Ion exchange

Ion exchange consists of replacing an ionic species by another ionic species in electrostatic interaction of the precursors with the surface of a support. The support containing the ion A is dipped into an excess volume (compared to the pore volume) of a solution containing ion B that is to be introduced. Ion B gradually penetrates into the pore space of the support and takes the place of ion A, which passes into the solution. This continues until equilibrium is established corresponding to a given distribution of the two ions between the solid and solution.

Natural ion exchangers: Natural exchangers are composed of a frame work having charge that is neutralized by ions of opposite charge. For example, zeolite has negatively charged framework due to the particular environment of aluminium. Aluminium, just like silicon, is effectively situated in the centre of a tetrahedron of four oxygen atoms which have four negative charges, where as aluminium has only three positive charges. The tetrahedron (AlO_4) thus have an overall one negative charge distributed over the oxygen atoms and this charge is neutralized by the presence of various cations such as Na^+, K^+ etc. These cations are not definitively bonded to the framework but may be replaced by other cations during an ion exchange operation. Zeolite has a constant number of these exchange sites which are equal to the number of aluminium atoms in their framework. Clays, silicates are also cation exchangers.

Mechanism of single ion exchange: Single ion exchange takes place when in the solid-solution system only two ions interact. If ion A^+ on the solid Z is to be replaced by ion B^+ present in the solution then in the simple case of two monovalent cations, the exchange equilibrium can be written as $A_z^+ + B_s^+ \rightleftharpoons B_z^+ + A_s^+$

The subscripts 's' and 'z' represent solution and solid, respectively. In case of ideal exchange, that is both the exchanger and solution are ideal with single type of adsorption sites, the equilibrium constant K_a can be written as

$$K_a \rightleftharpoons \frac{C_{BZ} C_{AS}}{C_{BS} C_{AZ}}$$

C_{AZ} = concentration of ion A^+ in the solid

C_{AS} = concentration of ion A^+ in the solution

C_{BZ} = concentration of ion B^+ in the solid

C_{BS} = concentration of ion B^+ in the solution

$C_{AZ} + C_{BZ} = C_Z$ = total concentration of cations in the solid

$C_{AS} + C_{BS} = C_S$ = total concentration of cations in the solution

Therefore it follows that

$$C_{BZ} = \frac{K_a C_Z C_{BS}}{C_S \left(K_a - 1\right) C_{BS}}$$

If it is not an ideal system, the above equation must be expressed in terms of concentration and activity coefficients.

Example: Na^+ ions in NaY zeolites can be replaced by NH_4^+ ions. NaY zeolite [$Na_2O.Al_2O_3$. 5 SiO_2] contains 9.9 wt% Na and 73% Na can be exchanged.

Book References :

- K.P. de Jong. , Synthesis of solid catalysts , Wiley –VCH, 2009
- J.T. Richardson, Principle of catalysts development, Plenum Press, 1989
- G. Ertl, H. Knozinger & J. Weitkamp, Handbook of Heterogeneous Catalysis Vol 1, Wiley – VCH, 1997
- R. J. Farrauto & C. H. Bartholomew, Fundamentals of Industrial Catalytic Processes, Blackie Academic & Professional, 1997