Lecture 9

2. Material Balances

2.1 Introduction to 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"**.**

Process classification

1. **Batch process**: The feed is charged (fed) into a vessel at the beginning of the process and the vessel contents are removed sometime later.
2. **Continuous process**: the inputs and outputs flow continuously throughout the duration of the process.
3. **Semibatch process**: Any process that is neither batch nor continuous.

Steady-State and Unsteady-State Systems

If the values of all the variables in a process (i.e., all temperatures, pressures, volumes, flow rates) do not change with time, the process is said to be operating at steady state.

If any of the process variables change with time, unsteady state operation is said to exist. By their nature, batch and semibatch processes are unsteady-state operations , whereas continuous processes may be either steady-state or transient.

Material balance for a component without reaction

Input – output = Accumulation (1)

If the system is at steady state (Accumulation = 0)

Input = output (2)

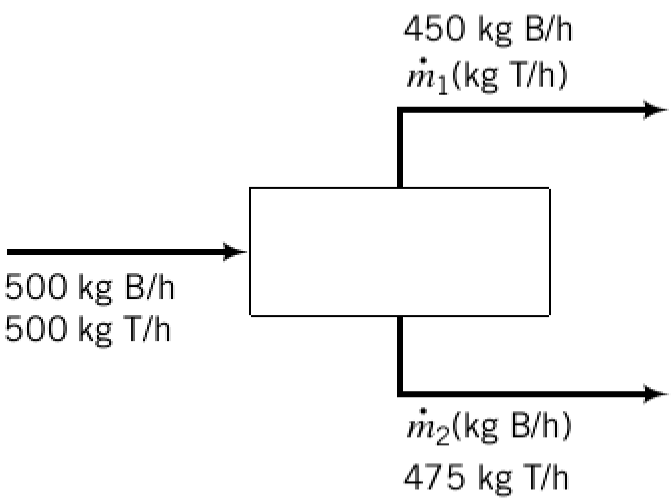
Material balance for Multiple Component Systems

Suppose the input to a vessel contains more than one component, such as 100 kg/min of a 50% water and 50% sugar (sucrose, $C_{12}H_{22}O_{11}$, MW = 342.3) mixture . The mass balances with respect to the sugar and water, balances that we call component balances.

Example 1

1000 kg/h of a mixture of benzene (B) and toluene (T) containing 50% benzene by mass is separated by distillation into two fractions. The mass flow rate of benzene in the top stream is 450 kg B/h and that of toluene in the bottom stream is 475 kg T/h. The operation is at steady state. Write balances on benzene and toluene to calculate the unknown component flow rates in the output streams.

Solution



Basis : 1 hour

In general : input = output

Benzen balance 500 kg B = 450kg B + m_2

m_2 = 50 kg B

Toluene balance 500 kg T = m_1 + 475 kg T

m_1 = 25 kg T

Check the calculation:

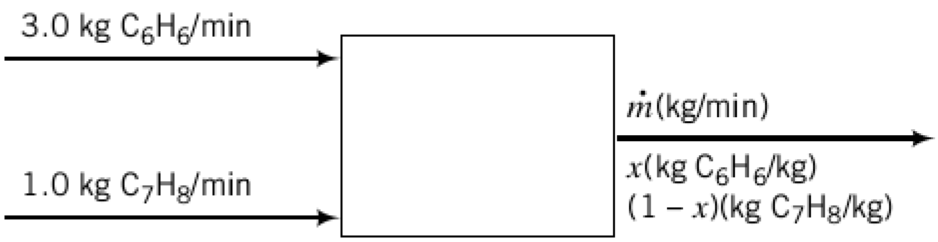
Total mass balance :   1000 kg = 450 + m_1 + m_2 + 475 (all in kg)

1000 kg = 450 + 25 + 50 + 475

1000 kg = 1000 kg

Example 2

Suppose 3.0 kg/min of benzene and 1.0 kg/min of toluene are mixed. Find the composition and mass rate of the product.



Solution

There are two unknown quantities, m and x, so two equations are needed to calculate them.

Basis : 1 minute

Total mass balance: 3 kg + 1 kg = m

m = 4 kg

benzen balance: $3\ \text{kg B} = \text{m(kg)} * \frac{\text{x(kg B)}}{\text{kg}}$

x = 0.75 kg B/ kg

2.2 General Strategy for Solving Material Balance Problems

1. Read and understand the problem statement.
2. Draw a sketch of the process and specify the system boundary.
3. Place labels for unknown variables and values for known variables on the sketch.
4. Obtain any data you need to solve the problem, but are missing.
5. Choose a basis.
6. Determine the number of variables whose values are unknowns.
7. Determine the number of independent equations, and carry out a degree of freedom analysis.
8. Write down the equations to be solved in terms of the knowns and unknowns.
9. Solve the equations and calculate the quantities asked for in the problem.
10. Check your answer(s).