Ion Exchange Technology Overview

Ion exchange is a reversible chemical reaction wherein an ion (an atom or molecule that has lost or gained an electron and thus acquired an electrical charge) from solution is exchanged for a similarly charged ion attached to an immobile solid particle. These solid ion exchange particles are either naturally occurring inorganic zeolites or synthetically produced organic resins. The synthetic organic resins are the predominant type used today because their characteristics can be tailored to specific applications.

An organic ion exchange resin is composed of high-molecular-weight polyelectrolytes that can exchange their mobile ions for ions of similar charge from the surrounding medium. Each resin has a distinct number of mobile ion sites that set the maximum quantity of exchanges per unit of resin.

Ion exchange reactions are stoichiometric, (i.e., predictable based on chemical relationships) and reversible. The strategy employed in using this technology is to exchange somewhat harmless ions (e.g., hydrogen and hydroxyl ions), located on the resin, for ions of interest in the solution (e.g., regulated metals). In the most basic sense, ion exchange materials are classified as either cationic or anionic and in that way they are similar to other solution phase reactions. For example:

$NiSO_4 + Ca(OH)_2 = Ni(OH)_2 + CaSO_4$

In this reaction, the nickel ions of the nickel sulphate ($NiSO_4$) are exchanged for the calcium ions of the calcium hydroxide [$Ca(OH)_2$ molecule. Similarly, a resin with hydrogen ions available for exchange will exchange those ions for nickel ions from solution. The reaction can be written as follows:

$2(R\text{-}SO_3H) + NiSO_4 = (R\text{-}SO_3)_2Ni + H_2SO_4$ (2)

R indicates the organic portion of the resin and SO_3 is the immobile portion of the ion active group. Two resin sites are needed for nickel ions with a plus 2 valence (Ni^{+2}). Trivalent ferric ions would require three resin sites.

As shown, the ion exchange reaction is reversible. The degree the reaction proceeds to the right will depend on the resins preference. or selectivity, for nickel ions compared with its preference for hydrogen ions. The selectivity of a resin for a given ion is measured by the selectivity coefficient. K. which in its simplest form for the reaction

$R^-A^+ + B^+ = R^-B^+ + A^+$ (3)

is expressed as: K = (concentration of B^+ in resin/concentration of A^+ in resin) X (concentration of A^+ in solution/concentration of B^+ in solution).

The selectivity coefficient expresses the relative distribution of the ions when a resin in the A^+ form is placed in a solution containing B^+ ions. Table 1 gives the selectivity's of strong acid and strong base ion exchange resins for various ionic compounds. It should be pointed out that the selectivity coefficient is not constant but varies with changes in solution conditions. It does provide a means of determining what to expect when various ions are involved. As indicated in Table 1, strong acid resins have a preference for nickel over hydrogen. Despite this preference, the resin can be converted back to the hydrogen form by contact with a concentrated solution of sulphuric acid (H_2SO_4)

$(R—SO_4)_2Ni + H_2SO_4 \rightarrow 2(R\text{-}SO_3H) + NiSO_4$

This step is known as regeneration. In general terms, the higher the preference a resin exhibits for a particular ion, the greater the exchange efficiency in terms of resin capacity for removal of that ion from solution. Greater preference for a particular ion, however, will result in increased consumption of chemicals for regeneration. Ion exchange resins are usually contained in vessels referred to as columns. The basic column consists of a resin bed, which is retained, in the column with inlet and outlet screens, and service and regeneration flow distributors. Piping and valves are required to direct flow, and instrumentation is required to monitor water quality and control regeneration timing. The systems are operated in cycles consisting of the following four steps:

Service (exhaustion) - Water solution containing ions is passed through the ion exchange column or bed until the exchange sites are exhausted.

Backwash - The bed is washed (generally with water) in the reverse direction of the service cycle in order to expand and resettle the resin bed.

Regeneration - The exchanger is regenerated by passing a concentrated solution of the ion originally associated with it (usually a strong mineral acid or base) through the resin bed.

Rinse - Excess regenerant is removed from the exchanger, usually by passing water through it.

Resins currently available exhibit a range of selectivity's and thus have broad application. As an example. for a strong acid resin. the relative preference for divalent calcium ions (Ca^{+2}) over divalent copper ions (Cu^{+2}) is approximately 1.5 to 1. For a heavy-metal-selective resin. the preference is reversed and favours copper by a ratio of 2.300 to 1.