Heat transfer

Definition:

Heat transfer is a dynamic process in which heat is transferred spontaneously from one body to another cooler one. The rate of heat transfer depends upon the differences in temperature between the bodies, the greater the difference in temperature, the greater the rate of heat transfer.

Problems:

1- Calculate the amount of heat in 30 minutes that will flow through a sheet of stainless steel, 10 mm in thickness, 0.6 meter wide and 1 meter long, , with a temperature of 70 °C on one side and 30 °C on the other side.

2- Choose the best insulating material for an internally heated vessel when the insulating wall thickness is 3 cm, the internal and the external temperatures are 98 and 20 °C, respectively. The cross sectional area of heat transfer is 500 cm^2. The proposed insulators are asbestos, cork or brick (k are 0.087, 0.021 and 0.05 Btu.ft/ft^2.hr.°F respectively). What would be the thickness of the insulators to reduce the rate of heat transfer to 1 watt?

3- Suppose you have a wall of thickness 8 inch covered by a layer of brick 5 inch thick. The temperature of the inner surface is 300 °F and that of the outer layer is 50 °F. The coefficient of thermal conductivity of the wall (k_1) is 1.5 Btu.ft/ft^2.hr.°F and of brick (k_2) is 0.05 Btu.ft/ft^2.hr.°F.

a- Calculate the rate of heat loss

b- The temperature of the interface

c- If k_2= 0.12 Btu.ft/ft^2.hr.°F, Find the thickness keeping the same temperature.

4- A wall is composed of 4.3 inch layer, the coefficient o0f thermal conductivity of which is 0.08 Btu.ft/ft^2.hr.°F packed by a layer of 9 inch in thickness, the k of which is 0.8 Btu.ft/ft^2.hr.°F. The temperature of the inside surface of the wall is 1400 °F and that of the outside surface is 170 °F.

Calculate the rate of heat loss through this wall and then the temperature of the interface between the two layers.

6- It is desired to limit the heat loss from a wall of polystyrene foam to 8 Js^{-1}, when the temperature on one side is 20 °C and on the other -18 °C. How thick should the polystyrene be? k of polystyrene is 0.03 W/m.K.

7- Iron and copper rods are joined together end to end in good thermal contact. The two rods have equal lengths and radii. The free end of the iron rod is maintained at a temperature of 120 °C and the free end of the copper rod is maintained at 10 °C.

a- Determine the temperature of the interface where the two rods are joined.

b- If each rod is 0.2 m long and 6 cm^2 in cross sectional area, what quantity of heat energy is conducted through the combination during a 30 minute interval? k of copper is 0.039 J/m.sec.°C and that of iron is 0.0068 J/m.sec.°C.

8- A Thin pipe of an outside diameter of 4.5 inch is insulated with a 3 inch thickness of an insulation having a thermal conductivity of 0.05 Btu.ft/ft^2.hr.°F. If the temperature of the outer surface of the pipe is 700°F and that of the outer surface of the insulator is 110 °F. Calculate the heat loss in Btu/hr.ft of the pipe length.

9- A pipe of an outside diameter 3.5 inch is insulated with a 2 inch thickness of an insulation having thermal conductivity of 0.05 Btu.ft/ft^2.hr.°F and a 1.25 inch thickness of an insulation having a thermal conductivity of 0.037 Btu.ft/ft^2.hr.°F. If the temperature of the outer surface of the pipe is 670 °F and that of the outer surface of the insulation is 100 °F. Calculate the heat loss in BTU/hr.ft of pipe length.

10- A lagged steam pipe has a total outside diameter of 0.12 m, including a 20 mm thick layer of calcium silicate insulation on the outside. The inner and outer surface of the insulation are at temperatures of 800 K and 400 K, respectively. Calculate the heat loss per unit length of pipe. Thermal conductivity of calcium silicate is 0.07 W/m.K.

Material Balance

Basic Principles:

One of the fundamental laws of physics states that mass can neither be produced nor destroyed-that is mass is conserved. This law of physics provides the basis for a tool which is used routinely in environmental engineering and science- the mass balance

If the unit operation, whatever its nature is seen as a whole it may be represented diagrammatically as a box, as shown in Fig. 1. The mass going into the box must balance with the mass coming out.

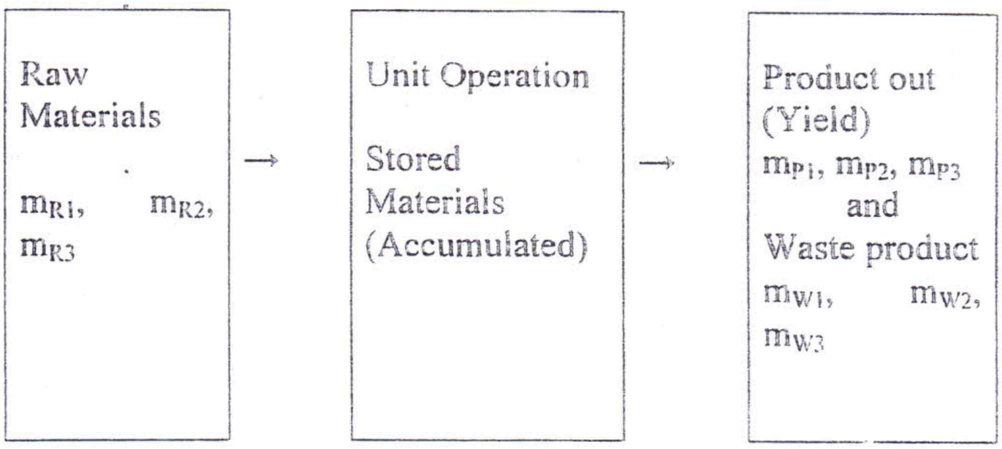

Figure 1: Material Balance

Classification of the process:

A- Based on how the process varies with time:

a- **Steady state process** is one that does not change with time. Every time we take a snapshot , many variables have the same values as in the first the snapshot.

b- **Unsteady-state (transient) process** is one that changes with time. Every time we take s snapshot, many of the variables have different values than in the first snapshot.

The Mass Balance Equation:

According to the law of **Conservation of Mass.** The total mass balance equation can be written as:

Input (Feed) = Output (Yield or Product) + Accumulation
Feed (F) = Yield (Y) + Accumulated materials (A)

If the process is at steady state, there is no accumulation of mass within the process.

Thus Input = Output
Feed = Yield (product)

$\sum$ Masses entering via feed streams = $\sum$ Masses exiting (leaving) via product streams

The mass of every material in every stream must be included. The above equation can be applied to batch and continuous processes as:

$\sum$ Mass in = $\sum$ Mass out for a batch process

and

$\sum$ Mass in by flow = $\sum$ Mass out by flow for a continuous process

Total balance:

Feed = mass of water removed + product (yield)

$F = X + Y$

Problems:

1- A furnace is loaded with materials at a rate of 5 Ton/hr. The scale losses are 2%. Find out the material output.

2- Moist granules are to be dried in a continuous oven, the inlet moisture content is 25% and the outlet moisture is 1%. The production is 2 tons/ hr on a dry basis. Find out how much quantity of moisture is removed per hour.

3- There are three separate furnace generating pollutant-laden gas streams. The gas flow rates from the three sources are 1500, 4500 and 2000 lb_m/min. What is the total flow rate going to the fabric filter serving these three sources?

4- Two hundred kg of wet material are to be dried by heating in a dryer. The wet material enters the dryer with 0.5 g water per g of the initial dry material. The dried material leaves the dryer with 20% moisture. Determine the mass of water removed.

5- Three hundred kg of wet material are to be dried, it enters the dryer with 60% w/w moisture and 90% of the water is removed. Determine the mass of the dried product.

6- A wet material contains 70% moisture is to dried at a rate of 1000 lb/hr to give a product containing 10% moisture. Fresh air at humidity of 0.001 lb water vapor/lb dry air is introduced in the dryer and leaves it at humidity of 0.003 lb water vapor/lb dry air. Calculate the weight of fresh air required per hour.

7- A wet scrubbing system has three separate inlet streams. The mass flow rates in these inlet streams are 100, 58 and 74 lb_m/min. The water spray flow rate is 60 lb_m/ min. and the outlet liquid stream (water) is 49 lb_m/min. Determine the gas outlet flow rate.

Evaporation

Problems

1- A given evaporator is to be fed with 10.000 lb/hr of solution containing 4% solute by weight. The feed is at a temperature of 100 °F, it is to be concentrated to a solution of 10 % by weight in an evaporator operating at a pressure of one atmosphere in the vapor space. In order to carry out the evaporation, the heating surface is supplied with steam at 5 p.s.i.g (227 °F)

a- What is the weight of vapor produced?

b- What is the total weight of steam required?

c- If the overall heat transfer coefficient of the evaporator is 270, what is the heating surface required?

N.B. From steam tables we found that the:

- B.P of water at one atmosphere is 212°F
- Latent heat of vaporization of water at 1 atm. Is 1034 Btu/lb
- Latent heat of vaporization of water at 5 p.s.i.g is 960 Btu/lb

2- An evaporator working at atmospheric pressure is to concentrate a solution from 5% to 30% solid by weight at a rate of 10.000 lb/hr. The solution which has a specific heat of one is fed to the evaporator at 20 °C. The dry saturated steam at 20 psig is fed and the condensate leaves at the temperature of the condensing steam 126 °C. The overall heat transfer coefficient is 400. Find:

a- How much steam is required?

b- What is the required area of heat transfer?

N.B. Latent heat of vaporization of water at 20 psig is 958 Btu/lb

- Latent heat of vaporization of water at 1 atmosphere is 1034 Btu/lb

3- A given evaporator is to be fed with 10.000 lb/hr of solution containing 2.5% solute by weight. It is to be concentrated to a solution of 8% solute by weight in an evaporator operating at a pressure of one atmosphere in the vapor space. The feed is at a temperature of 80 °F. In order to carry out the evaporation, the heating surface is supplied with steam at 5 psig and 227 °F.

a- What is the weight of vapor produced?

b- What is the total weight of steam required?

c- If the overall heat transfer coefficient of the evaporator is 270, what is the heating surface required?

~~d- Calculate the above requirements if the feed enters at 220 °F~~

N.B. From steam tables we found that the:

- B.P of water at one atmosphere is 212°F
- Latent heat of vaporization of water at 1 atm. Is 1034 Btu/lb
- Latent heat of vaporization of water at 5 p.s.i.g is 960 Btu/lb

4- A given evaporator is to be fed with 5000 lb/hr of a solution containing 1% solid by weight, the feed is at a temperature of 90 °F and it is to be concentrated to a solution of 2% solid by weight in an evaporator operating at a pressure of 5 psi vacuum. In order to carry out the evaporation, the heating surface is supplied with steam at 7.5 psig (B.P. is 240 °F)

a- What is the weight of vapor produced?

b- What is the total weight of steam required?

c- What is the overall heat transfer coefficient of the evaporator if the total surface area is 750 ft^2?

N.B. From steam tables we found that the:

- B.P of water at 5 psi vacuum is 192°F
- Latent heat of vaporization of water at 5 psi vacuum is 982.5 Btu/lb
- Latent heat of vaporization of water at 7.5 p.s.i.g is 950 Btu/lb