Lecture 11

Membrane separations

In a membrane-separation process, a feed consisting of a mixture of two or more components is partially separated by means of a semipermeable barrier (the membrane) through which one or more species move faster than another or other species. The most general membrane process is shown in Figure 1 where the feed mixture is separated into a retentate (that part of the feed that does not pass through the membrane, i.e., is retained) and a permeate (that part of the feed that does pass through the membrane). Although the feed, retentate, and permeate are usually liquid or gas, they may also be solid. The barrier is most often a thin, nonporous, polymeric film, but may also be porous polymer, ceramic, or metal materials, or even a liquid or gas. The barrier must not dissolve, disintegrate, or break. The optional sweep, shown in Figure 1, is a liquid or gas, used to help remove the permeate. Many of the industrially important membrane separation operations are listed below.

In membrane separations: (1) the two products are usually miscible, (2) the separating agent is a semipermeable barrier, and (3) a sharp separation is often difficult to achieve. Thus, membrane separations differ in two or three of these respects from the more common separation operations of absorption, stripping, distillation, and liquid-liquid extraction.

Although membranes as separating agents have been known for more than 100 years, large-scale applications have only appeared in the past 50 years. In the 1940s, porous fluorocarbons were used to separate $^{235}UF_6$ from $^{238}UF_6$. In the mid-1960s, reverse osmosis with cellulose acetate was first used to desalinize seawater to produce potable water (drinkable water with less than 500 ppm by weight of dissolved solids). Commercial ultrafiltration membranes followed in the 1960s. In 1979, Monsanto Chemical Company introduced a hollow-fiber membrane of polysulfone to separate certain gas mixtures-for example, to enrich hydrogen- and carbon dioxide-containing streams. Commercialization of alcohol dehydration by pervaporation began in the late 1980s, as did the large-scale application of emulsion liquid membranes for removal of metals and organics from wastewater.

The replacement of the more-common separation operations with membrane separations has the potential to save large amounts of energy. This replacement requires the production of high-mass-transfer-flux, defect-free, long-life membranes on a large scale and the fabrication of the membrane into compact, economical modules of high surface area per unit volume.

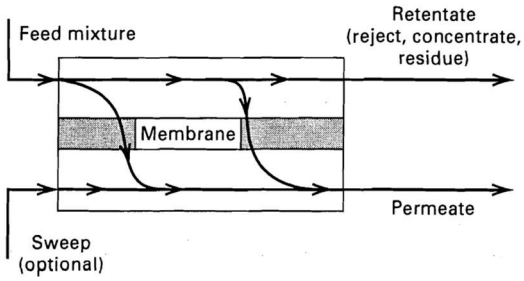

Figure 1 - General membrane process

Industrial applications of membrane separation processes:

1. Reverse osmosis:
   - Desalinization of brackish water
   - Treatment of wastewater to remove a wide variety of impurities
   - Treatment of surface and ground water
   - Concentration of foodstuffs
   - Removal of alcohol from beer and wine
2. Dialysis:
   - Separation of nickel sulfate from sulfuric acid
   - Hemodialysis (removal of waste metabolites, excess body water, and restoration of electrolyte balance in human blood)
3. Electrodialysis:
   - Production of table salt from seawater
   - Concentration of brines from reverse osmosis
   - Treatment of wastewaters from electroplating
   - Demineralization of cheese whey
   - Production of ultrapure water for the semiconductor industry
4. Microfiltration:
   - Sterilization of drugs
   - Clarification and biological stabilization of beverages
   - Purification of antibiotics
   - Separation of mammalian cells from a liquid
5. Ultrafiltration:
   - Preconcentration of milk before making cheese
   - Clarification of fruit juice
   - Recovery of vaccines and antibiotics from fermentation broth
   - Color removal from Kraft black liquor in paper-making
6. Pervaporation:
   - Dehydration of ethanol–water azeotrope
   - Removal of water from organic solvents
   - Removal of organics from water
7. Gas permeation:
   - Separation of CO_2 or H_2 from methane and other hydrocarbons
   - Adjustment of the H_2/CO ratio in synthesis gas
   - Separation of air into nitrogen- and oxygen-enriched streams
   - Recovery of helium
   - Recovery of methane from biogas
8. Liquid membranes:
   - Recovery of zinc from wastewater in the viscose fiber industry
   - Recovery of nickel from electroplating solutions