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Novel Separation Processes

Dr. Sirshendu De
Professor, Department of Chemical Engineering
Indian Institute of Technology, Kharagpur
e-mail: sde@che.iitkgp.ernet.in

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Fundamentals of Separation Processes

In most of the chemical engineering systems, separation processes are integral part of the entire process flowsheet. If we consider a reactive system, where, certain products are of primary interest, separation units are either put in the upstream or downstream. In such a system, the reactor is the heart of the system. It may happen that the reactants are gaseous and should be devoid of moisture. In such cases, a separation unit must be present as an upstream unit. On the other hand, if a particular product is kept in mind, a separation unit must be placed at the downstream of the flowsheet. There may be processes, where, the separation is the only objective. For example, if we consider a treatment process of an industrial effluent, separation is the only process that is involved. There may be a number of separation processes involved in a system. In an effluent treatment process, there are three steps, namely, primary, secondary and tertiary treatment processes. All these processes are primarily separation processes. Primary treatment processes include coagulation, flocculation, etc. Secondary treatment processes are mainly oxidation ponds, etc. Tertiary treatment processes involve adsorption, membrane separation, etc. In food and juice processing industries, separations are primary stages of operation. Most of the pharmaceutical industries have separation units as integral parts in the downstream or they are the main units. In milk processing separation processes are primary.

Most of the separation processes involve, either separation of solutes from the solvent or, separation of a mixture of solutes. It may be noted that the components those need to be separated are in a mixture naturally. In order to effect separation, one has to put either energy or an extra material from outside to disturb stability. This is equivalent to the concept of exceeding the activation energy of separation by an external agent (agent may

be energy or matter). This point can be elaborated by some examples. Consider a case of separation of salt from sea water. In this system, thermal energy is added to the system and water is evaporated leaving behind the salts. Consider another case of separation of charged colloidal particles which are stable in a solution. In such systems, a coagulant, like potassium alum or ferric chloride or calcium oxide (selection depends upon the operating pH) is added. These coagulants are generally of opposite charges of the colloids. These colloids get themselves attached to the coagulants by electrostatic attractive forces and the whole assembly becomes heavier and settles down. In this case, we add an external agent (a matter i.e., coagulant) to effect separation. This can be schematically presented in Fig.1.1.

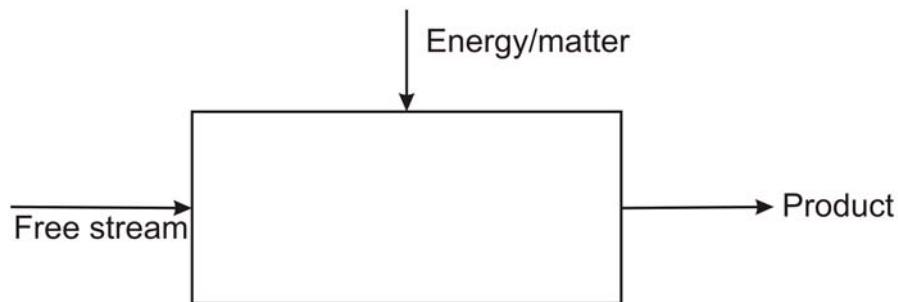


Fig.1.1: Schematic of a separation process

1.1 Separation Factor:

The extent of separation is defined by separation factor. Separation factor between two species 'i' and 'j' is defined as

$$\alpha_{ij} = \frac{x_{i1} / x_{j1}}{x_{i2} / x_{j2}} \quad (1.1)$$

Where, 1 and 2 are two streams. If $\alpha_{ij} = 1$, no separation occurs. If $\alpha_{ij} < 1$, stream '1' is concentrated in 'j' and stream '2' is concentrated in 'i'. If $\alpha_{ij} > 1$, stream '1' is concentrated in 'i' and stream '2' is concentrated in 'j'.

Grossly, the separation processes are divided into two categories, namely, equilibrium governed separation processes and rate governed separation processes. In equilibrium governed separation processes, the product phases are in equilibrium with the inlet phases. On the other hand, in rate governed separation processes, product phase composition or separation occurs due to the difference of rate of physical transport of species alone. Distillation, absorption etc. are examples of equilibrium governed separation processes. On the other hand, membrane based processes are rate governed separation process.

Chemical potential in interfacial mass transfer

A species of molecules is said to be in equilibrium when there does not exist a chemical potential gradient across the boundaries of the system. Chemical potential (μ) of a system is defined as the amount of change of energy on introduction of a new species in the system keeping the entropy and volume unchanged. Typically the partial molar Gibbs energy is referred as the chemical potential of the system. In the absence of any external

force field, the total energy change of the system is $dG = -SdT + VdP + \sum_{i=1}^c \mu_i dN_i$. The

above expression clearly shows that $\mu_i = \left(\frac{\partial G}{\partial N_i} \right)_{T, P, N_{j \neq i}} = \left(\frac{\partial U}{\partial N_i} \right)_{S, V, N_{j \neq i}}$ where U is the

internal energy of the system. At equilibrium, for a constant temperature and pressure, μ of each of the species are constant and equal.

Mass transfer is inherently a non-equilibrium process, characterized by the net motion of molecules down a chemical potential gradient (concentration gradient). The mass transfer often takes place across an interface between the two phases. At the interface between two phases, the chemical potential of the diffusing components of the two phases are equal to each other. One can imagine of an infinitely thin region where the phases are in equilibrium with this plane. The energy changes in mass transfer processes include internal entropy, volume and interfacial changes, which occur simultaneously and as a result of the mass transfer.

In mass transfer processes, the molar or mass potential provides the total energy density change, i.e. per mole or per unit mass. Thus, at equilibrium, it is this total energy density that must be constant, whereas in non-equilibrium systems its gradient provides a driving force for mass transfer.

Use of Navier Stokes equation in mass transfer

In most practical industrial scale cases, the separation should occur under a steady state conditions. Under such situations, the feed and product phases flow past each other. In almost all the cases, the flow directions of the two phases are countercurrent in nature in order to have the higher driving force. The interface (in case of equilibrium governed

separations) or interphase (in case of rate governed) between the two flowing streams dictates the mass transfer of the species either through the equilibrium relations or transport laws through the interphase. In order to get an idea the variation of solute concentration in the bulk phases, the coupled mass transfer and velocity field have to be solved in conjunction. The velocity field is characterized by equations of motion or Navier Stokes equation and the concentration field (mass transfer) is denoted by solute balance equation in its differential form. Since, the solute balance equation contains, the convective terms, it is coupled with the velocity field. Therefore, the simultaneous solution of these would result the concentration field of the solute to be separated in the feed side. After that, the concentration field is evaluated at the interface and its value is evaluated in the other phase by using the equilibrium relation (in case of equilibrium governed processes) or transport law through the interphase (in case of rate governed processes). The bulk concentration profile of the target or other phase is then obtained by simultaneous solution of velocity and concentration field in that phase.