Cl above 0.5 ppm. Deaerate if O_2 is high or use bisulfate chemical feeder 2. Adjust backwash, compensate for temperature, make up lost resin volume
Cation Leakage	1. Poor regen contact	1. Channeling of bed 2. Bed deposits 3. Leaks in multiport valves	1. See previous 2. See previous 3. Check flows before and after. Check for leaks.
	2. Inadequate regeneration	1. See previous 2. Poor rinse	1. ---- 2. Fast rinse cations to pH 3 and anions to pH 10 or below.
	3. Changes in influent	1. See previous	1. ---
	4. Improper design	1. Inadequate regeneration scheme 2. Improper flow design 3. Wrong resin choice 4. Bed too shallow	1. Consult technical manual 2. Consult technical manual 3. Consult technical manual 4. Increase resin depth to min. 30". Use underbedding. Check for resin leakage during regen or backwash.
	5. Bed fouling	1. $CaSo_4$ 2. Iron 3. Oil 4. Dirt	1. HCl treatment 2. HCl treatment (or hydrosulphite) 3. Warm surfactant, air lance, backwash 4. Adequate backwash
Anion Leakage	1. Poor contact	1. See cation (above)	1. See cation (above)
	2. Inadequate regeneration	1. See cation (above) 2. Low regenerant temperatures	1. See cation (above) 2. Increase temperature or regen level to remove silica

DI Troubleshooting Guide

Problem	Source	Cause	Remedy
	3. Changes in influent	1. See previous	1. See previous
		2. Poor cation quality	2. Na^+ leakage will cause silica leakage Increase regen on cation
		3. Increase in silica	3. Increase regenerant level
	4. Cation resin in anion	1. Broken bottom screen	1. Strong backwash on anion. Remove anion resin. Discard cation from bottom. Brine float if necessary. Repair mechanical. Make up cation shortage.
		2. Cation too fine	2. Use 16 - 40 mesh cation. Use smaller openings on cation collector screens
	5. Improper design	1. See cation (above)	1. Choose proper resin for the job
	6. Bed fouling	1. Iron	1. HCl treatment
		2. Ca^{++} or MgOH	2. HCl treatment
		3. Organics	3. Brine/caustic squeeze or NaOCl treatment
		4. Silica	4. Warm NaOH treatment and rinse
		5. Metal precipitate	5. HCl treatment
		6. Cation fines	6. See 4-2 above
Low Service Flow	1. Increase pressure drop	1. Dirt in bed	1. Backwash bed
		2. Soft resin. Resin fines	2. Possible resin is oxidized. Check resin moisture. Replace if high. Backwash resin fines from bed. Replace resin.
		3. Valve not opening	3. Check each valve for electrical or pneumatic connection.
		4. Blockage of distributors	4. Check distributors/screens
		5. Change in influent	5. Lower temperature influent will increase ΔP.
		6. Too long a distance Too small a pipe	6. Need larger pump or lines
		7. Drop in line pressure	7. Check influent line pressure. Changes in influent

DI Troubleshooting Guide

Problem	Source	Cause	Remedy
			service.
		8. Poor design	8. Too small a system. Too deep a bed.
Mixed Bed Problems	1. Clumping	1. Anion resin	1. Use de-clumping aid on anion
		2. Organic fouling	2. Caustic/brine entire bed. Double regen
		3. Resin "static"	3. Brine kill entire bed. Double regen
	2. Poor separation	1. Resin not exhausted	1. Brine kill entire bed. Double regen.
		2. Inadequate backwash flow	2. Increase B/W flow. Adjust for temperature.
		3. Cation fines	3. Brine float anion. Remove from vessel. Scrape or backwash cation fines out. Replace cation volume.
		4. Aged resin	4. Check cation moisture. Replace if high.
		5. Fouling by Ca^{++}, Mg^{++} or metals	5. HCl treat entire bed. Double regen
Resin Attrition	1. Mechanical	1. Excess flow rates	1. Max flow of 8-10 gpm/ft^2. Use low flow on colder water.
		2. Water hammer	2. Use slower closing valves, anti-shock device
		3. Excessive physical handling, transfers	3. Slower transfer rates. Use low impact pump or air transfer.
		4. Freeboard to shallow	4. Use lower backwash rate. Screen B/W outlet. Remove some resin.
		5. Air entrained in backwash	5. Deaerate backwash water
		6. Cold backwash water	6. Use lower backwash in winter months
		7. Broken screen or lateral	7. Check and repair
		8. Resin choice	8. Use tougher resin for job
	2. Chemical	1. Oxidation	1. Treat for excess Cl or O_2. Use higher X-linked resin.
		2. Osmotic shock	2. Reduce concentration of regen solutions
		3. Thermal shock	3. Allow bed to change temperature more gradually
		4. Resin choice	4. Use proper resin for job

DI Glossary Of Terms

Abbreviations: SAC (strong acid cation)
WAC (weak acid cation)
SBA (strong base anion)
WBA (weak base anion)

Acid: compound that can neutralize base; i.e. HCl, H_2CO_3

Acidity: a presence of anions associated with hydrogen low pH.

Affluent: what we all wish we were.

Alkalinity: a condition caused by presence of bicarbonate, carbonate, or hydroxide ions. Usually indicated by elevated pH.

Anion: negatively charged ion.

Base: compound that can neutralize acid; i.e. NaOH, $NaHCO_3$.

Bed Volume: space occupied by resin or other media. Does not consider void occupied by fluid. 1 ft^3 = 7.48 gal. = 28.3 liters.

Brine: a salt solution, usually sodium chloride.

Capacity: *Total* - a measure of a resin's absolute ability to exchange ions until effluent = influent
Operating - the practical capacity of a resin with well-defined parameters of breakthrough and regeneration level.
Kinetic - rate of reaction or exchange. Affected by temperature, pore structure and specific ion.
Volume - capacity/unit wt.; i.e. Kgr/ft^3
Dry - capacity per unit weight. Does not take into account the moisture content of the resin.
Salt splitting - that portion of the resin capacity capable of exchanging with neutral salts (i.e. NaCl) as opposed to simply neutralizing acid or base (i.e. H_2SO_4 or $NaHCO_3$).

Cation: positively charged ion.

Chloramine: a combination of chlorine and ammonia to form a disinfectant that is somewhat less reactive and less likely to react with organics.

Classification: (of resin bed) a size gradient of resin from the bottom (coarse) to the top (fine) of a bed. Accomplished by backwashing to minimize pressure drop and accomplish resin separation in mixed beds.

Colloidal: small non-ionized particle of compound. Too small for normal filtration and not responsive to ion exchange.

Color Throw: the color often associated with new cation or anion resin. Consists of "leftover" incompletely reacted compounds of manufacture. Rinses readily from resin.

Conductivity: a measure of ability of electric current to travel through a substance. Indicates relative amount of dissolved ionic material present in water. Pure water has very low conductivity.

Cross Linking: the ratio of divinylbenzene to styrene in common IE resins. Higher x-link provides a tougher resin with lower moisture. Generally, lower operating capacity due to lower kinetics.

Degasifier: device used to mechanically remove dissolved gases from water (i.e. CO_2 or oxygen).

Deionize: the removal of ions from water through ion exchange, plating, RO or distillation.

Effluent: what comes out.

Ejector: (eductor) device for drawing chemical into a feed stream. Works on venturi principle and vacuum.

Electrolytes: materials such as salts, acids or bases that conduct electrical current when dissolved in water.

Elution: removal of ions from a resin by regeneration.

Equilibrium: a static condition where the driving force governing a reaction equals zero.

Equivalent Wt.: the molecular weight of a substance divided by its valence.

Extrapolation: an educated guess at the proper value when we follow a curve off its graph.

Fines: small particles usually less than .3 mm (50 mesh)

FMA: free mineral acidity (the sum of chlorides, sulfates, nitrates, sulfites, phosphates, etc. that make up a water analysis). FMA usually excludes only weak acids such as H_2CO_3 and H_2SiO_3.

Free Base: the regenerated form of a weak base anion resin, WBA do not enter into typical "exchange" reactions. Rather they "absorb" acids completely.

Freeboard: the space above the resin bed and below the top or backwash distributor. 50% freeboard means there is a space above the bed equal to half the bed depth. Prudent design dictates 50-100% free board.

Free Chlorine: level of Cl° present as OCl- ion. Not combined with organics or base such as ammonia (see chloramine).

Free CO_2: CO_2 gas dissolved in water (carbonic acid).

Gel (resin): term applied to clear, jelly-like appearance of some IER's. Opposite of macroporous resins which have distinct, large physical pores. Gels are generally lower x-linked than macros.

Gram Equiv Wt: the weight of a substance, in grams, equal to its equivalent weight. NaCl is 23 + 35.5 = 58.5 It takes 1 gram equivalent of HCl (36.5 grams) to neutralize 1 equivalent of NaOH (40 grams).

Hardness: Combination of multi-valent ions in water. Includes calcium, magnesium, iron and other metals.

Headloss: pressure drop through a system. Measured in psi or ft. of head. 1 psi = 2.31 ft. of head. This is important to calculate when sizing a pump.

Influent: what goes in.

Leakage: the amount of ions coming from a resin bed during service. It relates to the thoroughness of the prior regeneration process.

Molecular Wt.: (atomic weight) a measure of the total number of protons and neutrons contained in an element or compound. This is a relative scale based upon Carbon = 12. Not to be confused with Atomic Number which is the number of electrons contained by an element. (i.e. H=1, C=6, O=8).

Monomer: single chemical building block capable of reacting with another monomer to form a chemical chain or polymer (i.e. styrene reacts to form polystyrene, ethylene to polyethylene).

Neutral: neither acid nor base. pH = 7.0.

Parallel: operating side by side at the same time. Opposite of series or sequential.

pH: negative log of hydrogen ion content. The scale runs from 0-14 with the lower numbers being more acidic, 7 is neutral and higher numbers being basic. 400 ppm of HCl in DI water has a pH = 2.500 ppm of NaOH has a pH of 12. Each reduction of 90% (1/10) is a reduction or increase of 1 pH point (i.e. 40 ppm HCl = pH 3.0, 4 ppm HCl = pH 4, etc.)

Polymer: a combination of many similar or dissimilar monomers reacted to form a compound having unique new properties. (i.e. polyethylene, polyvinyl chloride).Potable Water: drinking water that is free from harmful bacteria and meets criteria for specific ion concentrations.

Potable Water: drinking water that is free from harmful bacteria and meets criteria for specific ion concentrations.

Precipitate: an insoluble substance that forms from a combination of soluble substances. (i.e. $CaSO_4$ from CaCl + Na_2SO_4 or $Mg(OH)_2$ from $MgSO_4$ + NaOH).

Recycle Regen.: to reuse acid or caustic. Usually the last 1/2 to 2/3 of a spent regenerant is used as the first 1/2 of the next regeneration cycle.

Regenerant: an ionic chemical used to restore an IER to its original form. Regenerants for DI resins usually are acids (H^+) or bases (OH^-). Softeners and dealkalizers use salts (Na^+ and Cl^-). This is measured as 100% active chemical regardless of the concentration of which it is supplied.

Salt: any product of neutralization between an acid and a base, i.e. NaCl, KNO_3 or $MgSO_4$.

Sequential: See Series.

Series: See Parallel.

Slippage: (or bypass) level or ions passing through a resin bed during service. This relates to simple inability of an IER to react fast enough (usually a result of too high a flow rate for a given bed volume).

Softening: removal of divalent scale causing ions (i.e. Ca^{++}, Mg^{++}, Fe^{++}). See Hardness.

Resistance: (specific) the electrical resistance of water and its ions within a specific distance of a one centimeter cube. Opposite of a conductance (measured in ohms). Resistance is measured in mhos. 1 micromho (.000001 mho) = 1 megohm (1,000,000 ohms).

Stratified Bed: a mixed resin type, usually WAC, SAC or WBA, SBA layered in the same tank.

Strong Acid: a highly ionized acidic substance. (i.e. HCl, H_2SO_4 or HNO_3). These are considered strong acids even in dilute solutions.

Strong Base: a highly ionized basic substance. (i.e. NaOH or KOH). These are strong bases even in dilute solutions.

Surface Velocity: refers to unit flow per unit area. Usually reported in gpm/ft^2.

TDS: total dissolved solids. Usually ppm or mg/l.

TOC: total organics carbon (organic).

TSS: total suspended solids (particulate).

Valence: the number of positive or negative charges an ion possesses, i.e. H+=1, Ca++=2, Al+++=3, Cl-=1, SO4--=2, PO4---=3.

Weak Acid: weakly ionized acidic substance, i.e. carbonic acid.

Weak Base: weakly ionized basic or alkaline substance, i.e. ammonium hydroxide.

Zeolite: a natural and/or manmade inorganic compound having the ability to enter into water softening reactions. Also called "mineral". Not to be confused with ion exchange resins.

About the Author

Chubb Michaud, author of this four-part series, is a chemical engineering graduate of the University of Maine and has been involved in ion exchange water treatment for over 10 years. He is a founder of Systematix Co. of Brea, CA and represents Purolite Co. in the Western States.