



Basics of Deionization

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Introduction

Deionization, also referred to as *demineralization*, is an ion-exchange process wherein virtually all of the dissolved ions in the water can be removed, producing pure water.

Depending on the type and combination of equipment, deionization can produce a purity from 100,000 ohms/cm to 18 million ohms/cm (or mega-ohms/cm).

Measurement of purity

Water purity is measured in units of *resistivity* (ohms/cm) or *conductivity* (microsiemens/cm). Resistivity and conductivity are reciprocal of each other, meaning as resistivity goes up, conductivity goes down, and vice versa. In pure water application, purity is typically measured in resistivity because conductivity would be too low to be measured accurately. Fig. 1 shows an example of this relationship. Purity is relative. For example, a pharmaceutical application may only require a 100K (100,000 ohms/cm) purity whereas a circuit board manufacturer may need at least a 10 meg (10 million ohms/cm) purity.

Resistivity (ohms)	Conductivity (microsiemens)	
18,000,000	0.055	← Ultra Pure
10,000,000	0.1	
100,000	10	← Pure
2000	500	← Typical Tap Water
200	5000	
20	50,000	← Seawater

Fig 1

Types of solids

Water dissolves minerals by dissociating the minerals to cations (+) and anions (-). For example, sodium chloride (NaCl), a table salt, will dissolve in water by dissociating to sodium (Na⁺) cation and chloride (Cl⁻) anion. The dissociated ions, having ionic charges, are easily removed by deionization.

Some gasses like carbon dioxide (CO₂) reacts with water to form carbonic acid (HCO₃) which dissociates to 2H⁺ and CO₃⁻². Likewise, these ions are easily removed by deionization.

Other solids, when dissolved in water, do not dissociate to ions, but they have enough density of charges that allow them to bridge with the water molecule. Examples are organic compounds like sugar, alcohol, and solvents. Although they do not dissociate to ions, they impart some ionic charges, and thus can be removed by deionization.

Lastly, other compounds like hydrophobic organics and some biological matters, when mixed in water, are non-ionic, and thus cannot be removed by deionization, but can be removed by other equipment such as multi-media filters, activated carbon filters, and reverse osmosis.

Types of resin

A deionizer (also referred to as DI) uses 2 opposing charged resins (cationic and anionic). The cationic resin removes the cations. The anionic resin removes the anions.

The cationic resin is typically made from styrene containing sulfonic acid groups which is negatively charged. Although the resin is actually negatively charged, it is called a “cationic” resin, referring to the cations that it will exchange. This resin typically comes in the hydrogen ion (H^+) form, meaning it is precharged with hydrogen ions on its exchange sites.

The anionic resin is typically made from styrene containing quaternary ammonium groups which is positively charged. Likewise, despite its positive charge, it is called an “anionic” resin, referring to the anions that it will exchange. This resin typically comes in the Hydroxide ion (OH^-) form, meaning it is precharged with hydroxide ions on its exchange sites.

Both resins can be strongly or weakly ionized. Cationic resin is referred to as *strong acid* or *weak acid*. Anionic resin is referred to as *strong base* or *weak base*. The basic difference is the weakly ionized resin will exchange only the weak ions, whereas a strongly ionized resin will exchange both weak and strong ions, but at the expense of a reduced capacity.

The strong base anion comes in type 1 or type 2. The basic difference is type 1 can remove silica and CO_2 better than type 2, but likewise at a reduced capacity.

There are other variations of resins to consider, with each providing its own advantages and disadvantages, such as, thermal, physical, and chemical stability, oxidation and organic fouling resistance, kinetics, and costs. Suffice it to say that one must choose the proper type of resin to fit the application.

Dual and mixed beds

Deionizers come in dual-beds or mixed-beds. In a dual-bed system, the cationic resin and the anionic resin are in separate vessels. Whereas in a mixed-bed, the cationic and the anionic resins are mixed in a single vessel. This is also called a single-bed DI.

In a dual-bed DI (Fig. 2), water is first passed through the cationic vessel where the cations in the water are exchanged with the hydrogen ions from the resin. The cationic resin, having a greater affinity for the cations, releases the hydrogen ions while grabbing the cations. The released hydrogen ions form acid with the remaining anions in the water. This water is then passed through the anionic vessel where the anions are now exchanged with the hydroxide ions from the resin. Similarly, the anionic resin, having a greater affinity for the anions, releases the hydroxide ions while grabbing the anions. The released hydrogen ions (H^+) from the cationic vessel and hydroxide ions (OH^-) from the anionic vessel now combine to form HOH or H_2O .

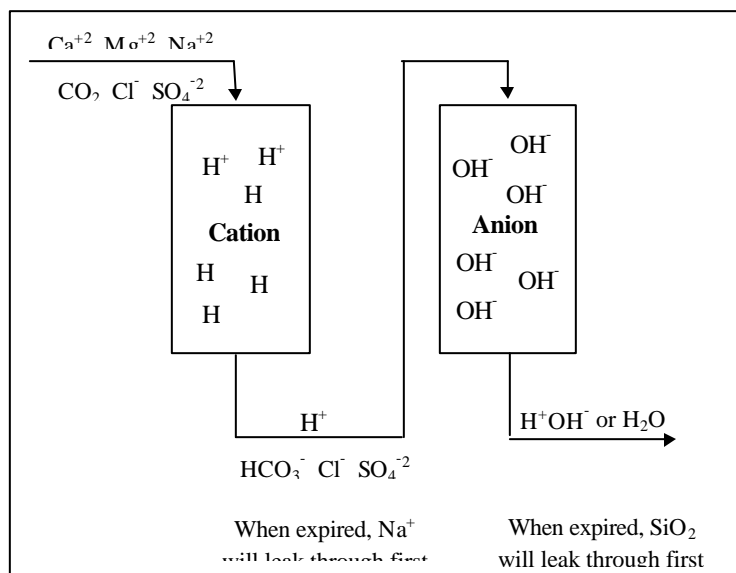


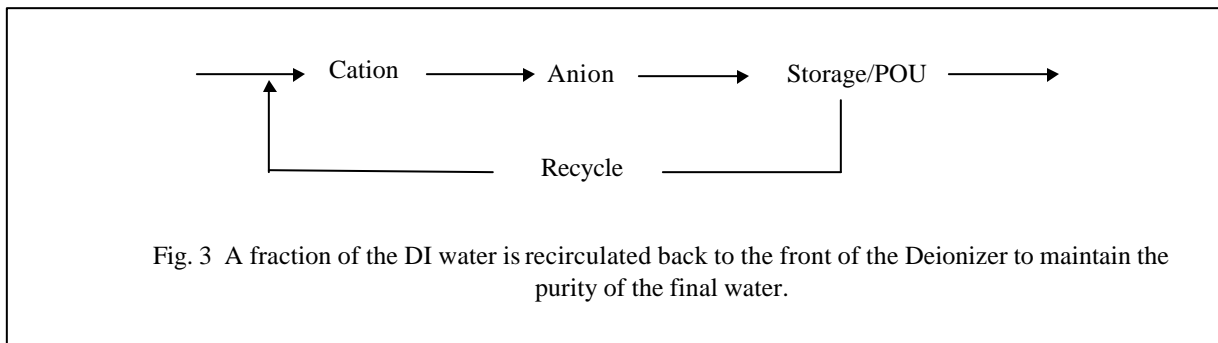
Fig 2. Typical Dual-Bed Deionizer

Not all of the ions will be exchanged. Some of the ions will slip by. If the DI water can be passed through the dual-bed again, the DI will have another chance to remove the ions that slipped by the first time. Each time this pass is repeated, more ions are removed and exchanged, producing an even purer water. In a mixed-bed, the water passes through the cationic resin and the anionic resin repeatedly virtually for an infinite time. As such, the resulting water is usually ultra pure. A mixed-bed can produce over 10M-ohm water, whereas a dual-bed typically produces only a 50K-100K water. Other variation is a combination of dual-bed and mixed-bed, where the mixed-bed is used as a polisher. Such set-up can produce ultra pure water up to 18 mega-ohm/cm.

Recycling the DI water

If the flow through the DI is temporarily halted, the water in the vessels will begin to take back the impure ions from the resin. When the flow is resumed, the first few gallons will usually be below specs. To prevent this, the DI water can be recycled back at a fraction of the service flow rate to the front of the DI to keep the water moving and the purity up. See Fig. 3

This method is also used where the DI water is stored after the deionizer. If the water is not used immediately, it will absorb gasses like CO₂ and other air-borne particles, reducing the purity of the water. To prevent the water from falling below specs, it can also be recycled back to front of the DI for similar benefits.



Expiration

Eventually the resins will expire, as all the hydrogen and/or hydroxide ions are expelled, and all the exchange sites are filled with impure ions. Thereafter, the DI will no longer remove any subsequent impure ions, allowing them to leak through, reducing water purity.

The most common indicator of a DI expiration is a sudden and significant drop in the resistivity of the DI water.

There are other indicators. When the cationic resin expires, the first ion to leak through will be Sodium (Na⁺). When the anionic resin expires, the first ions to leak through will be Silica (SiO₂) and/or carbonate alkalinity (CO₃⁻²).

Regeneration

To bring the water purity back to spec, the DI must be regenerated. Most DI are regenerated based on resistivity, while others are based on the ion leakage.

The cationic resin is regenerated with acid to replace the hydrogen ions. The preferred acid is Hydrochloric Acid (HCl), typically 20°Be (32%) @ about 2 gallons per ft³ of resin.

The anionic resin is regenerated with caustic to replace the hydroxide ions. The preferred caustic is a Rayon or Mercury grade Sodium Hydroxide (NaOH), typically 50°Be (50%) @ about 1 gallon per ft³ of resin.

A dual-bed can be regenerated in series or parallel. Series regeneration means the cationic vessel is regenerated first, then it supplies the water to regenerate the anionic vessel. Parallel regeneration means both the cationic and anionic vessels are regenerated

simultaneously, reducing regeneration time, and enabling the DI to be returned to service faster. With a parallel regeneration, an alternate softwater or equivalent must be used to regenerate the anionic vessel, to prevent fouling the anionic resin. An alternate softwater or equivalent must also be used to regenerate mixed-beds for the same reason.

In a dual-beds, the regenerants are typically introduced downflow the resin beds and discharged through the risers. In a mixed-bed, the cation and anion resins are first stratified via backwash. The cation resin - being heavier than the anion resin - will settle at the bottom half. The acid is introduced at the bottom, while the caustic is introduced at the top. The regenerants meet at the interface collector at the middle of the tank where they are discharged. After regeneration, compressed air is introduced to re-mix the resins.

Neutralizing the spent regenerant

The resins have greater affinity towards the impure ions than the hydrogen and hydroxide ions. As such, the resins will release the hydrogen and hydroxide ions during the service cycle, to grab the impure ions. In order to reverse this preference during regeneration, the DI is regenerated with "excess" regenerants (hydrogen and hydroxide ions) to literally force the impure ions off the resins. Only a fraction of the regenerants is used. Most of the regenerants, along with the released impure ions, are discharged. To prevent the discharge of spent acid and caustic to the sewer, they are typically routed to a neutralization tank where they neutralize each other. Further adjustment of the pH may be necessary to comply with the final discharge requirements of the local water district.

Sizing the deionizer

Cationic resin is rated at about 20,000 grains per ft³ @ 2 gal HCl regenerant per ft³ of resin. Anionic resin is rated at about 12,000 grains per ft³ @ 1 gal NaOH regenerant per ft³ of resin

Despite the higher capacity of the cationic resin, dual-beds typically come with equal amount of cationic and anionic resin. In essence, the cationic vessels are oversized, because they also supply the regenerant water for the anionic vessels. Mixed-beds come with a 40/60 blend of cationic and anionic resin.

Non-ionic treatment

Deionizers do not remove non-ionic solids such as hydrophobic organic and some biological matters. Since these particles may be present in water, it would be prudent to add other equipment such as multi-media filters, activated carbon filters, reverse osmosis, and/or ultra-violet light to remove the non-ionic solids and to keep microbiological growth and fouling under control. If the water contains significant amount of dissolved gasses like CO₂, removing them mechanically via degasifiers may be more cost efficient.

Conclusion

There are many factors that should be considered in designing the right deionization System. Aside from the typical volume, flow rate, and pressure, a dealer should also know the application, desired purity spec, and the impurities in the raw water. Armed with this information, it can then engineer the right combination of equipment and resins to produce the required water purity.