Mass Transfer: Separation processes Operations

Introduction

A large number of unit operations are used in the separation of a substance into its component parts. They involve a change in composition of mixtures and solutions. The changes are mostly in nature.

Separations involve a non-spontaneous process because it reverses the process of mixing. Separation decreases the entropy of the system, and a separating agent (energy , mass or membrane) must be used to carry out the process.

Separation of mixtures may be mechanical in nature: filtration, sedimentation, etc.

Separation of solutions involves mass transfer operations characterized by the transfer of a substance through another on a molecular scale. These operations are interphase mass transfer processes involving the creation of a second phase by the addition of an energy-separating agent (ESA) or by a mass separating agent (MSA).

The main separation techniques are:

- **Phase creation**

  Most common industrial technique. A second phase is created which is immiscible with the feed. This is done by increasing or decreasing the temperature or pressure on the feed

- **Phase addition**

  Involves the introduction of a solvent to the system which selectively solvates one component of the feed

- **Barrier separation**

  Increasingly important. Barrier selectively transports one species relative to another across the membrane

- **Solid agent separation**

  Solid particles are added to the feed which are either inert and carry substances using separation; or react with the feed to cause separation

- **Separation by force field**

  Common in laboratory and for specialized separations and involves the use of electric and magnetic fields to preferentially move one species over another

Types of Mass Transfer separation Operations

The type depends on the way different phases are contacted:

I. Direct Contact

-Phases are immiscible or partially miscible

-Most widely used and most important

- Depends on the fact that the contacted phases, consisting of several components, are initially not at equilibrium. The system tends to reach equilibrium as a result of a slow process of diffusion between the two phases.

- Depending on the state of the phases, the following interfaces may be distinguished:

Gas/Gas: Practically not realized (almost all gases are completely soluble).

Gas/Liquid: - Distillation: all components are present in different proportions in the two phases

- Gas Absorption (or desorption): one or more components distribute between the two phases.

- Humidification (or dehumidification): one phase is pure and the other consists of two or more components

Gas/solid: - Fractional sublimation (vaporization of solid solutions (not used practically).

- Drying: not all components are present in the two phases.
- Adsorption (or desorption): Diffusion takes place from gas phase to solid phase or vice versa.

Liquid / Liquid: solvent extraction

Liquid/Solid - Crystallization

- Leaching

Solid/Solid: very slow rate of diffusion within solid phases.

II) Indirect contact:

* phases are separated by a membrane

* membrane → porous (molecular sieves)
           → nonporous

* substances move between phases by diffusion through the membrane

* porous membranes are selective-they permit the diffusion of certain molecules.

* non porous membranes preferentially dissolve the solute or the solute and solvent which then diffuses through the membrane - the process is called permeation or dialysis.

- these operations involve different phases:

  - Gas/Gas
    - → effusion-microporous membrane
    - → permeation - non—porous membrane.
  - Gas/Liquid - permeation processes (non-porous membranes)
  - Liquid I Liquid: Dialysis - membrane permeable to solvent and dissolved substance.
  - Electro dialysis - electromotive force is used to assist the diffusion process.
  - Reverse osmosis (R/O) - desalination of water.

III) Direct contact of miscible phases:

- Thermal diffusion - concentration difference is created by a temperature gradient
- Centrifugation - separation occurs as a result of slightly different forces acting on various molecules of different masses.

IV) Surface Concentration:

Foam separation: some substances when dissolved in a liquid in contact with a gas are found to concentrate on the free surface. By forming foam on the surface of the liquid, the surface area between the gas and the liquid is increased and the solute is concentrated in the foam and can be collected at the surface.

Choice of a separation method:

Factors to be considered in the selection of a separation process:

- Physical properties of the materials to be separated.
- Cost of process to be used (fixed or operating).
- Knowledge of design and availability of data for design.
- Operability (Simplicity, ease of maintenance.)
- Safety: assessment of major risks.
- Environmental and social factors.

Design Principles:

There are four principal design factors involved in the design of mass transfer equipment:

i) number of equilibrium stages or the equivalent quantity for continuous operations. These are determined based on phase equilibrium data and material balances.

ii) Contact time:-

This is connected with:

- efficiency in stage wise operations.
- size of equipment (volume or length) in continuous operations.

Contact time may be established from a combination of factors:

- material balances.
- equilibrium characteristics → final concentrations and mass transfer rates.

iii) Flow rate:

This factor determines the cross sectional area of the equipment. The permissible flow rate is established from hydrodynamics for a given geometry of a device.

iv) Energy requirements:

Both thermal and mechanical energies are required

Thermal energy →
- establishment of temperature gradients
- creation of new phases-evaporation
- cooling - condensation, overcoming heat of solution.

Mechanical energy →
- transport of fluids or solids
- dispersing liquids and gases.