Lecture 8

The Balance Concept

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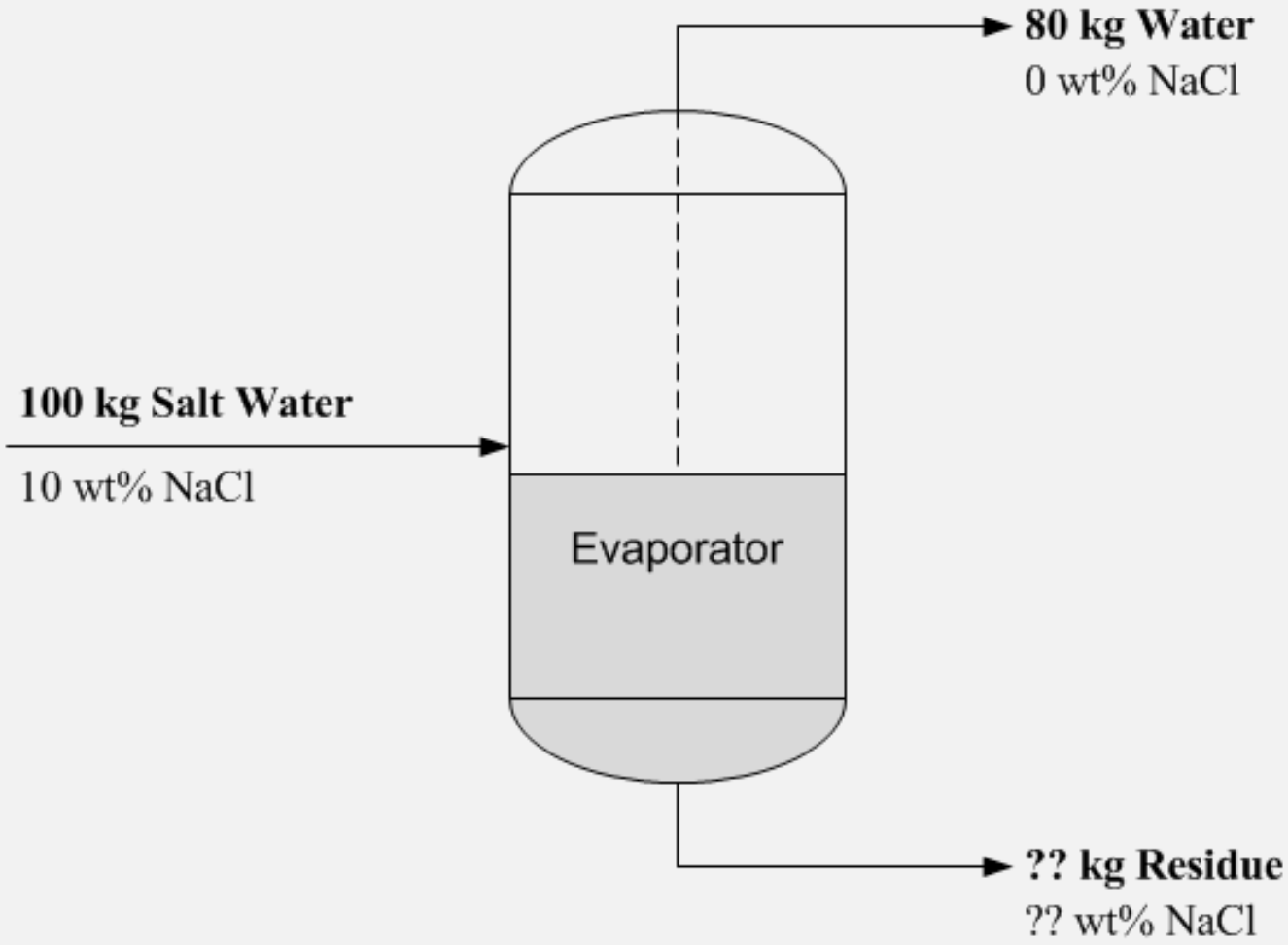
The Material Balance Analysis

- Material balances are nothing more than the application of the conservation law for mass
- Material balance calculations are almost invariably a prerequisite to all other calculations in the solution of both simple and complex chemical engineering problems.
- Material balance analysis is simply an accounting of all materials flowing, generated, or consumed in a chemical process.

Evaporation of Water from Salt Water



System and Control Volume

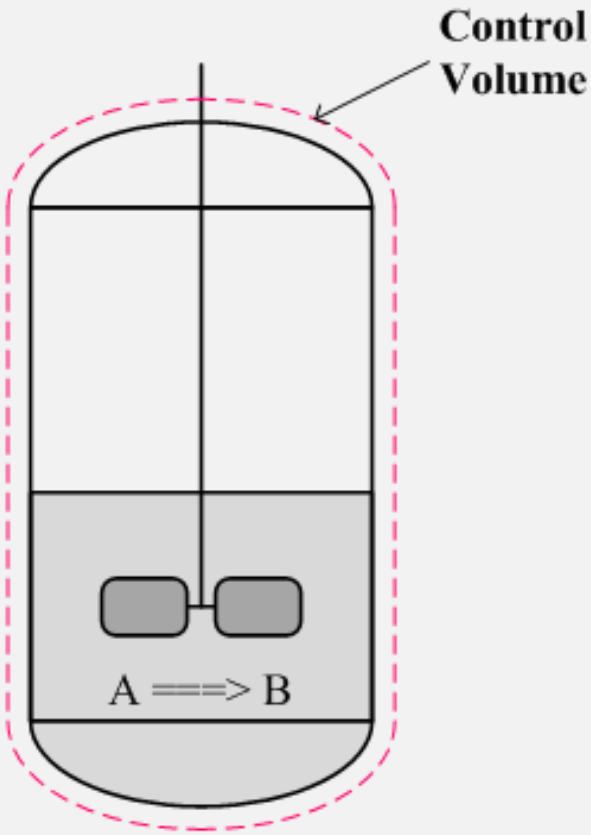
A system is any arbitrary portion of a process set out specifically for analysis. A control volume is any imaginary or tangible boundary which encloses the system.

Types of System

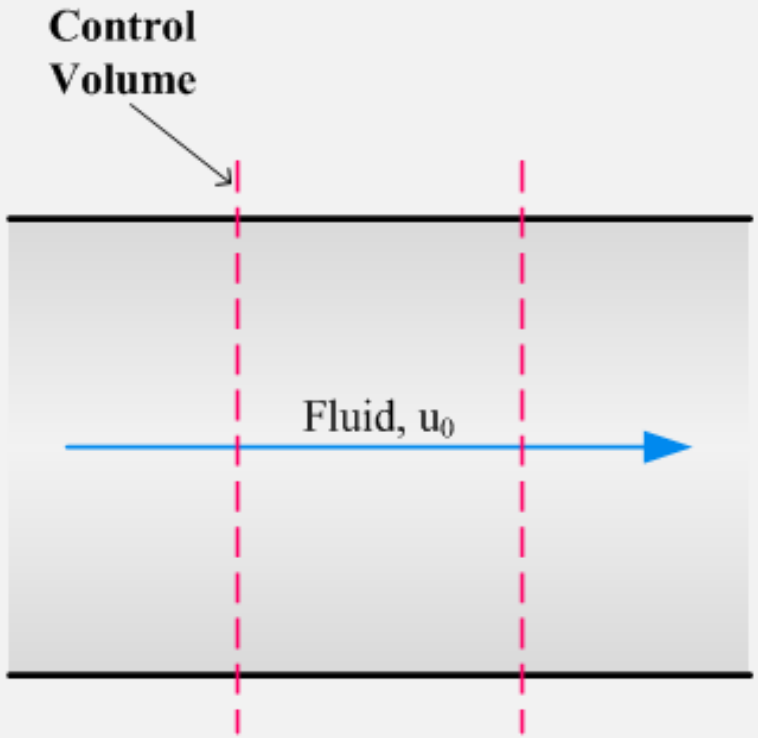
Closed System
A system is closed if there is no mass passing through the control volume during the period of analysis.

Open System
A system is open if mass can pass through the control volume during the period of analysis.

Batch Reaction in a Vesel



Fluid Flow in a Pipe



The Steady-State Process

In a steady-state process, the values of all variables in the process (such as chemical composition, temperature, pressure, etc.) do not change with time. Otherwise, it is an unsteady-state process.

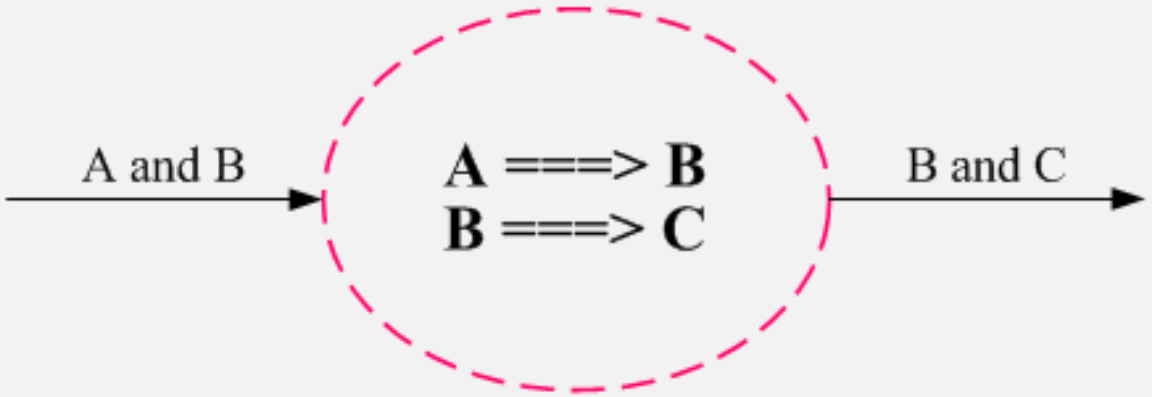
For a steady-state process:

$$\frac{\Delta x_i}{\Delta \theta} = 0 \quad \text{or} \quad \frac{dx_i}{d\theta} = 0$$

where x_i = any process variable (T, p, ...) and θ = time

The Mass Balance Equation

Consider a control volume



Balancing B within the control volume,

$$\Delta m_B = +(\text{mass increases})_B \; -(\text{mass decreases})_B$$

$$\Delta m_B = +\text{Input}_B + \text{Generated}_B - \text{Consumed}_B - \text{Output}_B$$

The Mass Balance Equation

Possible scenarios for B,

If $(input + generation)_B > (output + consumption)_B$,

then the amount B within the control volume increases (accumulation)

If $(input + generation)_B < (output + consumption)_B$,

then the amount B within the control volume decreases (depletion/negative accumulation)

If $(input + generation)_B = (output + consumption)_B$,

then the amount B within the control volume will not change (steady-state)

The Mass Balance Equation

The general mass balance equation can be written as

Acc/Dep = Input + Generation – Output – Consumption

For a steady-state process, there is no accumulation or depletion of materials:

Input + Generation – Output – Consumption = 0

OR

Input + Generation = Output + Consumption

The Mass Balance Equation

If there is no chemical reaction, there is no means for a material to be generated or consumed, then

Acc/Dep = Input – Output

If there is no chemical reaction and steady-state condition exists, then:

0 = Input – Output

OR

Input = Output

Degrees of Freedom (DF) Analysis

The procedure of determining whether enough information is given to solve the problem. To determine the degrees of freedom (DF):

$$\mathbf{DF = U - V}$$

where U = number of unknown variables to be solved.
V = number of independent equations relating the unknown variables.

What are independent equations?

An equation is independent if it cannot be derived algebraically from the other equations.

Degrees of Freedom (DF) Analysis

Possible cases depending on the value of DF:

DF = 0: there are equal number of unknowns and independent equations and the problem, in principle, can be solved.

DF > 0: there are more unknowns than independent equations and the problem is underspecified and has infinitely many solutions.

DF < 0: there are more independent equations than unknowns and the problem is overspecified and has no exact solution.

Degrees of Freedom (DF) Analysis

Consider the following set of equations used for solving *x*, *y*, and *z*.

$$3x - 4y + 5z = 6$$
$$-2x + 7y - 13z = -20$$
$$x + 3y - 8z = -14$$

Determine whether enough equations are available to solve for the values of *x*, *y*, and *z*.

Possible Sources of Equations in Material Balance Analysis

1. Material balance equations.
2. Stoichiometric relationships based on chemical reactions (particularly useful when solving reactive processes)
3. Energy balance equations (to be discussed later).
4. Physical constraints on some variables.
5. Process specifications.
6. Physical properties and laws