Chapter 4. Fundamentals of Material Balances

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Introduction

- Material Balance (Mass Balance)
  - Based on the law of conservation of the mass
  - (total mass input) = (total mass output)
- Objectives of this chapter
  - Drawing process diagrams
  - Writing material balance equations
  - Understanding process variables
  - Solving equations with unknown variables

4.1 Process Classification

- Classification of processes
  - Batch : feed is charged, products are removed some time later
  - Continuous : inputs and outputs flow continuously
  - Semibatch process : mixed process

  - Steady state (정상상태) : process variables do not change with time
  - Transient (unsteady) state (과도상태) : process variables change with time : small scale productions

Balances

- The general balance equations

(Input) + (Generation)
= (Output) + (Consumption) + (Accumulation)

  – Balance (or Inventory)

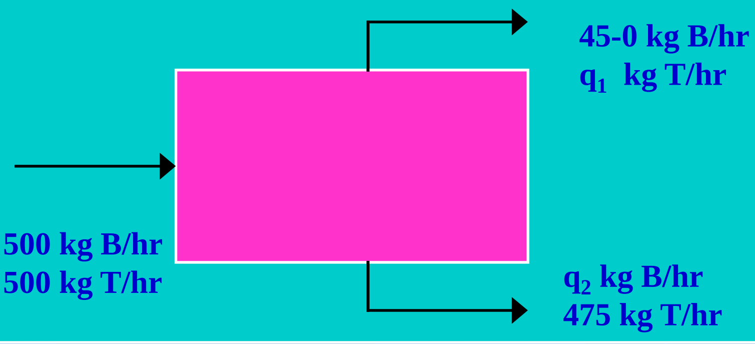
- Two types of balances
  – Differential balance : per time
  – Integral balance : during a certain period of time

Example

Problem

100 kg /hr of a mixture of benzene (B) and toluene(T) that contains 50% benzene by mass are separated by distillation into two fractions. The mass flow rate of benzene in the top stream is 450 kg B/hr and that of toluene in the bottom stream is 475 kg T/hr. The operation is at steady state. Write balances on benzene and toluene to calculate unknown component flow rate in the output streams.

Process diagram



Material Balance

*** Benzene balance**

$$500 = 450 + q_1$$

*** Toluene Balance**

$$500 = q_2 + 475$$

Solution :

Q_1 = 50 kg T/hr

Q_2 = 50 kg B/hr

Integral balances on batch or semi-batch processes

- Integral balance on batch processes
  – Sometimes it can be treated like steady-state processes
- Integral balance on Semi-batch and continuous process
  – Sometime it can be easily solved.
  – Require integration over period of time

4.3 Material Balance Calculations

- **Objective :**

  Given values of input, output → calculate unknown values

- **Flow Charts : simple way to visualize process flow**
  - PFD (Process flow diagram)
  - P&ID (Process and Instrument diagram), …

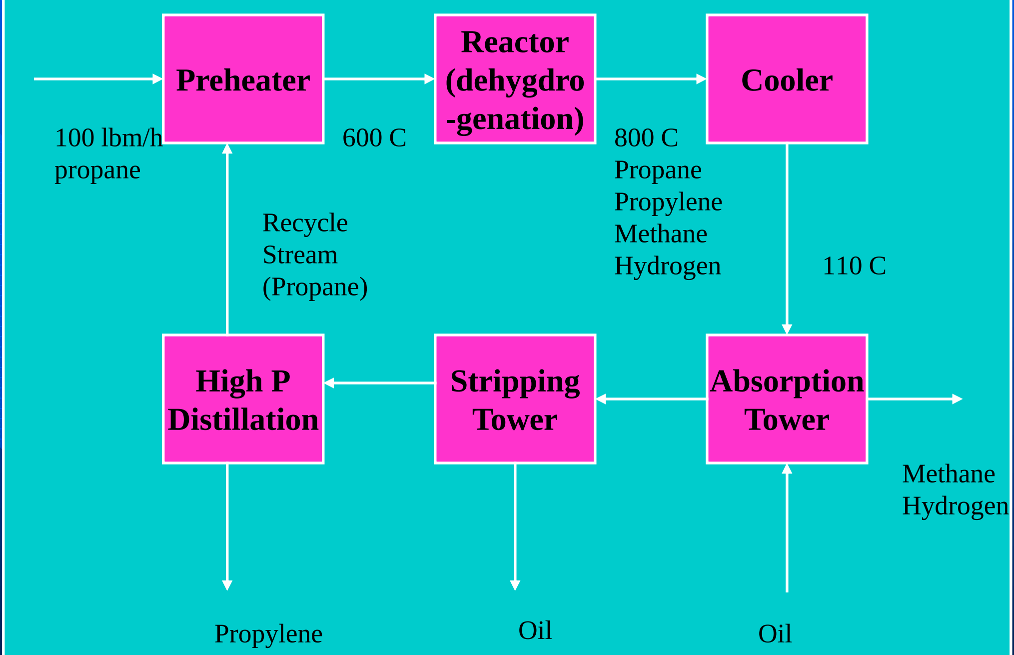
Benefits of using flowcharts

Process Description

The catalytic dehydrogenation of propane is carried out in a continuous packed bed reactor. One thousand pounds per hour of pure propane are fed to preheater where they are heated to a temperature of 670 C before they pass into the reactor.The reactor effluent gas, which includes propane, propylene, methane and hydrogen, is cooled from 800 C to 100 C and fed to an absorption tower where the propane and propylene are dissolved in oil. The oil then goes to a stripping tower in which it is heated, releasing the dissolved gases; these gases are recompressed and sent to a high pressure distillation column in which the propane and propylene are separated. The product stream from the distillation column contains 98 % propane. The stripped oil is recycled to the absorption tower.

Complex, not easy to understand

Flowchart



Compact, easy to understand

Drawing a flowchart

- Write the values and units of all known stream variables at the location of the streams on the chart.

400 mol/h

→

0.21 mol O_2 /mol
0.79 mol N_2 /mol
T=320 ^oC, P = 1.4 atm

- Assign algebraic symbols to unknown stream variables.
- Write variable names and units on the chart.

400 mol/h

→

x mol O_2 /mol
(1-x) mol N_2 /mol
T=320 ^oC, P = 1.4 atm

Material Balances

- Flowchart scaling up/down
  - Changing values of all amounts or flow rates by proportional amount.
  - Compositions remain unchanged.
- Basis of calculation
  - If flow rates are given, use specified values and units.
  - If flow rates are not given, assume one of input flow rates.

Problem Bookkeeping

- A procedure to discover that all the required information is available to solve specified problem.
- Procedure
  - Drawing flowchart
  - Identifying variables
  - Identifying equations
  - Degree of freedom analysis

Available Relations

- Material balances
  - No. of species (N) = No. of equations
- An energy balance
  - One unknown (T, Q, or m)
- Process specification
  - Requirement (based on economics,…)
- Physical properties and laws
  - Thermodynamic relations and physical properties data
- Physical constraints
  - X1 =1 then X2 = 1-X1, …

Outline of a Procedure for Material Balance Calculations

- Draw a flow chart, and fill in all given values.
- Choose as a basis of calculation an amount or flow rate of one of the process streams.
- Label unknown stream variables on the chart.
- Do the problem bookkeeping.
- Convert volume flow rates to mass or molar flow rates.
- Convert mixed mass and molar flow rates to mass or molar flow rates.
- Translate given information to equations.
- Write material balance equations.
- Solve equations.
- Scale up/down.