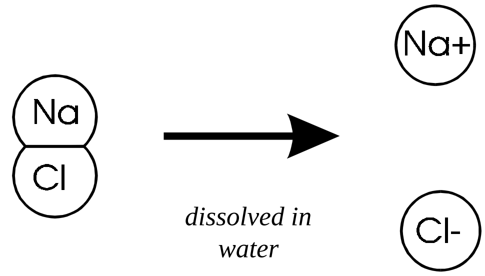
trionetics, inc.

Application Note
Ion Exchange & DI - How it Works

Background

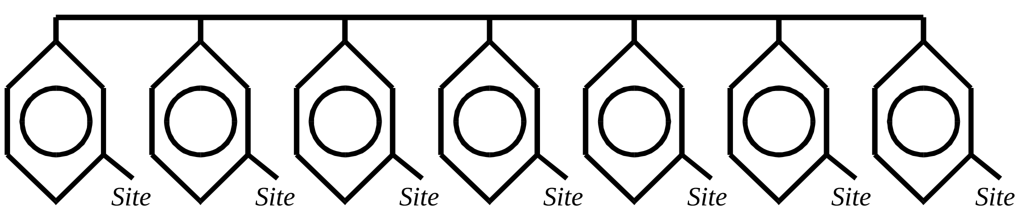
Soluble chemical compounds, when dissolved in water, become *ionized*; that is, their molecules dissociate into positively and negatively charged components called *ions*. Consider common table salt, sodium chloride. In its solid form, this compound consists of one sodium atom (Na) and one chlorine atom (Cl) tightly coupled together (NaCl). When dissolved in water, however, the compound splits into two ions, Na+ and Cl-.



Absolutely pure water is a very good insulator; that is, it resists the flow of electricity through it. With ions present, however, electricity will flow through water. Positive ions tend to migrate towards the cathode, or negatively charged electrode and are called *cations*. Negative ions flow towards the anode, or positive electrode, and are called *anions*. Because of this effect, measurement of the resistance of water is a very good indication of how pure it is: the higher the resistance, the purer the water.

Ion Exchange

Contaminant ions can be removed from water in a process called *ion exchange*. As the name implies, contaminant ions are not merely removed from the water; instead, they are *exchanged* for another kind of ion. This process occurs in ion exchange *resin*. These resins are usually long chain hydrocarbons such as polystyrene. Attached to these long chain molecules are *sites* that, because of their chemical makeup, tend to attract and hold ions. Ion exchange happens at these sites.

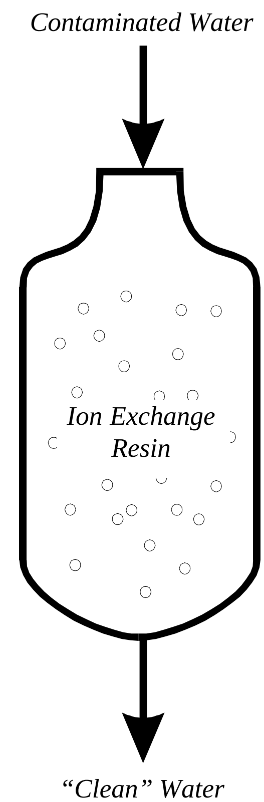


Resin is formed into small porous beads to increase the number of sites that are exposed to water and can participate in ion exchange.

Initially, resin is loaded with a harmless ion, usually hydrogen (H+) for cations and hydroxide (OH-) for anions. As waste water passes through the resin, the contaminant ions in the water displace the harmless ions from the sites on the resin. This is because the resin has a greater *affinity* for the contaminant ion. Affinity for most resins is based loosely on ionic size and charge. In general, affinities are as follows:

single charge ions (H+, Na+) < 2 charges (Ca++, Mg++) < 3 charges (Fe+++) < etc.

Although ion exchange sounds complex, practical implementation is very simple. Water, contaminated with some dissolved ionic species (dissolved metals, cyanide or some other pollutant), is passed through a column filled with ion exchange resin. Water is discharged from the bottom of the column with little or undetectable concentrations of contaminants. Sites closest to the entrance fill up first. This means that resin at the top of the column will become loaded first. If the column were made of glass you could actually watch as the column loaded from the top down. Copper contaminants change sand-colored resin to blue, for example.



When most of the sites in a resin column are occupied by a single type of ion, then the resin is said to be *loaded*. As the sites begin to fill up, chances decrease that a contaminant ion will encounter a site occupied by an ion it can displace. This means that the closer to loaded a column is, the more likely it is that contaminants will pass through the column (this is called *leakage*).

The contaminated solution must remain in contact a certain amount of time in order for all contaminant ions to find a site to exchange with a harmless ion. If the flow rate through the column is too high, reducing conatct time with the resin, all contaminants may not be removed.

Regeneration

After a column has become loaded, there is a way to restore it so it may be used again and again. *Regeneration* involves displacing the contaminant ions removed from waste water and replacing them with harmless ions to allow the process to start all over again. This sounds impossible: after all, the only reason the harmless ions were exchanged for contaminant ions in the first place was the resin's greater affinity for them. The affinity is so great that almost imperceptible amounts of contaminant ions are left in the water after flowing through the column.

The key to regenerating Ion Exchange systems is concentration. Typical concentrations in waste water being treated are on the order of 15 ppm, or about 0.5 mM. Columns are regenerated with acid or caustic concentrations of 1000 mM or greater. This 200,000% difference in concentration literally knocks the contaminant ions out of occupied sites and replaces them with harmless ions.

The greater affinity of resin for contaminant ions is very real and hard to overcome. Indeed, some resins cannot be regenerated at all; they have to be replaced after becoming loaded. Because of the extremely high concentrations of the regenerant chemicals compared to the concentration of contaminant in the waste water being treated, contaminants are knocked out of the resin sites and end up in the chemical being used for regeneration. No volume is added to the regenerant, but the concentration is reduced. Regenerating at less than designated regenerant strength requires more regenerant chemical and more time to get a complete regeneration. At the same time, there are upper limits to how strong the regenerant can be. Too much concentration will damage the equipment or destroy the resin.

DeIonization (DI) Systems

DI Systems are fairly simple in theory. Since all contyaminants dissolved in water separate into positivley and negatively charged ions, if we use two different resins, one that is cation specific and one that is anion specific, we should be able to remove all ions, and thus all impurities from wate.

Separate Bed DI Systems

In Separate Bed DI Systems, ion exchange occurs across at least two different columns. The first is a *cation* column, which is filled with resin loaded with positive hydrogen ions (H+). As water passes through this column, the positively charged impurities in the water (such as sodium [Na+], magnesium [Mg++] and calcium [Ca++]) are exchanged for the hydrogen ions.

A similar exchange takes place in the second column, the *anion* column. This column is filled with resin loaded with negative hydroxide ions (OH-). As the now cation-free water from the cation column passes through, any negatively charged contaminants (such as chloride and sulfate) are removed from the water and replaced by hydroxide ions from the resin. The water now has a neutral pH (hydroxide [OH-] and hydrogen [H+] ions exchanged in the columns combine, forming water [H_2O]) with high resistance, typically greater than 1 meg-ohm/cm^2.

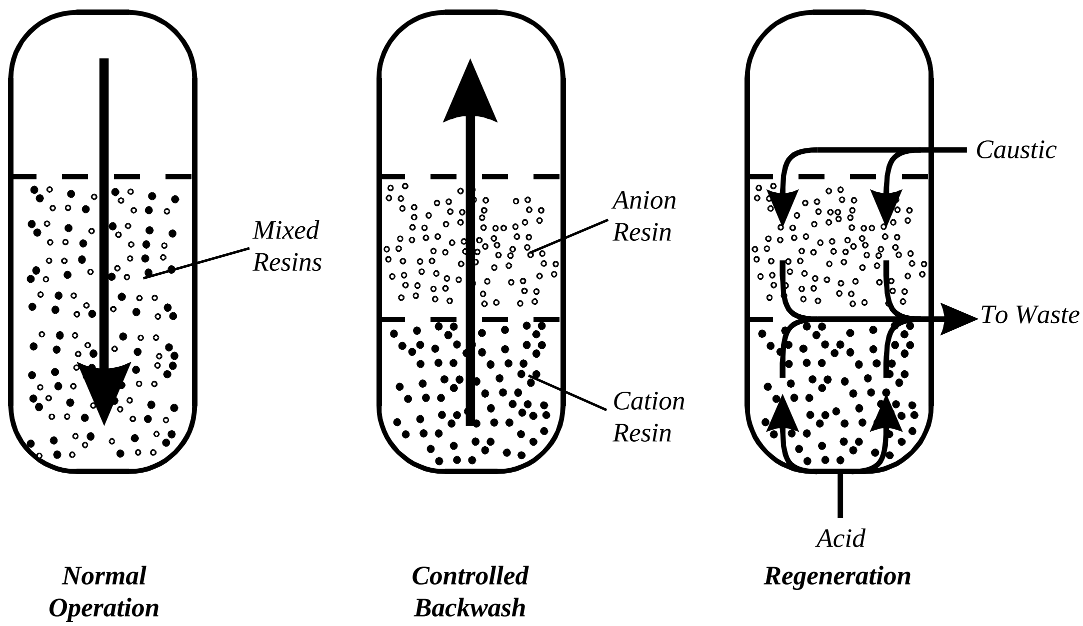
Further improvements in water quality can be made by adding yet another column. As mentioned before, the cation resin will show a greater affinity for Magnesium (Mg++) or Calcium ions (Ca++) than for Sodium ions (Na+) because of their higher charges. If there is a large concentration of Magnesium and/or Calcium in the influent, Sodium will leak through the leading cation column. In the anion column, sodium will combine with freed hydroxide ions (OH-) forming sodium hydroxide (NaOH), which is alkaline and raises pH. Another cation column can be installed following the anion column to remove any residual sodium ions and return pH close to 7.0 SU. Because most cations are removed in the first column, the trailing cation column will load much more slowly than the first. Systems are usually set up so that the trailing cation column only regenerates every fifth time the leading cation column regenerates.

Mixed Bed DI Systems

In a Mixed Bed DI System water is purified by removing all ions in one pass through an ion exchange bed. The bed itself consists of two different ion exchange materials, so that ions are actually removed in the same two step ion exchange process.

Normally, water enters the top of the column, flows down through the mixed bed and treated water exits at the bottom of the column. The two different resins are mixed together. To regenerate both resins in the mixed bed, they must be separated so that the acid for cation regeneration does not exhaust the anion resin and the caustic for anion regeneration does not exhaust the cation resin.

This separation is accomplished by backwashing at a controlled rate. Water enters at the bottom of the column, flows upward through the mixed bed and exits at the top of the column. The anion exchange resin is lighter and separates from the heavier cation resin, rising to the top. Accurately placed distributors make it possible to feed acid and regenerate only the cation resin without contacting the anion resin. Similarly, the anion resin is regenerated with caustic without disturbing the cation resin. Both resins are regenerated at the same time.



After both resins have been regenerated, they are thoroughly mixed by injecting air into the bottom of the column. Two columns are usually provided so that one column may always be treating water while the other is being regenerated.

Testing Water Quality

Contaminants dissolved in water tend to dissociate into positively and negatively charged ions. Impressing an electrical voltage across such a solution will cause the ions to move to the electrodes of opposite charge, causing a current to flow. Therefore conductivity is a direct measure of the ions present in water; the higher the conductivity, the more contaminants present in the water.

Most Mixed Bed DI Systems operate with such low electrolyte (ion) levels in the treated water that conductivity readings are too low for convenient use. Resistance, the reciprocal of conductivity, has a range of values from 500,000 to 15,000,000 ohms (15 Mega ohms) for more convenient scale readings. The resistance of pure water has been calculated to be 26,000,000 ohms (26 Mohms). Water after three distillations in glass has a resistance of approximately 1 Mohm. The resistance of treated water from Seaprate Bed DI Systems is about 1-2 Mohms, 5 Mohms with a trailing cation column and a Mixed Bed DI System is usually well over 10 Mohms.