WATER DEIONIZATION

Notes about principles and plants

The salinity of water

The water available from well and other sources usually contains many dissolved substances of several origin and type.
Most part of them are salts of calcium, magnesium, potassium and sodium, the so called "salinity" of water. It is different from sample to sample according to the type of rocks and minerals the water has flown through. For example the rain water does not have any salinity, except the small quantity due to the atmospher, while the sea water has a very high salinity. These two examples are the two ends of the samples, while between them there are all the rest that we commonly face: water from well, from spring, from surfaces sources (rivers, lakes). They can have very different salinity; water from a spring in high mountain usually have a very low salinity like rain water, while water from a well along the coast can be brackish and have very high salinity.
The salts are dissolved in water as "dissociated" form; indeed they are like "broken" in two separated parts, one with a positive electrical charge (called cation) the other one with negative one (called anion).
Owing to the presence of cations and anions in water, it is an electrical conductor, and its conductivity depends on the quantity of ions the water itself contains.
Therefore, the conductivity can be used to approximately indicate the salinity of water, although not all the salts are dissociated the same way.
A water with low conductivity will be a low salinity water, while high conductivity means water with high quantity of dissolved ions and then high salinity.

The salinity of water can cause serious problems, according to its value and the utilization of water.
There are many process to remove salinity off the water (distillation, reverse osmosis, etc.); this bullettin concerns one the most diffused of them, the deionization by ion exchange resins.

Ion exchange resins for deionization

The resins are horganic substances, industrially prepared.
Their special characteristic is that they have a "mobile" functional group, on a base called matrix. The functional group is a part chemically balanced between the matrix of the resins itself and the ions dissolved in the water. The cation resins will have the fiunctional group balanced with cations , while anion resins will be with anion. This way allows the exchange of ions between the resins and the water.
A cation resin can exchange cations when its functional group is "equipped" with a sodium ion or hydrogen ion. The first case, the resin can exchange only ions of calcium and magnesium, and releasing sodium (Na+)to the water, so this resins can be used for softening only (see bullettin "softening").

The second case, instead, the resin can exchange all the cations in water, releasing hydrogen ion (H^+). This way allow to get water completely free of cations, and containing only the acids (the anions) related to the dissolved salts.

An anion resin, instead, can exchange anions when its functional group is "equipped" with an hydroxyl (OH^-). Therefore, whether a water completely free of cations flows through an anion resins, the final result will be a water completely free of cations and anions, hence a water completely free of salts (deionized water).

The chemical reactions of the above descriptions are:

cation excange

R-H	+	C^+	↔	R-C	+	H^+
cation resin in hydrogen form (regenerated)		cation (generic)		cation resin (exhausted)		hydrogen ion

anion excange

R-OH	+	A^-	↔	R-A	+	OH^-
anion resin in hydroxyl form (regenerated)		anion (generic)		anion resin (exhausted)		oxidryl ion

deionization (sum of both)

$$R\text{-}H + C^+ + R\text{-}OH + A^- \leftrightarrow R\text{-}C + R\text{-}A + H^+ + OH^-$$

Where C^+ and A^- stands for the ions (salinity as dissociated form), while H^+ and OH^- will join to form water (H_2O).

The exhausted resins can be regenerated, meaning to re-built the originary form, according to the above mentioned reactions.
For example if we increase very much the concentration of H^+ ions (see cation exchanging reaction) the reaction itself will be balanced towqards left part of the same, so the resins in H^+ form is reproduced and cations are released.
The same will happen for anion exchanging whether we increase concentration of OH^- ions. Since H^+ ions are typical of acid and OH^- of alkanine, the regeneration of the resins is featured by flowing hydrochloric acid (HCl) or sulphoric acid (H_2SO_4) through cation resins and causic soda (NaOH) through anion resins.

The practical application of the above theorical principle is a little bit more complicated that how it appears. There are many other factors, not considered until now, that can influence the ion exchaning and the deionization process. One of them is the fact that it is quite impossible to exchange all cations and anions (then to remove it off water); the above mentioned reactions is a balance, then it is obvious that there will be always a leakage of some ions and, therefore, a residual of salinity in treated water.

When deionized water is required, it is important to specify the quality, hence the max allowable value of salinity, according to the application of a deionizer.
It will allow to select and/or design the most suitable deionization system for the application,and according to the quality of the available raw water.
Indeed several type of resins (cation and anion) are available, with very different charactiestics of structure, performances, etc.. The utilization of these resins is usually selected according to the special case, in order to always identify the most suitable deionization system.

The below list shows some of the available resins, with short notes about their utilization.

Strong cation resins (solphonic)

They are the most commonly used in deionization system. These resins allow to remove all cations contained in water.

Weak cation resins (carboxilic)

The most typical characteristics of these resins is that they can exchange only some cations, exactly the cations correspondent to the bicarbonates contained in water.
They are manly used for dealkalization of water, as purpose of treatment or as a first stage for a total deionization. They are also used as a buffer resins, to remove leakage of residual sodium ions released from strong cation resins.
The ratio chemical for regeneration/exchange capacity is very high for this type of resins, and higher than the one of the strong cation ones.
It is even possible to regenerate these resins using as a chemical the waste of the regeneration of the strong cation resins.

Weak anion resins

The characteristics of these resins is that they can exchange only some anions, and hence they are used a intermediate stage of final polishing, when the removal of bicarbonates and silica is not required.
The quantity of chemical required for regeneration is very shorter than the one for strong anion ones.

Strong anion resins

These resins allow to remove all anions contained in water, hence they are used for last stage for deionization process.

The subject is not concluded, since there are some resins with higher or lower exchange capacity, selective resins to remove particolar cations or anions, etc. The choice of the most suitable resins and the combination of them is usually made according to the raw water and the required quality of treated water.
A deionization line includes a combination of more type of resins used one after one. One deionization system is different from another one for the dimensions, construction characteristics, the type of the resins used, the system of how to make regeneration.

Deionization lines

Naturally, many and different lines of deionization are designed. These notes concern only some of the most diffused.
The main frame of a deionization line consists of a bed of strong cation resins and a bed of strong anion resins (standard line of a separated bed system); they work as above explained way.
The water treated by a similar line of deionization will have a value of conductivity between 3÷10 µS/cm (resistivity 300 ÷100 kΩ x cm). It must be noted that these values and other values connected to, (like pH) are influenced by the quality of raw water and the operating features of the system (flow rate, linear flow, regeneration level); this influences is very important for each type of deionization line.

The water treated by a separated bed system can be further deionized, in order to improve the quality:
for example the treatment by a weak cation resins (carboxilic) will allow to remove quite all the residual of sodium ions (with also a neutral pH), while the treatment by a mixed bed resins will remove all residual of salinity, with a neutral pH of treated water and a conductivity of approx 0.1 µS/cm (resistivity 10 MΩ x cm).
A mixed bed is just a deep mixing of strong cation resins and strong anion resins; they work the same way of many separated bed systems on serial line.
It is obvious that each "micro-bed" will treated water with salinity slightly lower than the preceeding "micro-bed", hence the water treated by a mixed bed system will be highly deionized.
However, mixed bed systems are mainly used as a polishing line, further to a separated bed system; it is not often used as main treatment, except for small plant.
It is caused mainly by the "delicate" system of regeneration (resins must be separated, first, then regenerated nad, after that mixed again).

It often happens that a water to be treated contains an high quantity of bicarbonates (related at the total anoins), then it can be more suitable to remove them by chemical-phisical process than by anion resins. Indeed, bicarbonates are balanced with carbon dioxide, a gas not very soluble in acid water. The water treated by a cation resins has a pH very low (acid), so it is very easy to remove carbon dioxide of bicarbonates.

HCO_3^-	+	H^+	$\leftrightarrow$	CO_2	+	OH^-	H^+
ion bicarbonate		hydrogen ion		carbon dioxide (gas)		oxidryl ion	hydrogen ion

where H^+ and OH^- will join to form water (H_2O).

The carbon dioxide is removed by a proper tower, named decarbonatation tower; the water rains in the tower from the top while air is injected by the bottom of the tower itself.
The dealkalized water, containing a very small residual of carbon dioxide, is collect in a tank placed below the tower. A proper pump will force the water to the anion exchanger.
Such a plant like this will be more expensive because of the tower, tank and pump than a standard separated bed system but, the plant with tower will have a shorter quantity of anion resins and then a shorther consumption of chemicals for regeneration.

Then the higher initial cost will be compensate by saving the chemicals: naturally, the higher is the quantity of treated water, the faster will be the balance in cost. That is the reason for which the system with tower is used mainly for large capacity system.
It should be also noted that the dealkalization can be also the only purpose of treatment; many industrial processes (beer brewery, for example) use dealkalized only water and not deionized.

The lines described above can also be modified/integrated by designer, including weak resins exchangers (cation and anion) to basic system of strong cation and anion ones.
These systems are used when very high quantity of water is treated and the higher cost is compensated by saving up of chemicals.

Deionization plants

A deionizer system consists of several vessels filled with proper resins; the water simply flows through the resins.
But, the deionizer must also allow to make the regeneration of the resins; hence there are several types of softeners, different not only for the dimensions and other chgaracteristics explained above, but for the way the regeneration is featured.
The principle of working is basically the same as above explained, but the systems of regenerations have been continuously developed; now sophisticated systems with electronic control are used.
Hwever, it is important to specify that there are systems that warranty reliability, long term dependability, accuracy in measurement and control; besides other systems are available, they can work and they can produce treated water but do not meet modern standard of reliability for industry.
Indeed, very delicate systems with simple multi-port valves are available, where there is not any possibility of checking, control, adjustment of time of the steps of regeneration-service.
Otherwise there are other systems with automatic facilities including single valves to divert the flows during regeneration/service, driving of the valves via solenoid valves and electronci cycle programmer. This control allows to adjust and modify the time of each step, to check and adjust the flows of regeneration and service and so on; besides, these systems are usually equipped with synoptical visualization of the whole flow system.

This bullettin is provide only as general directions about the principles and applications of water deionization.

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