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Process Chem and Pharmaceutical Engineering 1

Mass Balance and Mass Transfer Part 2

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Chapter Description

- **Aims**
  – Apply the knowledge of mass balance and mass transfer in separation process
- **Expected Outcomes**

  - Differentiate between batch, semi-batch and continuous processes

  - Perform mass balance on Unit Operations

  - Comprehend the process and to draw a fully label flowchart

  - Describe the difference of mass transfer in laminar, turbulent flows and interfacial surfaces
- **References**

– Elementary Principles of Chemical Processes, Global Edition, Richard M. Felder, Ronald W. Rousseau, Lisa G. Bullard, Wiley, 4th Edition, 2017.
– Unit Operations of Chemical Engineering, McCabe Smith Harriott, Mc Graw Hill, 7th Edition, 2005.

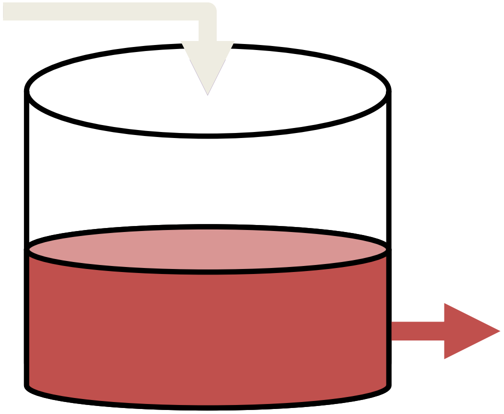
Process Classification

There are three classifications of chemical processes:

batch, continuous or semibatch.

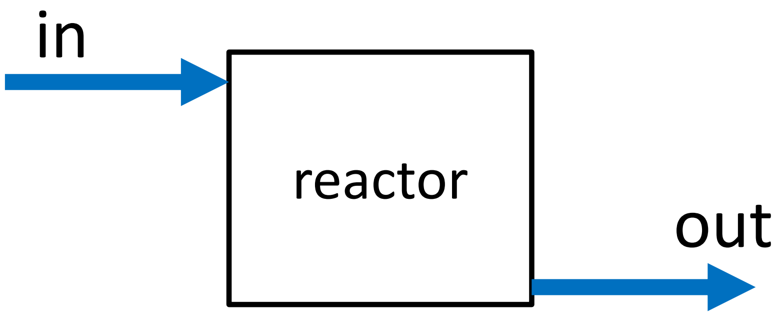
Batch Process

- The feed is fed into a vessel at the beginning of the process and the vessel contents are removed sometime later.



Continuous Process

- The inputs and outputs flow <u>continuously</u> throughout the duration of the process.



Semi-batch Process

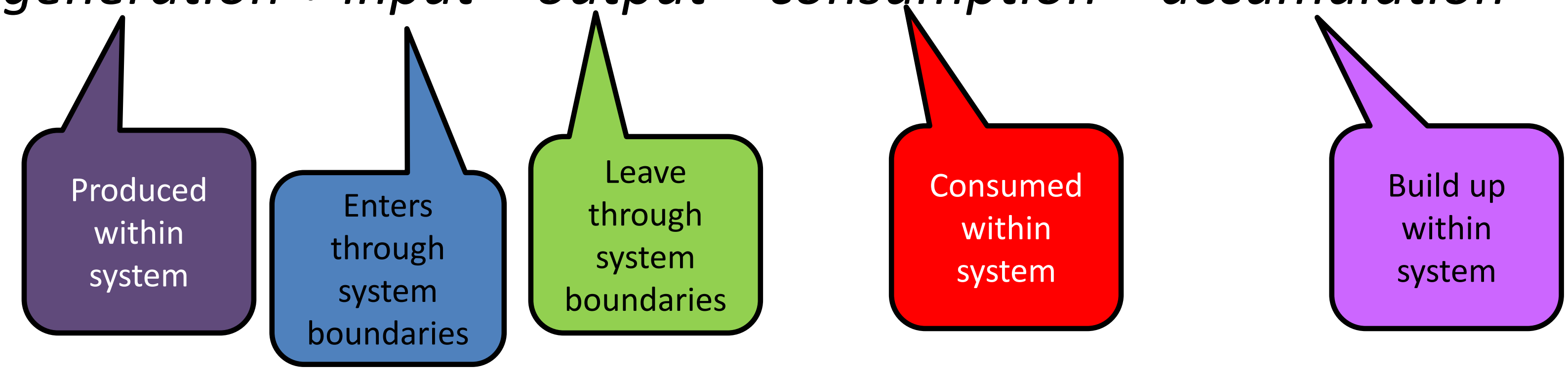
- Any process that is neither batch nor continuous.
- E.g: feed is continuously supplied into the unit operation

- If the values of process variables (i.e., all temperatures, pressures, volumes and flow rates) do not change with time, the process is operated at steady state.

- If any of the process variables change with time, the process is transient or unsteady-state operation.

General Mass Balance Equation

generation + input – output – consumption = accumulation



General Balance Equation

Input + Generation − Output − Consumption = Accumulation

- If $\dot{m}_{in} \neq \dot{m}_{out}$, these are possible explanations:

a. methane is being consumed as a reactant/generated as a product within the unit

b. methane is accumulating in the unit possibly adsorbing on the walls

c. methane is leaking from the unit

d. the measurements are wrong

Batch Processes

Consider a process of NH_3 production from N_2 and H_2 in a batch reactor

- At t_0 = n_0 mol of NH_3 in the reactor
- t_0 < NH_3 does not leave or enter the reactor < t_f
- The quantity of NH_3 that accumulates in the reactor between t_0 and t_f is $n_f - n_0$
- Generation = Accumulation

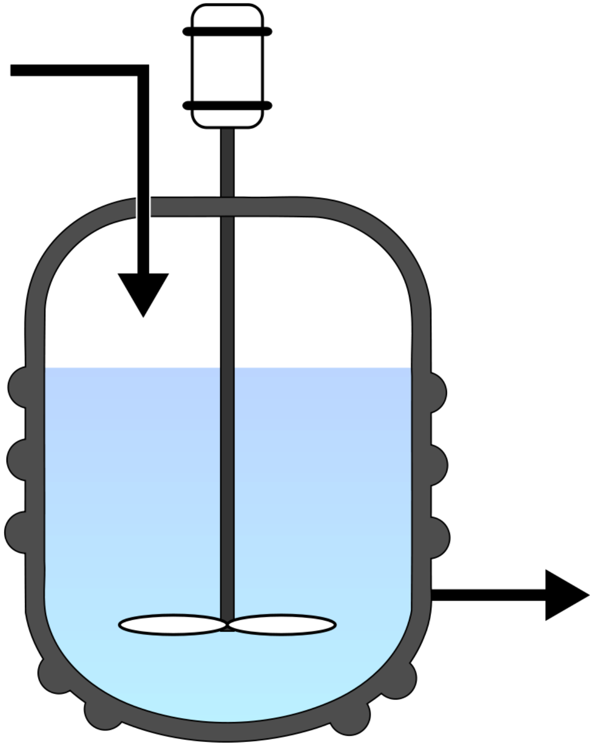
Initial input + generation = final output + consumption

Continuous Process

- At steady-state, accumulation = 0

Generation + Input = Output + Consumption

- If the balance is on nonreactive species or on total mass, the generation and consumption terms equal zero and the equation reduces to input = output



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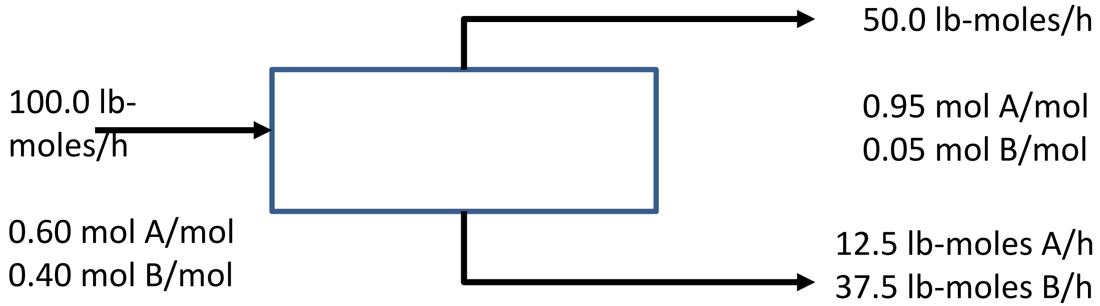
Step to make a process flowchart

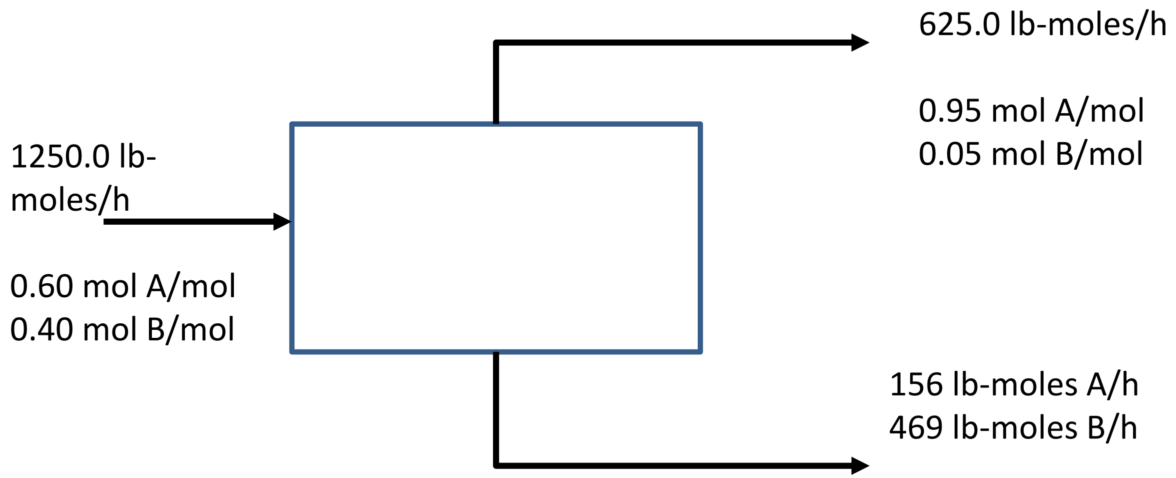
- 1. Write the values and units of all known stream variables at the location of the stream on the chart.
- 2. Assign algebraic symbols to unknown stream variables and write these variable names and their associated units on the chart.

Scale-up of a Separation Process Flowchart

A 60-40 mixture (by moles) of A and B is separated into two fractions. It is desired to achieve the same separation with a continuous feed of 1250 lb-moles/h. Scale the flowchart accordingly.



- The scale factor is:
- $\frac{1250\ lb-moles/h}{100\ mol} = 12.5\,\frac{lb-moles/h}{mol}$
- The masses of all streams in the batch process are converted to flow rates as follows:
- $Feed = 100\ mol\ x\ 12.5\,\frac{lb-moles/h}{mol} = 1250\ \mathrm{lb-moles/h}$
- $Top\ product\ stream = (50.0)x(12.5\ ) = 625\ lb - moles/h$
- $Bottom\ product\ stream = (37.50)x(12.5) = 469\ lb - moles/h$


625.0 lb-moles/h
0.95 mol A/mol
0.05 mol B/mol
1250.0 lb-moles/h
0.60 mol A/mol
0.40 mol B/mol
156 lb-moles A/h
469 lb-moles B/h

Mass Transfer Operation

- A group of operations for separating the components of mixtures is based on the transfer of material from one homogeneous phase to another.
- It requires driving force and involves mass transfer operations technique like distillation, gas absorption, dehumidification, adsorption, liquid extraction, leaching, crystallization, membrane separations, etc.

Molecular Movement

Theory of Diffusion

- **Diffusion:** Movement of molecules from high concentration to low concentration.
- Diffusion also caused by:

Activity gradient	Pressure gradient	Temperature gradient	External field

- Concentration gradient tends to move the component in such a direction as to equalize concentrations and destroy the gradient

Theory of Diffusion

✓ Fick's First Law of Diffusion states that the flux is directly proportional to concentration gradient

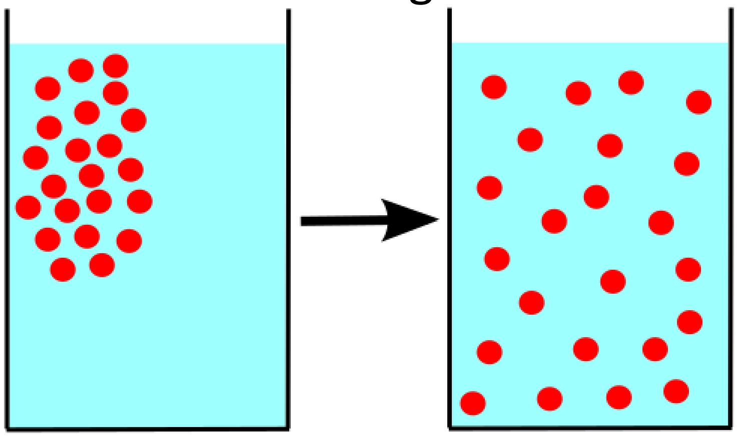
$J = -D\frac{dC}{dx}$ (-ve sign dictates that the flux mass moves from high to low concentration region)

J = diffusion flux

D = diffusion coefficient

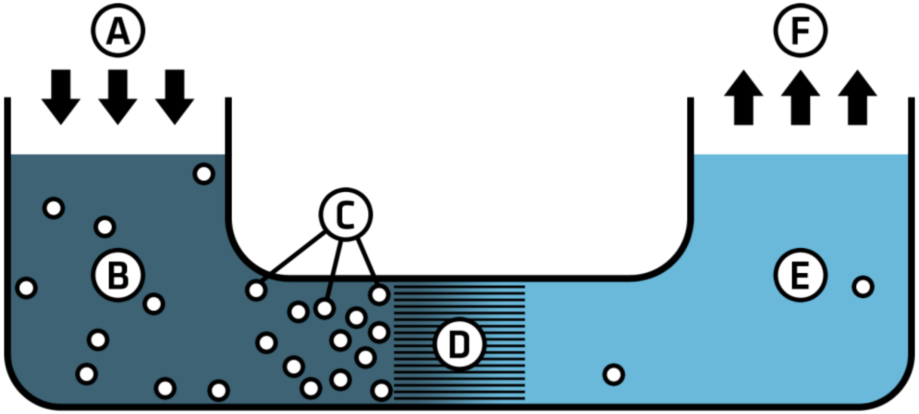
dC = concentration gradient

dx = distance travelled



Reverse osmosis

- When a hydraulic pressure is applied to the concentrated solution, water molecules will pass through the membrane to the more dilute solution side.
- This process enables the separation of water from ions and low-molecular weight organic ions.



Molecular Movement

Ultrafiltration

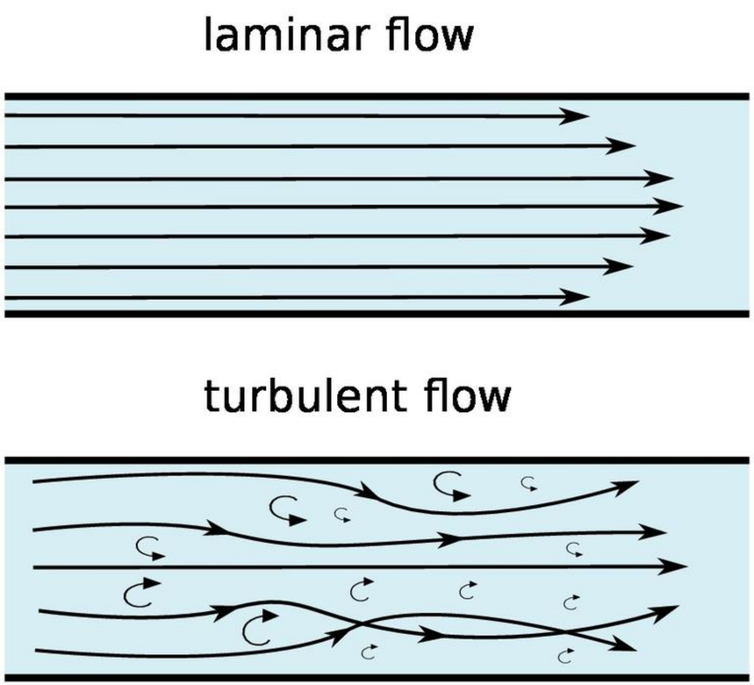
- ✓ Enables precise separation, concentration and purification of dissolved and suspended constituents according to their relative molecule size or weight.

Microfiltration

- ✓ Microfiltration membranes enable efficient and precise separation and concentration of suspended and colloid particles.

Laminar and Turbulent Flow

- Laminar flow
  - There is little or no mixing of the fluid across the ”boundaries” of each layer as the fluid flows along the flow path.
- Turbulent flow
  - It appears chaotic and rough with much intermixing of the fluid.



Mass transport in laminar flow

- For steady-state mass transfer through a stagnant layer of fluid, the mass transfer rate can be predicted by using:
- $J_A = \frac{D_v \rho_M}{B_T}\left(y_{A,i} - y_A\right)$
- Where
- J_A = molar flux of component A (kg mol/m^2)
- D_v = volumetric diffusivity (m^2/h)
- ρ_M = molar density of the mixture (kg mol/m^3)
- B_T = film thickness
- y_A= mole fraction of A at outer edge of film
- $y_{A,i}$ −= mole fraction of A at interface or inner edge of film

Mass transport in turbulent

- In a turbulent stream the moving eddies transport matter from one location to other.
- The mass transfer in turbulent streams:
- $J_{A,t} = -\varepsilon_N \frac{dc}{db}$

Where

$J_{A,t}$ = molal flux of A, relative to phase as a whole, caused by turbulent action

ε_N= eddy diffusivity

Conclusion of The Chapter

This chapter discussed about difference between batch, semi-batch and continuous processes, how to draw a fully label flowchart, perform mass balance on Unit Operations and the difference of mass transfer in laminar, turbulent flows and interfacial surfaces.

Elementary Principles of Chemical Processes, Global Edition, Richard M. Felder, Ronald W. Rousseau, Lisa G. Bullard, Wiley, 4th Edition,2017.

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