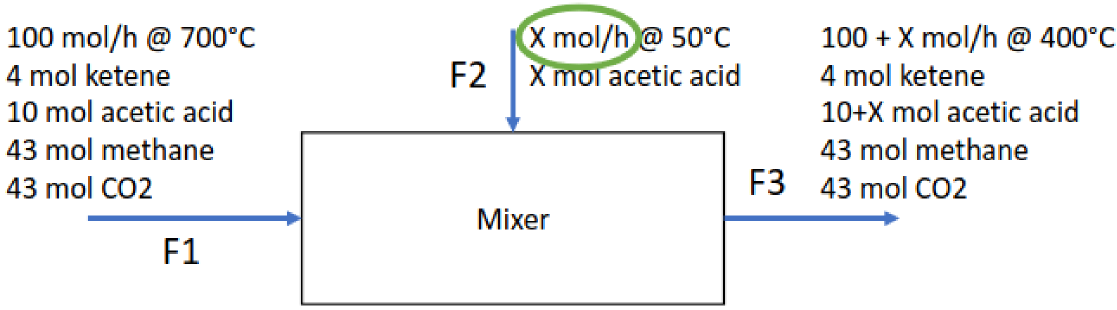
Introduction to Chemical Engineering I

Problem Sheet 7 Solutions

Problem 1 Question A



There is no indication of accumulation, heat transfer or reaction heat evolution, hence

$$\cancel{E_{acc}} = E_{in} + E_{out} \cancel{+ E_{gen}} \cancel{+ E_{cons}}$$

The heat input and output can be determined using specific heat of the components $\hat{E}$

$$E_{in} = -E_{out} = \sum \dot{n} * \hat{E}$$

If we choose a reference temperature of 400°C, the integration range for the outputs is none

$$E_{out} = \int_{400}^{400} 4C_{p,Ket} + (10 + X)C_{p,Ac} + 43C_{p,CH4} + 43C_{p,CO2}dT = 0$$

The energy of the input streams can be determined over the sum of their contributions

$$E_{in} = E_{F1} + E_{F2} = 0$$

Rearranging tells us, that the excess energy of F1 has to equal the energy absorbed by F2

$$E_{F1} = -E_{F2}$$

$$\int_{400}^{700} 4\ C_{p,Ket} + 10\ C_{p,Ac} + 43\ C_{p,CH4} + 43\ C_{p,CO2}\ dT = -\mathrm{X} \int_{400°C}^{50°C} C_{p,Ac}dT$$

We can include the negative sign in the integral by swapping the integration boundaries

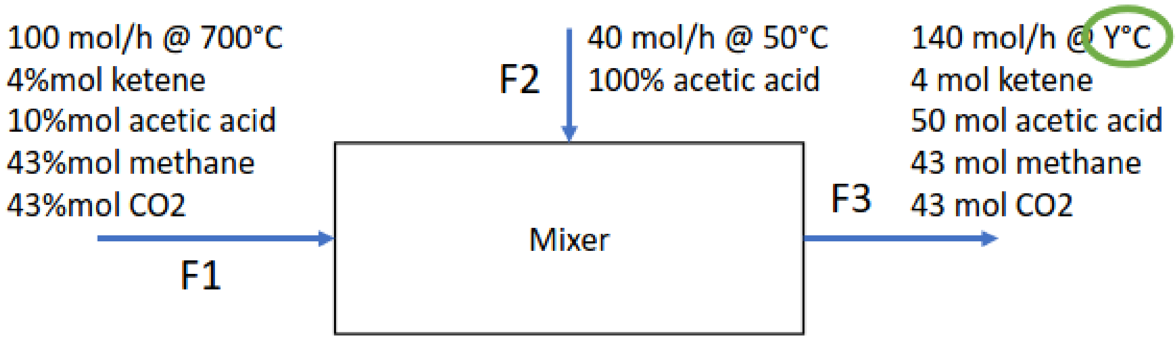
$$-\mathrm{E}_{\mathrm{F2}} = \mathrm{X} \int_{50°C}^{400°C} C_{p,Ac}dT$$

Rearrangement yields

$$X = \frac{\int_{673.15}^{973.15} \begin{matrix} 4\ (4.11 + 2.966 \cdot 10^{-2}T) + 10\ (8.20 + 4.805 \cdot 10^{-2}) \\ +43\ (4.750 + 1.2 \cdot 10^{-2}\mathrm{T}) + 43\ (6.393 + 1.01 \cdot 10^{-2}\mathrm{T})\ dT \end{matrix}}{\int_{323.15}^{391.4} 36\ dT + 5830 + \int_{391.4}^{673.15} 8.20 + 4.805 \cdot 10^{-2}\mathrm{T}\ dT} = 31.22[mol]$$

The sign of ΔH_{VL} depends on the direction of phase transition. Acetic acid requires energy to evaporate. From the point of view of the system, it is receiving energy, hence ΔH_{VL} has a positive contribution.

Question B



Reference temperature chosen: 700°C

Just as before, the system is only affected by energy inputs linked to mass flow:

$$\cancel{E_{acc}} = E_{in} + E_{out} \cancel{+ E_{gen}} \cancel{+ E_{cons}}$$

$$E_{in} = E_{out}$$

Due to the reference temperature we chose, the integration range for the inputs at F1 is none, we only need to consider the heat of acetic acid:

$$E_{in} = E_{F1} + E_{F2} = \int_{700}^{700} 4\, C_{p,Ket} + 10\, C_{p,Ac} + 43\, C_{p,CH4} + 43\, C_{p,CO2}\, dT + \int_{700}^{50} 40\, C_{p,Ac}\, dT$$

$$= 40\left(\int_{391.4}^{323.15} 36\, dT - 5830 + \int_{973.15}^{391.4} 8.2 + 4.805 * 10^{-2} T\, dT\right)$$

As for the outputs, since our final temperature is unknown, we need to rearrange to find the upper bound of our integral

$$E_{out} = \int_{700}^{Y} 4\, C_{p,Ket} + 50\, C_{p,Ac} + 43\, C_{p,CH4} + 43\, C_{p,CO2}\, dT$$

$$= \int_{700}^{Y} 4\,(4.11 + 2.966 \cdot 10^{-2} T) + 50\,(8.20 + 4.805 \cdot 10^{-2})$$
$$+ 43\,(4.750 + 1.2 \cdot 10^{-2}\mathrm{T}) + 43\,(6.393 + 1.01 \cdot 10^{-2}\mathrm{T})\, dT$$

Rearrangement yields

$$Y = 613.65\ [K] = 340.5\ [°\mathrm{C}]$$

Problem 2

a. $\left(C_p\right)_{\mathrm{H_2O(l)}} = 75.4\ \mathrm{kJ/(kmol{\cdot}^\circ C)} = 75.4\ \mathrm{kJ/(kmol{\cdot}^\circ C)}\quad V = 1230\ \mathrm{L}$,

$$n = \frac{V\rho}{M} = \frac{1230\ \mathrm{L}}{}\left|\frac{1\ \mathrm{kg}}{1\ \mathrm{L}}\right|\frac{1\ \mathrm{kmol}}{18\ \mathrm{kg}} = 68.3\ \mathrm{kmol}$$

$$\dot{Q} = \frac{Q}{t} = \frac{n\cdot\int_{T_1}^{T_2}\left(C_p\right)_{\mathrm{H_2O(l)}}dT}{t} = \frac{68.3\ \mathrm{kmol}}{}\left|\frac{75.4\ \mathrm{kJ}}{\mathrm{kmol{\cdot}^\circ C}}\right|\frac{(40-29)\ ^\circ\mathrm{C}}{8\ \mathrm{h}}\left|\frac{1\ \mathrm{h}}{3600\ \mathrm{s}}\right. = \underline{\underline{1.967\ \mathrm{kW}}}$$

b. $\dot{Q}_{\text{total}} = \dot{Q}_{\text{to the surroundings}} + \dot{Q}_{\text{to water}}$, $\dot{Q}_{\text{to the surroundings}} = 1.967\ \mathrm{kW}$

$$\dot{Q}_{\text{to water}} = \frac{Q_{\text{to water}}}{t} = \frac{n\cdot\int_{29}^{40} C_{P(H_2O)}dT}{t} = \frac{68.3\ \mathrm{kmol}}{3\ \mathrm{h}}\left|\frac{75.4\ \mathrm{kJ/(kmol{\cdot}^\circ C)}}{3600\ \mathrm{s/h}}\right|\frac{11\ ^\circ\mathrm{C}}{} = 5.245\ \mathrm{kW}$$

$$\dot{Q}_{\text{total}} = \underline{\underline{7.212\ \mathrm{kW}}} \Rightarrow E_{\text{total}} = 7.212\ \mathrm{kW} \times 3\ \mathrm{h} = \underline{\underline{21.64\ \mathrm{kW{\cdot}h}}}$$

c. $Cost_{\text{heating up from 29 °C to 40 °C}} = 21.64\ \mathrm{kW{\cdot}h} \times \$0.10/(\mathrm{kW{\cdot}h}) = \underline{\underline{\$2.16}}$

$Cost_{\text{keeping temperature constant for 13 h}} = 1.967\ \mathrm{kW} \times 13\ \mathrm{h} \times \$0.10/(\mathrm{kW{\cdot}h}) = \underline{\underline{\$2.56}}$

$Cost_{\text{total}} = \$2.16 + \$2.56 = \underline{\underline{\$4.72}}$

d. If the lid is removed, more heat will be transferred into the surroundings and lost, resulting in higher cost.