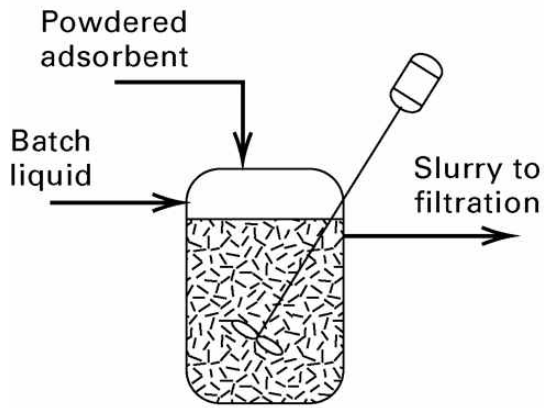
Lecture 7.
Sorption–Separation Equipment

- Adsorption
  - Stirred-tank, slurry operation
  - Cyclic fixed-bed batch operation
  - Thermal (temperature)-swing adsorption
  - Fluidizing bed for adsorption and moving bed for desorption
  - Inert-purge-swing regeneration
  - Pressure-swing adsorption
  - Displacement-purge adsorption
  - Continuous countercurrent operation
- Ion Exchange
- Chromatography

Equipment for Adsorption (1)

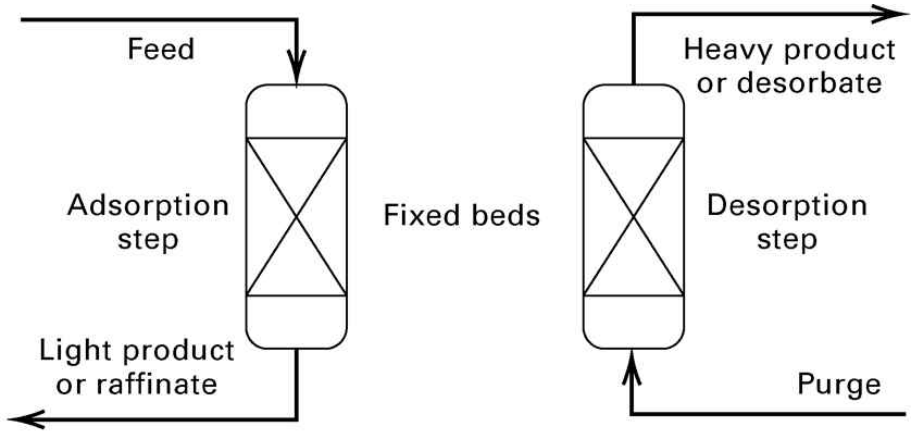
- Various configurations and operating procedures in sorption–separation equipment: due to wide range of sorbent particle size and the need to regenerate solid sorbent
- Stirred–tank, slurry operation (contact filtration)
  - A powdered adsorbent, of $d_p < 1$ mm, is added with water, to an agitated tank to form a slurry
  - The internal resistance to mass transfer within the pores of small particles is small
  - Even with good stirring, the external resistance to mass transfer from bulk liquid to external surface of adsorbent particles may not be small because small particles tend to move with liquid



  - Main application: removal of small amounts of large, dissolved molecules, such as coloring agents, from water
  - Spent adsorbent: removed from the slurry by sedimentation or filtration, and discarded because it is difficult to desorb large molecules

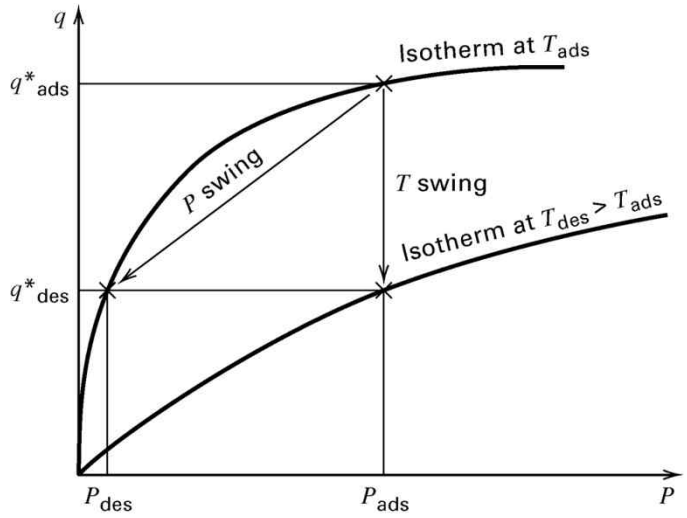
Equipment for Adsorption (2)

- Cyclic fixed-bed batch operation
  - Widely used with both liquid and gas feeds
  - Bed pressure drop decreases with increasing particle size, but solute transport rate increases with decreasing particle size
  - To avoid jiggling, fluidizing the bed, or blowing out fines during adsorption, the feed flow is often downward
  - For removal of small amounts of dissolved hydrocarbons from water, spent adsorbent is removed from the vessel and reactivated thermally at high temperature or discarded



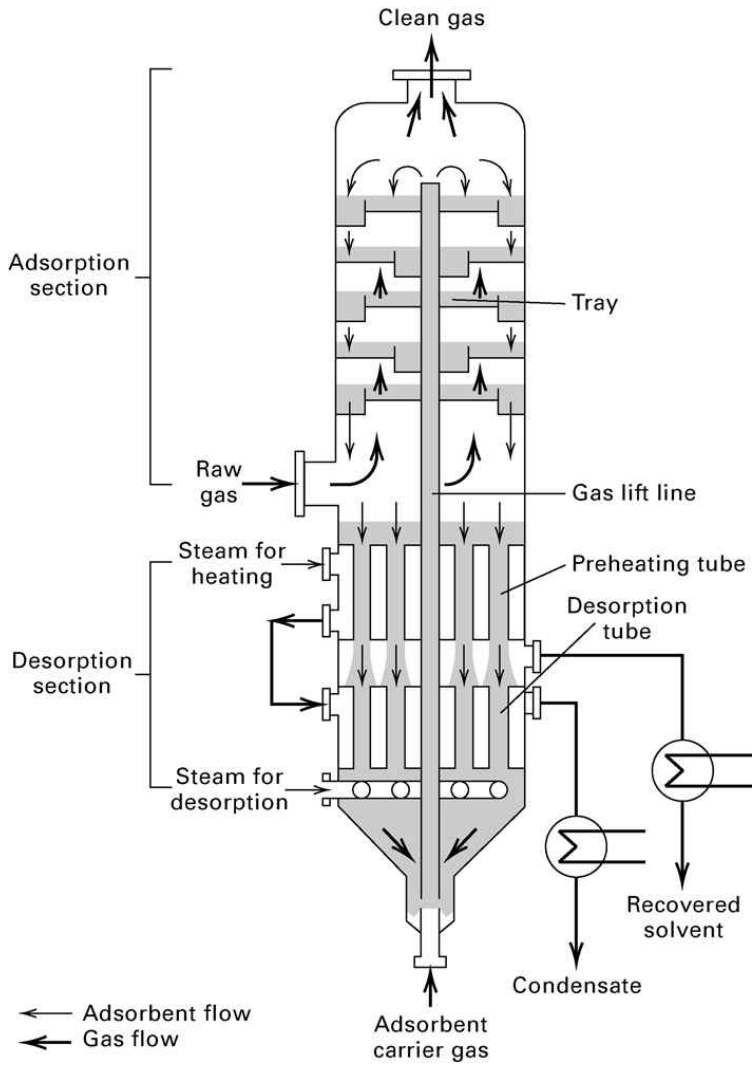
Equipment for Adsorption (3)

- Thermal (temperature)–swing adsorption (TSA)
  - The adsorbent is regenerated by desorption at a temperature higher than used during adsorption
  - Bed temperature is increased by
    - Indirect heat transfer from jackets surrounding the beds or coils located in the beds
    - heat transfer from an inert, nonadsorbing, hot purge gas, such as steam (more common)
  - Because heating and cooling of the bed requires hours due to the low bed thermal conductivity, a typical cycle time for TSA is long, usually hours to days



Equipment for Adsorption (4)

- Fluidizing bed for adsorption and moving bed for desorption
  - Particles are attrition-resistant
  - In the adsorption section, sieve trays are used with raw gas passing up through the perforations and fluidizing the adsorbent
  - From the adsorption section, the solids pass to the desorption section, where they first flow down through preheating tubes and then through desorption tubes
  - Steam is used for indirect heating in both sets of tubes and for stripping in the desorption tubes
  - At the bottom, the regenerated solids are picked up by a carrier gas, which flows up through a gas-lift line to the top

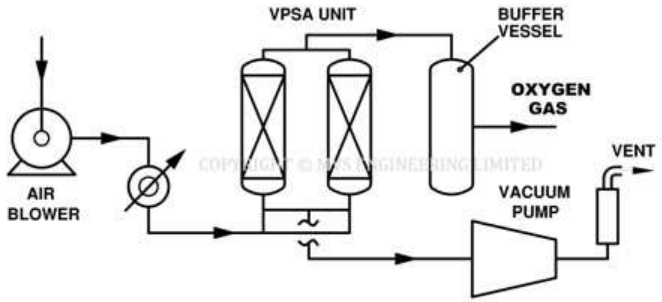


Equipment for Adsorption (5)

- Inert-purge-swing regeneration
  - Desorption is at the same temperature and pressure as the adsorption step
  - The gas used for purging is nonadsorbing (inert) or only weakly adsorbing
  - Used only when the solute is weakly adsorbed, easily desorbed, and of little or no value
  - The purge gas must be inexpensive so that it does not have to be purified before recycle
- Pressure-swing adsorption (PSA)
  - Adsorption takes place at an elevated pressure, whereas desorption occurs at near-ambient pressure
  - Used for bulk separation because the bed can be depressurized and repressurized rapidly, making it possible to operate at cycle times of seconds to minutes, and small beds have relatively large throughputs

Equipment for Adsorption (6)

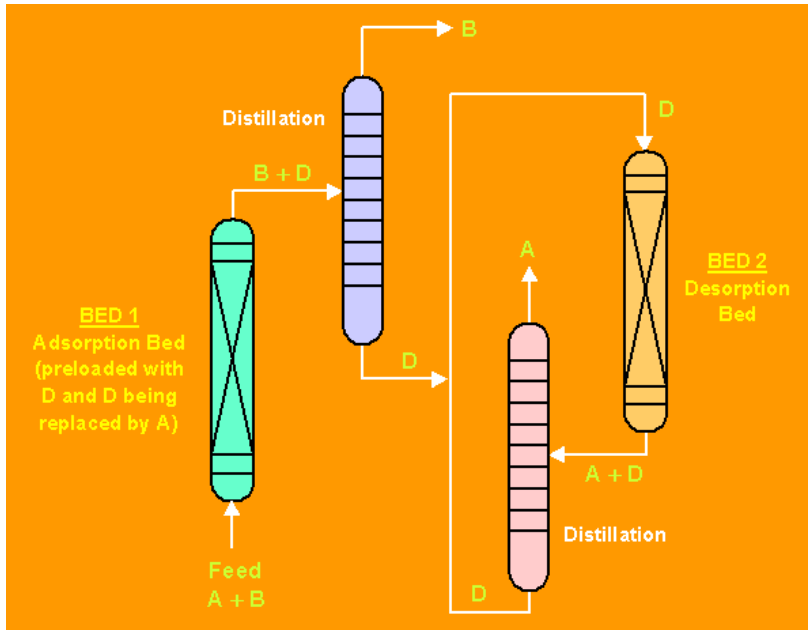
- Vacuum-swing adsorption (VSA)
  - Adsorption takes place at near-ambient pressure and desorption under vacuum
- PSA and VSA
  - Widely used for air separation
    - If zeolite adsorbent is used, adsorption equilibrium is the controlling factor, with N_2 more strongly adsorbed than O_2 and argon
    - If carbon molecular sieves are used, O_2 and N_2 have almost the same adsorption isotherms, but the effective diffusivity of O_2 is much larger than that of N_2



  - The adsorbed gas, which is desorbed at low pressure, is quite impure
  - For the separation of air, large plants use VSA because it is more energy-efficient than PSA
  - Small plants often use PSA because that cycle is simpler

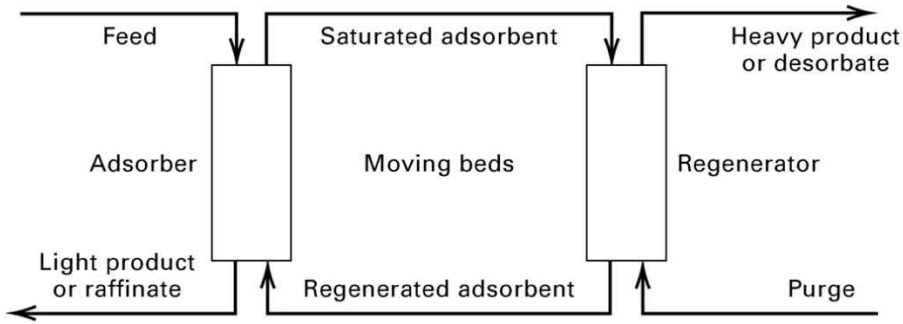
Equipment for Adsorption (7)

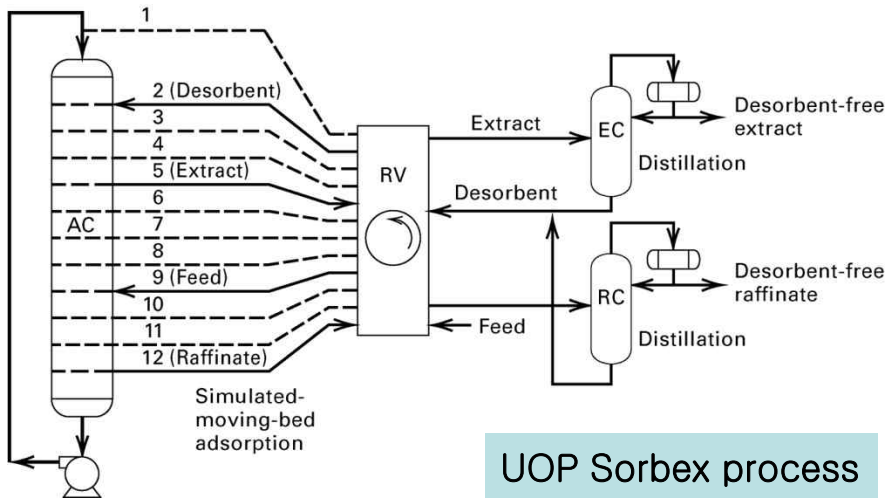
- Displacement-purge adsorption (DPA); displacement-desorption
  - A strongly adsorbed purge gas (displacement fluid) is used in desorption to displace adsorbed species
  - Another step is required to recover the purge gas
  - Viable only where TSA, PSA, and VSA cannot be used because of pressure of temperature limitations
  - The net heat generated or consumed in the adsorbent is close to zero because the heat of adsorption of the displacement fluid is likely to be close to that of the original adsorbate



Equipment for Adsorption (8)

- Most commercial applications of adsorption involve fixed beds that cycle between adsorption and desorption: compositions, temperature, and/or pressure at a given location vary with time
- Continuous countercurrent operation
  - Circulate solid adsorbent in a moving bed to achieve steady-state operation
  - Problem: adsorbent attrition
  - Successful system for commercial separation of liquid mixtures: simulated-moving bed
    - Countercurrent movement of solids is simulated by a downward movement of liquid
    - The valve periodically change the four operational locations



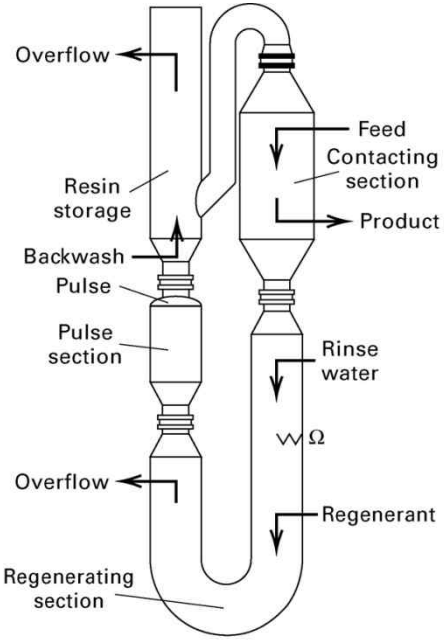


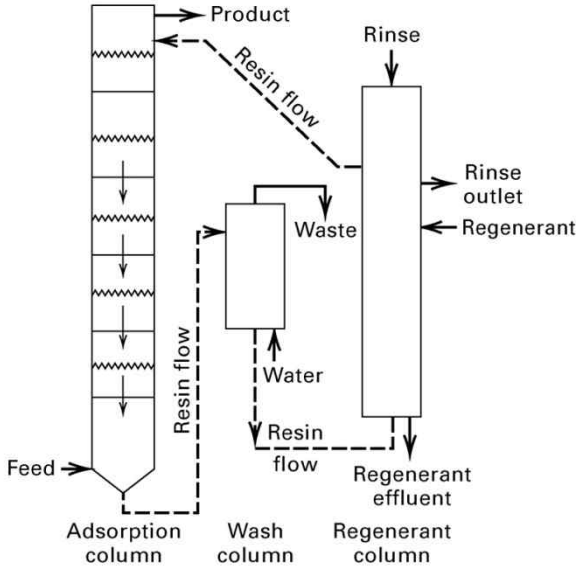
UOP Sorbex process

Equipment for Ion Exchange

- Fixed beds in a cyclic operation is most common
- Stirred tanks can be used for batch contacting
  - With an attached strainer or filter to separate resin beads from the solution after equilibrium is approached
  - Agitation is mild to avoid resin attrition, but sufficient to achieve suspension of resin particles
- Continuous countercurrent contactors for high efficiency

Higgins moving packed-bed process





Himsley fluidized-bed process

- The resin beads are fluidized by upward flow of liquid
- Periodically the flow is reversed to move incremental amounts of resin from one stage to the stage below

Equipment for Chromatography

- Batch (elution) chromatography
  - A timer or detector splits the column effluent by residence time, sending it to different separators
  - An additional cleanup step is required to purity the carrier fluid before it is recycled to the column
- Countercurrent-flow or simulated-moving-bed mode unit
- Continuous, crosscurrent chromatograph
  - The packed annular bed rotates slowly about its axis, past the feed-inlet point
  - Eluant (solvent or carrier gas) enters the top of the bed uniformly over the entire cross-sectional area
  - Helical path → each component is eluted from the bottom of the packed annulus at a different location