Tutorial on Mass and Energy Balance

1. A solution which is 80% oil, 15% usable by-products and 5% impurities, enters a refinery. One output is 92% oil and 6% usable by-products. The other output is 60% oil and flows at the rate of 1000 lit/hr (assume no accumulation, percents by volume)

a. What is the flow rate of input?

b. What is the percent composition of the 1000 lit/hr output?

c. What percent of the original impurities are in the 1000 lit/hr output?

Solution

Basis:

Input Stream A = X lit / hr

Output Stream B = Y lit / hr

Output Stream C = 1000lit / hr

Material balance equations

1) Total: X = Y + 1000 (EQ1)

2) Oil: 0.8^ * X=0.92^ * Y + 0.6 * 1000 (EQ-2)

3) UBP: 0.15^ * X=0.06^ * Y + v * 1000 (EQ-3)

4) IMP: 0.05^ * X=0.02^ * Y + w * 1000 (EQ-4)

5) OUTPUT impurities & UBP: v + w = 0.4 (EQ-5)

Solving Equations 1 and 2; substituting value of X in EQ-

0.8 (Y + 1000) = 0.92Y + 600

0.8Y + 800 = 0.92Y + 600 , Y = 1666lit / hr

Substituting Y in EQ-1

X = 1666 + 1000 = 2666lit / h * r = Flow rate of input stream

Substituting value of X and Y in EQ-3, v = 30%

Substituting value of v in EQ-5, w = 10%

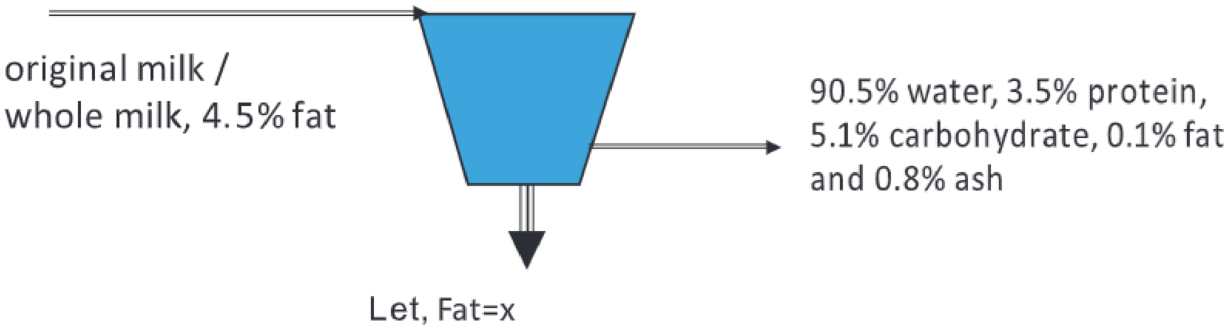
Thus composition of 1000 lit/hr output stream is 60% oil, 30% usable by products and 10% impurit

Impurities in input stream = 0.052666=133.3 lit/hr

Impurities in 1000 lit/hr stream (10%) = 100lit / h * r

Therefore impurities in 1000 lit/hr stream as % input stream = 100/133.3 = 75%

2. Skim milk is prepared by the removal of some of the fat from whole milk. This skim milk is found to contain 90.5% water, 3.5% protein, 5.1% carbohydrate, 0.1% fat and 0.8% ash. If the original milk contained 4.5% fat, calculate its composition assuming that fat only was removed to make the skim milk and that there are no losses in processing.



Solution :

Basis: 100 kg of skim milk.

This contains, therefore, 0.1 kg of fat. Let the fat which was removed from it to make skim milk be x kg.

Total original fat = (x + 0.1) kg

Total original mass = (100+x) kg

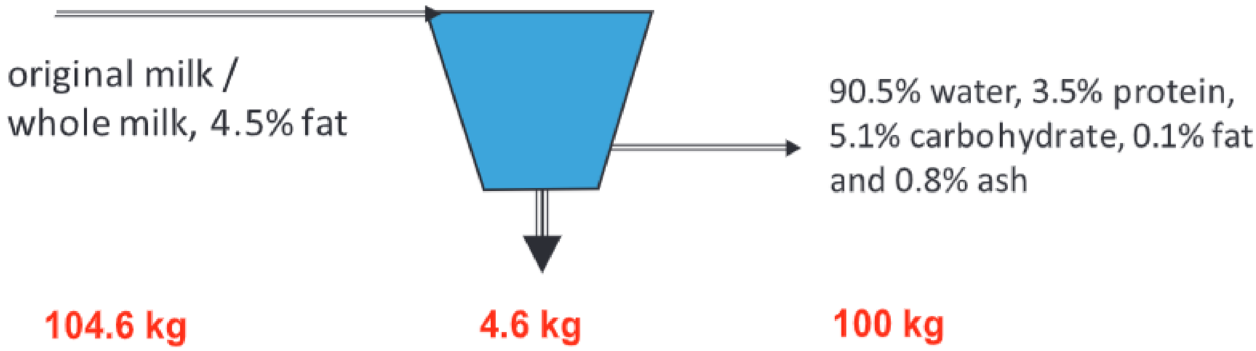
and as it is known that the original fat content was 4.5% so

$(x+0.1) /(100 + x)=0.045$

$x + 0.1=0.045(100+ x)$

$x = 4.6$ kg

So the composition of the whole milk is then fat = 4.5%, water = 90.5/104.6 86.5 %, protein 3.5/104.63.3%, carbohydrate=5.1/104.6=4.9% and ash = 0.8%



3. In a continuous centrifuging of milk, if 35,000 kg of whole milk containing 4% fat is to be separated in a 6 hour period into skim milk with 0.45% fat and cream with 45 %

fat, what is the flow rate of the two output streams from the continuous centrifuge which accomplishes the separation?

In continuous processes, time also enters into consideration and the balances are related to unit time. Thus in considering a continuous centrifuge separating whole milk into skim milk and cream, if the material holdup in the centrifuge is constant both in mass and in composition, then the quantities of the components entering and leaving in the different streams in unit time are constant and a mass balance can be written on this basis. Such an analysis assumes that the process is in a steady state, that is flows and quantities held up in vessels do not change with time.

Solution :

Solution Basis:
Total mass input per hour = 35000/6=5833 kg
Total mass output for skim milk = Y
Total mass output for cream = z

Material Balance Equations:

1) Mass In = Mass Out: 5833 = Y + Z (i.e. Z=5833-Y)... EQ-1
2) Fat In = Fat Out: 0.04* 5833=0.0045* Y+0.45* Z... EQ-2

Substituting Z from EQ-1 to EQ-2

0.04* 5833 0.0045 Y+0.45* (5833-Y)
Y = 5369 kg/hr
Substituting Y in EQ -1
Z=464 kg/hr

4. A furnace shell has to be cooled from 90°C to 55°C. The mass of the furnace shell is 2 tonnes; the specific heat of furnace shell is 0.2 kcal/kg °C. Water is available at 28°C. The maximum allowed increase in water temperature is 5°C. Calculate the quantity of water required to cool the furnace. Neglect heat loss.

   Solution

   Energy Stream #1
   Mass of furnace shell (m) = 2000 kg
   Specific heat (Cp) = 0.2 kcal/kg °C
   Initial furnace temperature (T_1) = 90°C

   Desired furnace shell temperature (T) = 55°C

Total heat that has to be removed from the furnace = m* Cp *(T,- T2) = 2000 * 0.2 *(90-55)

Energy Stream #2
Quantity of water required = X kg
Specific heat of water = 1 kcal/kg °C
Inlet cooling water temperature (T) = 28°C
Maximum cooling water outlet temperature (T) = 33°C
Heat removed by water X * 1 * (33-28) = 5X kcal

For energy balance:
Energy Stream #1 = Energy Stream #2
or Quantity of water required (X) = 14000/5 = 2800 kg

5. Production rate from a paper machine is 340 tonnes per day (TPD). Inlet and outlet dryness to paper machine is 40% and 95% respectively. Evaporated moisture temperature is 80 °C. To evaporate moisture, the steam is supplied at 35 kg/cm2. Latent heat of steam at 35 kg/cm2 is 513 kcal/kg. Assume 24 hours/day operation a) Estimate the quantity of moisture to be evaporated b) Input steam quantity required for evaporation (per hour). Consider enthalpy of evaporated moisture as 632 kcal/kg.

Solution

Production rate from a paper machine: 340 TPD or 14.16 TPH (tonnes per hour)
Inlet dryness to paper machine: 40%
Outlet dryness from paper machine: 95%

Estimation of moisture to be evaporated
Paper weight in the final product: 14.16 x 0.95 = 13.45 TPH
Weight of moisture before dryer: [(100-40)/40] x 13.45 = 20.175 TPH
Weight of moisture after dryer: 14.16 x 0.05 = 0.707 TPH
Evaporated moisture quantity: 20.175 -0.707=19.468 TPH

Input steam quantity required for evaporation
Evaporated moisture temperature: 80 °C
Enthalpy of evaporated moisture: 632 kcal/kg
Heat available in moisture (sensible & latent): 632 x 19468 = 12303776 kcal/h

For evaporation minimum equivalent heat available should be supplied from steam
Latent Heat available in supply steam at 3.5 kg/cm2 = 513 kcal/kg
Quantity of steam required: 12303776/513-23984 kg or 23.98 MT/hour