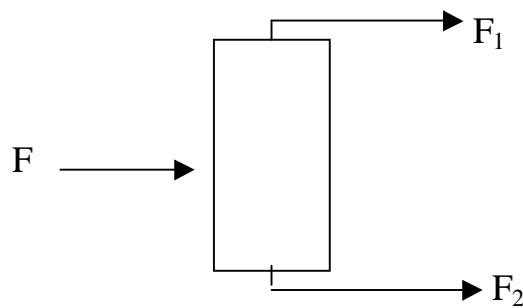


# ENERGY BALANCE

## (1) HEAT BALANCE ACROSS FRACTIONATOR 1



Feed,  $F = 17384.33$  kg/hr.

Wt% :  $X_{EB} = 0.1103$

$X_{PX} = 0.1903$

$X_{OX} = 0.1842$

$X_{TMB} = 0.1114$

Recycle,  $R = 20951.9$  kg/hr.

$X_{EB} = 0.085$

$X_{PX} = 0.225$

$X_{MX} = 0.475$

$X_{OX} = 0.215$

Stream,  $F_1 = 31880.85 \text{ kg/hr}$ .

$$X_{EB} = 0.116$$

$$X_{PX} = 0.252$$

$$X_{OX} = 0.1$$

$$X_{MX} = 0.532$$

Stream,  $F_2 = 6455.38 \text{ kg/hr}$ .

$$\text{Wt\% } X_{ox} = 0.7$$

$$X_{TMB} = 0.3$$

Assume fresh feed enters at  $30^\circ\text{C}$ .

Let the base (reference) temperature be  $273 \text{ K}$

$$C_{p_{EB}} \text{ at } 303 \text{ K} = 1.7673 \times 1000 \text{ J/kg}^\circ\text{K}$$

$$C_{p_{PX}} \text{ at } 303 \text{ K} = 1.117 \times 1000 \text{ J/kg}^\circ\text{K}$$

$$C_{p_{MX}} \text{ at } 303 \text{ K} = 1.7432 \times 1000 \text{ J/kg}^\circ\text{K}$$

$$C_{p_{OX}} \text{ at } 303 \text{ K} = 1.7828 \times 1000 \text{ J/kg}^\circ\text{K}$$

$$C_{p_{TMB}} \text{ at } 303 \text{ K} = 1.8195 \times 1000 \text{ J/kg}^\circ\text{K}$$

$$\begin{aligned} \therefore \text{Enthalpy of F, } h_F &= (0.1103 \times 1.7673 + 0.1903 \times 1.117 + 0.1842 \times 1.7828 \\ &\quad + 0.1114 \times 1.8195 + 0.114 \times 1.8195) \times 1000 \times \\ &\quad 17384.33 \times (303-273) \end{aligned}$$

$$\therefore h_F = 4.89 \times 10^8 \text{ J/hr.}$$

Enthalpy of stream r : Assume R enters at its bubble point.

$$\begin{aligned} h_R &= (0.085 \times 2.1 + 0.225 \times 1.998 + 0.475 \times 1.93 + 0.215 \times 1.945) \times 1000 \\ &\quad \times (413 - 273) \times 20951.9 \end{aligned}$$

$$\therefore h_R = 5.75 \times 10^9 \text{ J/hr.}$$

$$\therefore h_{\text{feed}} = h_R + h_F = 4.89 \times 10^8 + 5.75 \times 10^9$$

$$\therefore h_{(R+F)} = 6.239 \times 10^9 \text{ J/hr.}$$

F + R stream = Flow rate = 38336.23 kg/hr.

$$X_{EB} = 0.0965$$

$$X_{PX} = 0.2092$$

$$X_{MX} = 0.4427$$

$$X_{OX} = 0.2010$$

$$X_{TMB} = 0.0506$$

Temperature of feed, T is determined by a heat balance.

$$\begin{aligned} &= (0.0965 \times 2.1 + 0.2092 \times 1.98 + 0.4427 \times 1.93 + 0.201 \times 1.945 + \\ &\quad 0.0506 \times 2.132) \times 1000 \times (T - 273) \times 38336.23 \\ &= h_e + h_F = 6.239 \times 10^9 \text{ J/hr.} \end{aligned}$$

$$\therefore T = 82.6^\circ\text{C}$$

specific heat capacities in the above calculation were determined at

$$(140 + 30) / 2 = 85^\circ\text{C}$$

Hence error in temperature is very small.

Enthalpy of stream  $F_1$

$F_1$  is a liquid stream emerging from the condenser at bubble pt.

$$T^{\text{sat}} = T_{\text{bp}} = 140^\circ\text{C}$$

$$\begin{aligned} h_{f1} &= (0.116 \times 2.10 + 0.252 \times 1.98 + 0.1 \times 1.945 + 0.532 \times 1.93) \times 1000 \times 31880.85 \\ &\quad \times (413 - 273) \\ &= 8.76 \times 10^9 \text{ J/hr.} \end{aligned}$$

$$\begin{aligned} h_{f2} &= (0.7 \times 1.99 + 0.3 \times 2.1) \times 1000 \times 6455.38 \times (423 - 273) \\ &= 1.958 \times 10^9 \text{ J/hr.} \end{aligned}$$

Latent heats :

$$\lambda_{EB} = 3.3725 \times 10^5 \text{ J/kg}$$

$$\lambda_{PX} = 3.3819 \times 10^5 \text{ J/kg}$$

$$\lambda_{MX} = 3.412 \times 10^5 \text{ J/kg}$$

$$\lambda_{OX} = 3.4514 \times 10^5 \text{ J/kg}$$

Condenser Load :

$$Q_c = (0.116 \times 3.3727 + 0.252 \times 3.3819 + 0.1 \times 3.4514 + 0.532 \times 3.412) \times 100000 \\ \times 31880.85$$

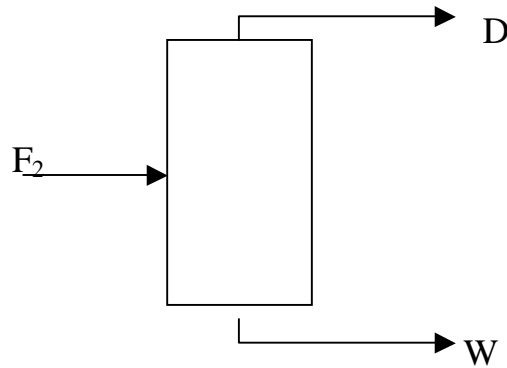
$$Q_c = 1.085 \times 10^{10} \text{ J/hr.}$$

Reboiler Load :

$$Q_B = Q_c + h_{F1} + h_{F2} - h_F$$

$$Q_B = 1.5329 \times 10^{10} \text{ J/hr.}$$

## HEAT BALANCE ACROSS FRACTIONATOR -2 :



$$F_2 = 6455.38 \text{ kg/hr}$$

$$\text{Molecular Weight, } M_w = 110.5 \text{ kg/kgmol}$$

$$\text{Hence, } F_2 = 58.42 \text{ kmol/hr}$$

$$\text{Mole fractions } X_{OX} = 0.673, X_{TMP} = 0.327$$

$$H_{F2} = 1.958 \times 10^9 \text{ J/hr}$$

$$D = 4463.83 \text{ kg/hr}$$

$$M_w = 106.1 \text{ kg/kgmol}$$

$$\Rightarrow D = 42.11 \text{ kmol/hr}$$

$$\text{Wt. \% } X_{OX} = 0.99, X_{TMB} = 0.01$$

$$\text{Mole fractions : } X_{OX} = 0.99, X_{TMB} = 0.01$$

$$W = 1991.55 \text{ kg/hr}$$

$$M_w = 119.3 \Rightarrow W = 16.69 \text{ kmol/hr}$$

$$\text{Mole fractions : } X_{OX} = 0.044, X_{TMP} = 0.956$$

$$\text{Wt. \% : } X_{OX} = 0.05, X_{TMB} = 0.95$$

$$T_{F2}^{\text{sat}} = 150^\circ\text{C}$$

$$T_D^{\text{sat}} = 144^{\circ}\text{C} \quad (\text{From T-x-y plot})$$

$$T_W^{\text{sat}} = 164^{\circ}\text{C} \quad (\text{From T-x-y plot})$$

$$H_D = (0.99 \cdot 1.99 + 0.01 \cdot 2.1) \cdot 1000 \cdot 4463.83 \cdot (417 - 273)$$

$$\Rightarrow H_D = 1.2799 \cdot 10^9 \text{ J/hr.}$$

$$H_W = (0.05 \cdot 1.99 + 0.95 \cdot 2.1) \cdot 1000 \cdot 1991.55 \cdot (437 - 273)$$

$$\Rightarrow H_W = 6.84 \cdot 10^8 \text{ J/hr.}$$

Minimum Reflux Ratio,  $R_m = 1.83$  (From design of column)

$$R = 1.5R_m = 2.74$$

$$V = 16709.69 \text{ kg/hr}$$

$$\text{And } L = 20734.34 - 1991.55$$

$$= 18742.79 \text{ kg/hr (assuming a total vaporiser)}$$

$$\text{Latent Heat of TMB} = 3.25 \cdot 10^5 \text{ J/hr}$$

### ***Condenser Load***

$$Q_c = (0.99 \cdot 3.4514 + 0.01 \cdot 3.25) \cdot 100000 \cdot 16709.69$$

$$= 5.76 \cdot 10^9 \text{ J/hr}$$

### ***Reboiler load ,***

$$Q_w = (0.95 \cdot 3.25 + 0.05 \cdot 3.4514) \cdot 100000 \cdot 18742.79$$

$$= 6.11 \cdot 10^9 \text{ J/hr}$$

## **(3) CRYSTALLISER HEAT BALANCE :**

Assume  $213^{\circ}\text{K}$  ( $-60^{\circ}\text{C}$ ) to be the reference temperature.

Feed in first stage is cooled to  $-60^{\circ}\text{C}$ . This is centrifuged and the mother liquor is taken out at  $-40^{\circ}\text{C}$ . The crystals melt (due to the heat generated by the centrifuging operation) and go to the second stage at  $20^{\circ}\text{C}$ . The second

stage feed is cooled to  $-20^{\circ}\text{C}$  and then centrifuged and the recycle sent back at  $0^{\circ}\text{C}$ . the p-xylene slurry is taken of as the final product at  $20^{\circ}\text{C}$ .

Heat balance across heat exchanger 1 :

$$M_N C_{pN} (\Delta T)_N = M_F C_{pF} (\Delta T)_{F1}$$

$$26663.99(0.1384*1.574+0.1074*1.224+0.1193*1.331+0.6349*1.587)*1000$$

$$*(t_1 + 40)$$

$$= 31885.85(0.116*2.25+0.252*1.821+0.532*2.09+0.1*2.05)(140-t_2)*1000$$

$$\Rightarrow 4.041(t_1+40)=6.498(140-t_2)$$

Assume the mother liquor is heated to  $100^{\circ}\text{C}$ .  $\Rightarrow t_1=100^{\circ}\text{C}$ .

$$\Rightarrow t_2=52.94^{\circ}\text{C}.$$

$$h_{F1}=31880.85(0.1167*1.87+0.252*1.661+0.532*1.813+0.1*1.773)*1000$$

$$*[52.94-(-60)]$$

$$= 6.392*10^9 \text{ J/hr.}$$

$$\Rightarrow h_R = 1.474*10^7 \text{ J/hr}$$

$$F = F_1 + R = 33591.44 \text{ kg/hr.}$$

$$\text{Wt. \% } X_{EB} = 0.1107, X_{PX} = 0.2611, X_{MX} = 0.534, X_{OX} = 0.0942$$

$$H_F = (0.1107*1.87+0.2661*1.661+0.534*1.813+0.0942*1.773)*1000$$

$$*33591.44 *[t-(-60)]$$

$$= 5.9645*10^7(t+60) \text{ J/hr.}$$

$$h_F = h_{F2} + h_R = 6.536*10^9 \text{ J/hr.}$$

$$\Rightarrow t = 45.59^{\circ}\text{C}.$$

$\Rightarrow$  The feed enters at  $45.59^{\circ}\text{C}$  and has to be cooled to  $-60^{\circ}\text{C}$  using ethene refrigerant.

Ethene enters at 110 K and leaves at 160 K. In this temperature range, ethene is a liquid.

PX condensed = 5845.35 kg/hr.

MX condensed = 1030.299 kg/hr.

$$\begin{aligned}\text{Heat of crystallization} &= 5845.35 \cdot 161.43 + 1030.299 \cdot 109.14 \\ &= 10.549 \cdot 10^5 \text{ J/hr.}\end{aligned}$$

$$\begin{aligned}MC_p &= 5.9645 \cdot 10^7 (45.39 - (-60)) \\ &= 6.286 \cdot 10^9 \text{ J/hr.}\end{aligned}$$

$$C_{pav} \text{ of ethene} = (2.457 + 2.395) / 2 = 2.426 \text{ KJ/kg K}$$

$$MC_p = 6.286 \cdot 10^9 + 10.549 \cdot 10^5$$

$$\Rightarrow M = 52,689.55 \text{ kg/hr of ethene refrigerant}$$

Heat loss in centrifuge and transportation =

$$\begin{aligned}&26663.99 \cdot (0.1384 \cdot 1.574 + 0.1074 \cdot 1.224 + 0.1193 \cdot 1.331 + 0.6394 \cdot 1.587) \\ &1000(-40 + 60) + 6868.65(0.85 \cdot 1.224 + 0.15 \cdot 1.587) \cdot 1000 \cdot (20 + 60) \\ &= 1.516 \cdot 10^9 \text{ J/hr.}\end{aligned}$$

$$h_Q = 0 \text{ J/hr.}$$

$$h_M = 6868.65(0.85 \cdot 1.224 + 0.15 \cdot 1.587) \cdot 1000 \cdot (20 + 60)$$

$$\Rightarrow h_M = 7.026 \cdot 10^8 \text{ J/hr.}$$

$$h_N = 8.099 \cdot 10^8 \text{ J/hr.}$$

$$h_N(\text{after emerging from H.E}) = 4.859 \cdot 10^9 \text{ J/hr.}$$

Second stage crystalliser :

Feed enters at 20°C and is cooled to -20°C by C<sub>2</sub>H<sub>4</sub>.

$$\begin{aligned}MC_p &= 6868.65(0.85 \cdot 1.224 + 0.15 \cdot 1.587) \cdot 1000 \cdot (20 + 20) \\ &= 3.5125 \cdot 10^8 \text{ J/hr.}\end{aligned}$$

$$\begin{aligned}\text{Heat of crystallization} &= 6868.65(0.99 \cdot 161.43 + 0.01 \cdot 109.14) \\ &= 11.052 \cdot 10^5 \text{ J/hr.}\end{aligned}$$

C<sub>2</sub>H<sub>4</sub> enters at 110 K and leaves at 160 K.

$$M(2.426 \cdot 10^9 \cdot 50) = 3.5125 \cdot 10^8 + 11.052 \cdot 10^5$$

$$\Rightarrow M=2904.82 \text{ kg/hr of } C_2H_2.$$

$$\Rightarrow H_A=6868.65(0.85*1.224+0.15*1.587)*(-20+60)*1000$$

$$\Rightarrow H_A=3.5125*10^8 \text{ J/hr.}$$

Heat loss in transportation and centrifuge =

$$1717.16(0.43*1.224+0.57*1.587)*1000*(20)+5151.49(0.99*1.224+0.01$$

$$1.587)*1000*(40)$$

$$=3.021*10^8 \text{ J/hr.}$$

$$\Rightarrow h_p=5151.49*(0.99*1.224+0.01*1.587)*1000*(20+60)$$

$$= 5.059*10^8 \text{ J/hr.}$$

### **REACTOR HEAT BALANCE :**

Reaction is an isomerisation reaction

The heat reaction is neglected.

Therefore heat entering,  $h_R$  = heat leaving

Preheater before reactor :

$$R= 20951.9 \text{ kg/hr at } 60^{\circ}C .$$

$$\text{Therefore } h_R= (4.859*10^9*20951.9)/26663.99$$

$$= 3.808*10^9 \text{ J/hr.}$$

Steam at 1 atm pressure is used as a heating medium.

$$2256.9*1000*M=20951.9(0.1384*1.54+0.1674*1.224+0.1193*1.331$$

$$+0.6349*1.587)*1000(454-60)$$

$$\Rightarrow M = 5541.34 \text{ kg/hr.}$$

Condenser after reactor

Cooling water at  $25^{\circ}C$ , heated to  $45^{\circ}C$ .

$$M*(45-25)*4.18*10^9=20951.9*(0.085*1.574+0.225*1.224+0.475*1.587$$

$$+0.215*1.331)*1000*(454-141)+20951.9(0.085*3.37$$

$$+0.225*3.3819+0.475*3.412+0.215*3.4514)*100000$$

$$\Rightarrow M=199107.03 \text{ kg/hr.}$$

