جامعة بابل – كلية هندسة المواد –قسم هندسة البوليمرات والصناعات البتروكيمياوية

مبادئ الهندسة الكيمياوية

Principles of Chemical Engineering

المرحلة الثانية

Lec. 4

"Material Balance"

The objectives from studying of this

1. Understand the features of open, closed, steady-state, and unsteady-state systems, and given a process in words or pictures, select the appropriate categories for the process.
2. Express in words what the material balance is for a process involving single or multiple components.
3. Determine whether positive or negative accumulation occurs in a process.
4. Understand the manner in which a chemical reaction affects the material balance.
5. Recognize a batch or semi-batch process and write the material balance for it.

What are material balances?
A material balance is nothing more than the application of the law of the **conservation of mass “** Matter is neither created nor destroyed**”**

What is the difference between the law of the conservation of mass and the concept of the material balance?
The conservation of mass focuses on the invariance of material in a system, whereas a material balance focuses on ensuring that the flows in and out of the system along with the material in the system can be equated.

As a generic term, material balance can refer to a balance on a system for the:

1- total mass
2- total moles
3- mass of a chemical compound
4- mass of an atomic species
5- moles of a chemical compound
6- moles of an atomic spices
7- Volume (possible)

The general equation for the principles of the material balance applicable to processes both with and without chemical reaction :

In put - output + generation - consumption = accumulation

1- Balance on the total moles,

▪In the absence of chemical reaction, the generation and consumption terms do not apply to a single chemical compounds

In put – output = accumulation

▪ with a chemical reaction present in the system, the generation and consumption terms do apply.

In put - output + generation - consumption = accumulation

2- Balance on the total mass,

The generation and consumption terms are ***zero*** whether a chemical reaction occurs in the system or not.

Input – output = accumulation

Notes:

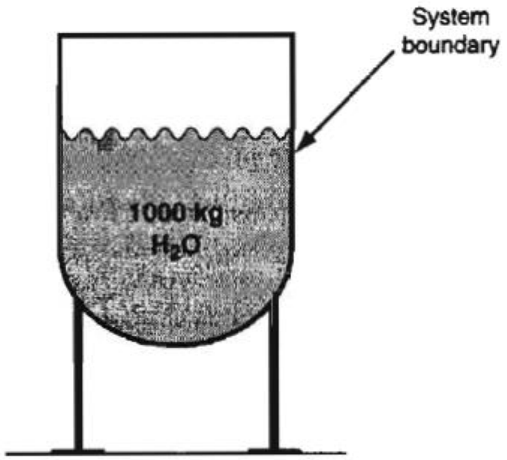
(a) both mass and mole balance for elements such as C, H, or O, the generation and consumption are not involve in material balance (i.e. equal zero).

(b) We can apply a balance on a volume when we have ideal mixing occurs and the densities of the streams are the same.

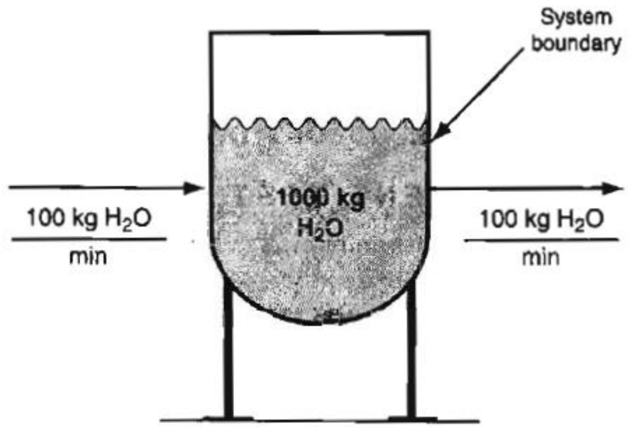
(c) We can inferred the generation and consumption terms from the stoichiometric equations

(d) The accumulation term refers to a change in mass or moles (plus or minus) within the system with respect to time.

(e) Closed system, material neither enters nor leaves the vessel, that is, no material crosses the system boundary.



(f) Open (flow) system, the material cross the system boundary (i.e. add and withdraw a material at certain rate)



(g) In ***Steady state*** problems the values of the variables in the system do not change with time, hence the accumulation term is ***zero***.

In put - output + generation - consumption = 0

The rate of addition is equal to the rate of removal as shown in Figure above.

(h) ***Unsteady state*** (or transient), problems formulated as differential equations with respect to time. The rate of addition (input) not equal to the rate of withdraw (output)

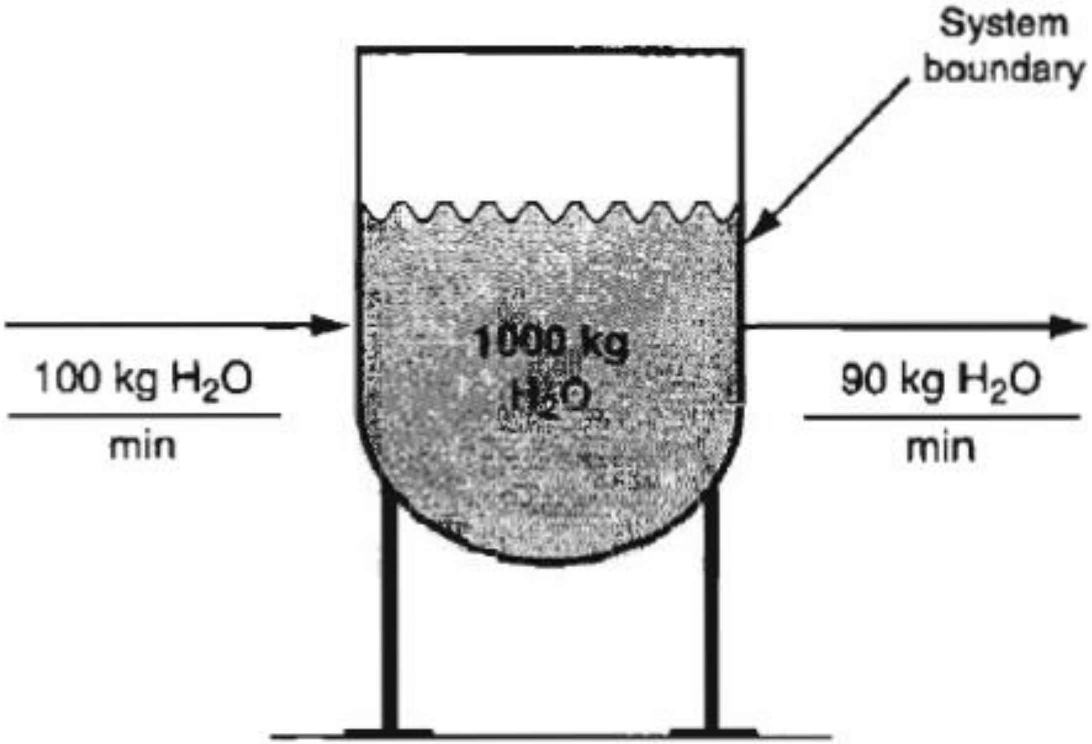


Figure 6.3 Initial conditions for an open unsteady-state system with accumulation.

(I) Semi-batch process, materials enters the process its operation, but does not leave. Instead mass is allowed to accumulate in the process vessel. Product is with draw only after the process is over.

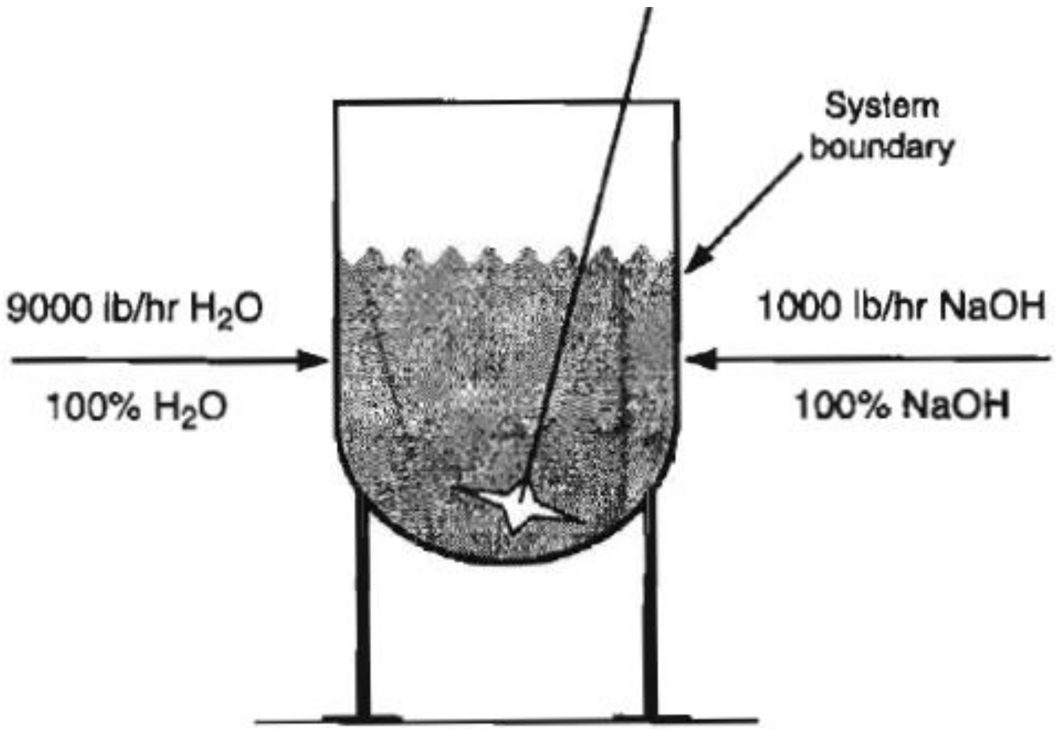


Figure 6.13a Initial condition for the semi-batch mixing process. Vessel is empty.

Accumulation An increase or decrease in the material (e.g., mass or moles) in the system.

Batch process A process in which material is neither added to nor removed from the process during its operation.

Closed system A system that does not have material crossing the system boundary.

Component balance A material balance on a single chemical component in a system.

Conservation of mass Matter is neither created nor destroyed overall.

Consumption The depletion of a component in a system due to chemical reaction.

Continuous process A process in which material enters and/or exits continuously.

Final condition The amount of material (e.g., mass or moles) in the process at the end of the processing interval.

Flow system An open system with material entering and/or leaving.

Generation The appearance of a component in a system because of chemical reaction.

Initial condition The amount of a material (e.g., mass or moles) in the process at the beginning of the processing interval.

Input Material (e.g., mass, moles) that enters the system.

Material balance The balance equation that corresponds to the conservation of mass.

Negative accumulation A depletion of material (usually mass or moles) in the system.

Open system A system in which material crosses the system boundary.

Output Material (e.g., mass, moles) that leaves the system.

Rate Flow per unit time

Semi-batch process A process in which material enters the system but product is not removed during operation.

Steady-state system A system for which all the conditions (e.g., temperature, pressure, amount of material) remain constant with time.

System Any arbitrary portion of or whole process that is considered for analysis.

System boundary The closed line that encloses the portion of the process that is to be analyzed.

Transient system A system for which one or more of the conditions (e.g., temperature, pressure, amount of material) of the system vary with time. Also known as an unsteady-state system.

Unsteady-state system A system for which one or more of the conditions (e.g., temperature, pressure, amount of material) of the system vary with time. Also known as a transient system.

Q / *Material for a distillation column*

A novice manufacturer of ethyl alcohol (denoted as EtOH) for gasohol is having a bit of difficulty with a distillation column. The process is shown in Figure E8.3. It appears that too much alcohol is lost in the bottoms (waste). Calculate the composition of the bottoms and the mass of the alcohol lost in the bottoms based on the data shown in Figure E8.3 that was collected during 1 hour of operation.

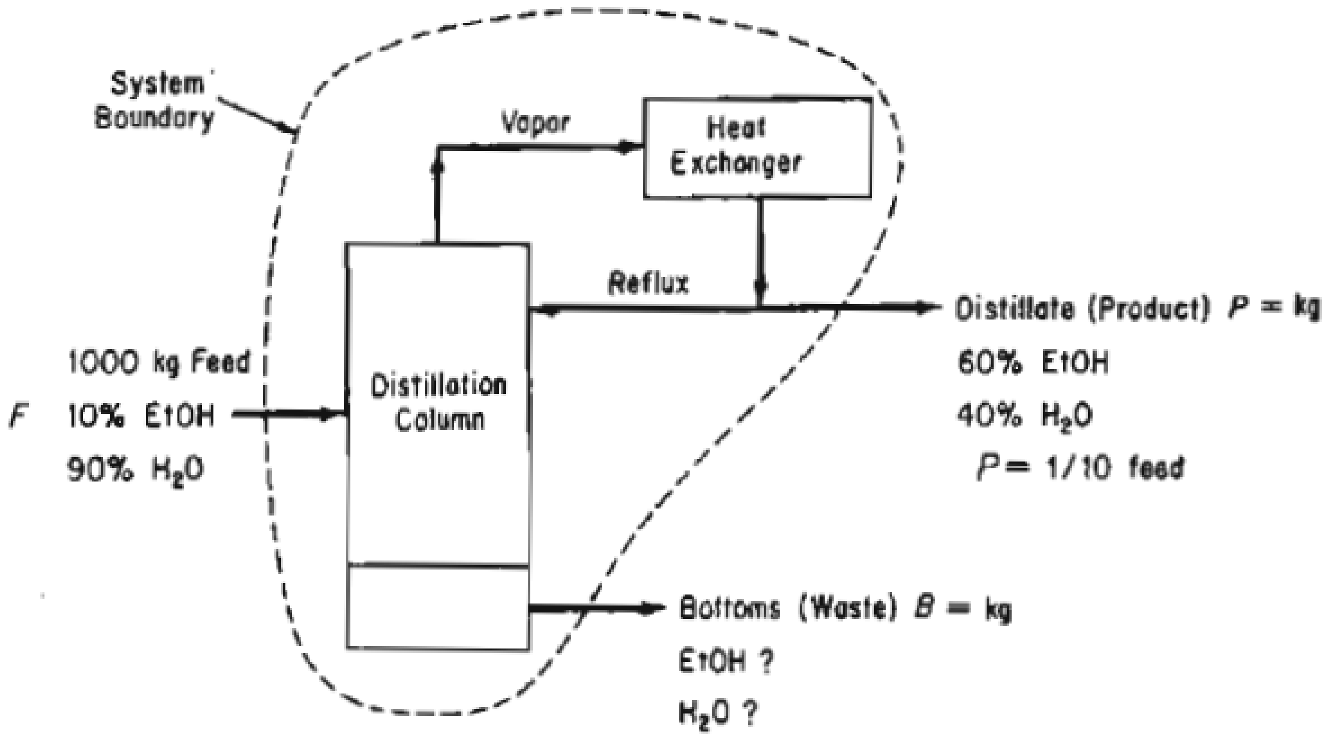


Figure E8.3

Steps 1, 2, and 3 See Fig. E2.11.
Step 4 Select as the basis the given feed

Basis: 1000 kg of feed

Step 3 (Continued) We are given that P is $\frac{1}{10}$ of F, so that

$$P = 0.1(1000) = 100 \text{ kg}$$

Steps 7, 8, and 9 Calculate B by direct subtraction using the total mass balance

$$B = 1000 - 100 = 900 \text{ kg}$$

Steps 5, 6, 7, 8, and 9 The unknown quantities are the bottoms compositions. We can make two component mass balances, or one sum of masses or mass fractions of the components in B plus one component mass balance, so that the problem has a unique solution.

The solution can be computed directly by subtraction.

	kg feed in	−	*kg distillate out*	=	*kg bottoms out*	*percent*
EtOH balance:	0.10(1000)	−	0.60(100)	=	40	4.4
H_2O balance:	0.90(1000)	−	0.40(100)	=	860	95.6
					900	100.0

If we use the total balance to calculate B, all we need to do is make one component balance because

$$\text{mass } H_2O \text{ in } B = 900 - 40 = 860 \text{ kg}$$

Step 10 *Check:* 900 kg B + 100 kg P = 1000 kg F.

Q3 H.W/

A drier takes in wet timber (20.1% water) and reduces the water content to 8.6%. You want to determine the kg of water removed per kg of timber that enters the process.

Let's next consider a more formal definition of the extent of reaction, one that takes into account incomplete reaction, and involves the initial concentrations of reactants and products. The extent of reaction is defined as follows:

$$\xi = \frac{n_i - n_{io}}{\nu_i} \tag{9.3}$$

where n_i = moles of species i present in the system after the reaction occurs

n_{io} = moles of species i present in the system when the reaction starts

ν_i = coefficient for species i in the particular chemical reaction equation (moles of species i produced or consumed per moles reacting)

ξ = extent of reaction (moles reacting)

Q4/ *Material balance with chemical reaction in which the fraction conversion is specified*

The chlorination of methane occurs by the following reaction

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

You are asked to determine the product composition if the conversion of the limiting reactant is 67%, and the feed composition in mole % is given as: 40% CH_4, 50% Cl_2, and 10% N_2.

Q5/ *Material balance with chemical reaction (combustion)*

(a) If 300 lb of air and 24.0 lb of carbon are fed to a reactor (see Fig. E2.3) at 600°F and after complete combustion no material remains in the reactor, how many pounds of carbon will have been removed? How many pounds of oxygen? How many pounds total?

(b) How many moles of carbon and oxygen enter? How many leave the reactor?

(c) How many total moles enter the reactor and how many leave the reactor?

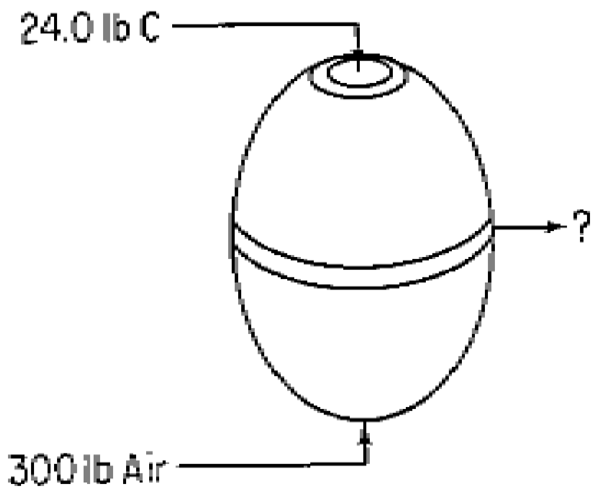


Figure E2.3

Q6/ *Material balance with chemical reaction*

Mercaptans, hydrogen sulfide, and other sulfur compounds are removed from natural gas by various so-called "sweetening processes" that make available otherwise useless "sour" gas. As you know H_2S is toxic in very small quantities and is quite corrosive to process equipment.

A proposed process to remove H_2S is by reaction with SO_2:

$$2\,H_2S(g) + SO_2(g) \rightarrow 3S(s) + 2H_2O(g)$$

In a test of the process, a gas stream containing 20% H_2S and 80% CH_4 was combined with a stream of pure SO_2. The process produced 5000 lb of S(s), and in the product gas the ratio of SO_2 to H_2S was equal to 3, and the ratio of H_2O to H_2S was 10. You are asked to determine the fractional conversion of the limiting reactant, and the feed rates of the H_2S and SO_2 streams.