1. A liquid mixture of benzene and toluene containing 40 wt% benzene at 90° C and a pressure $P_o$ is fed at a rate of 30 m$^3$/h into a flash evaporator where a portion of it evaporates. The liquid and vapor streams are in equilibrium at 75° C and $P_{tank}$. The liquid product contains 41 mole % benzene. (35 pts)

a) What are the molar flow rate and molar composition of the feed stream? What is the minimum pressure needed to keep the feed stream in the liquid state until it enters the flash tank?

b) What is $P_{tank}$ (which is less than $P_o$), the mole fraction of benzene in the vapor, and the molar flow rates of the liquid and vapor products?

c) Calculate the required heat input rate in kilowatts.

a) Basis: 100 g 40 g/78.11 g/mol + 60/92.13 g/mole = 1.16 moles
Benzene: .512 moles/1.16 = .44 Toluene = .56
Volume = 40g/.879 + 60/.866 = 114.8 cm$^3$
Actual feed: 30 m$^3$/h*10$^6$cm$^3$/m$^3*$1.16 moles/114.8 cm$^3$*1 hr/3600 s = 84.2 moles/s of feed
At T = 90° C, $p^*$benzene = 1021 mm Hg, $p^*$toluene = 407 mm Hg; $P = .44*1021+.56*407 = 677.2$ mm Hg/760 = .891 atm

b) At T = 75° C, $p^*$benzene = 648 mm Hg, $p^*$toluene = 244 mm Hg. $P_{tank} = .41*648 + .59*244 = 409.64/760 = .54$ atm. For benzene: $yP = .41*648$ $y = .65$ $y_{toluene} = .35$

Material balance: 84.2 = n$_L$ + n$_v$ Benzene balance: 37 = .65*n$_v$ + .41*n$_L$ n$_L$ = 73.875 n$_v$ = 10.325

Reference: Benzene(l) at 90° C, Toluene (l) at 90° C

<table>
<thead>
<tr>
<th>Substance</th>
<th>n$_{in}$</th>
<th>$H_{in}$</th>
<th>n$_{out}$</th>
<th>$H_{out}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene(l)</td>
<td>47.1</td>
<td>-----</td>
<td>30.3</td>
<td>-2.187</td>
</tr>
<tr>
<td>Benzene(v)</td>
<td>-----</td>
<td>-----</td>
<td>6.7</td>
<td>28.827</td>
</tr>
<tr>
<td>Toluene(l)</td>
<td>37.1</td>
<td>-----</td>
<td>43.6</td>
<td>-2.633</td>
</tr>
<tr>
<td>Toluene(v)</td>
<td>-----</td>
<td>-----</td>
<td>3.625</td>
<td>32.681</td>
</tr>
</tbody>
</table>
Benzene

\[ \text{Hvap} := 30.7765 \quad \text{bp} := 80.1 \]

\[ a := 74.06 \times 10^{-3} \quad b := 32.95 \times 10^{-5} \quad c := -25.2 \times 10^{-8} \quad d := 77.57 \times 10^{-12} \]

\[ a_L := 126.5 \times 10^{-3} \quad b_L := 23.4 \times 10^{-5} \]

\[ \int_{90}^{75} a_L + b_L \cdot T \, dT = -2.187 \quad \int_{90}^{80.1} a_L + b_L \cdot T \, dT = -1.449 \quad \text{Hvap} := 30.7765 \]

\[ \int_{80.1}^{75} a + b \cdot t + c \cdot t^2 + d \cdot t^3 \, dt = -0.5 \quad H_1 := -1.449 + 30.7765 - 0.5 \quad H_1 = 28.827 \]
Toluene

\[ H_{\text{vap}} T := 33.47 \quad \text{bp}_T := 110.62 \]

\[
\begin{align*}
    a &= 94.18 \times 10^{-3} \\
    b &= 38 \times 10^{-5} \\
    c &= -27.86 \times 10^{-8} \\
    d &= 80.33 \times 10^{-12} \\
    a_l &= 148.8 \times 10^{-3} \\
    b_l &= 32.4 \times 10^{-5} \\
\end{align*}
\]

\[
\int_{90}^{110.62} a + b_l T \, dT = 3.738 \\
\int_{90}^{110.62} a + b \cdot T \, dT = -2.633 \\
\int_{75}^{110.62} a + b \cdot T + c \cdot t^2 + d \cdot t^3 \, dt = -4.527
\]

\[ H_2 := 3.738 + 33.47 - 4.527 \quad H_2 = 32.681 \]

\[ Q := 30.3 - 2187 + 6.7 \times 28.827 + 43.6 - 2.633 + 3.625 \times 32.681 \quad Q = -6.607 \times 10^4 \]
2. A 2.00 L flask containing humid air at 40\degree C is slowly cooled until drops of moisture form at 20\degree C (consider this process to be at 1 atm). Find: (25 pts)
   a) the relative humidity, absolute humidity, and wet-bulb temperature at the start of the process
   b) the mass of water in the flask
   c) the enthalpy change for this process in kJ
   d) What is the energy balance for this system (use the humid air as your system)? Calculate the heat in joules that must be transferred from the air to accomplish the cooling.

   a. \[ T_{do} = 40\degree C, \quad T_{devp, point} = 20\degree C \quad \Rightarrow \quad h_r = 33\%, \quad h_w = 0.0148 \text{ kg H}_2\text{O/kg dry air} \]
   \[ T_{wb} = 25.5\degree C \]

   b. Mass of dry air: \[ m_{da} = \frac{2.00 \text{ L}}{10^3 \text{ L}} \times \frac{1 \text{ kg dry air}}{0.92 \text{ m}^3} = 2.2 \times 10^{-3} \text{ kg dry air} \]
   Mass of water: \[ \frac{2.2 \times 10^{-3} \text{ kg dry air}}{1 \text{ kg dry air}} \times \frac{0.0148 \text{ kg H}_2\text{O}}{1 \text{ kg dry air}} \times \frac{10^3 \text{ g}}{1 \text{ kg}} = 0.033 \text{ g H}_2\text{O} \]

   c. \[ \hat{H}(40\degree C, \ 33\% \text{ relative humidity}) = (78.0 - 0.65) \text{ kJ/kg dry air} = 77.4 \text{ kJ/kg dry air} \]
   \[ \hat{H}(20\degree C, \ \text{saturated}) \approx 57.5 \text{ kJ/kg dry air} \ (\text{both values from Fig. 8.4-1}) \]
   \[ \Delta H_{40\to 20} = \frac{2.2 \times 10^{-3} \text{ kg dry air}}{\text{kg dry air}} \times \frac{(57.5 - 77.4) \text{ kJ}}{1 \text{ kJ}} \times \frac{10^3 \text{ J}}{1 \text{ kJ}} = -44 \text{ J} \]

   d. Energy balance: closed system
   \[ n = \frac{2.2 \times 10^{-3} \text{ kg dry air}}{1 \text{ kg}} \times \frac{10^3 \text{ g}}{29 \text{ g}} + \frac{0.033 \text{ g H}_2\text{O}}{18 \text{ g}} = 0.078 \text{ mol} \]
   \[ Q = \Delta U = n\Delta \hat{U} = n(\Delta H - nR\Delta T) = \Delta H - nR\Delta T \]
   \[ = -44 \text{ J} - \frac{0.078 \text{ mol}}{\text{mol} \cdot \text{K}} \times \frac{8.314 \text{ J}}{\text{mol} \cdot \text{K}} \times \frac{(20 - 40)\degree C}{1 \text{ K}} = -31 \text{ J} \ (23 \text{ J transferred from the air}) \]
3. HCl(g) at 20° C and 780 torr is absorbed in water at 25° C to produce a 6M HCl solution (SG = 1.12, \( C_p = 2.76 \text{ J/g} \cdot \text{°C} \)). Taking 1 L of product solution as your basis: (20 pts)

a) Estimate the volume in liters that must be fed to the absorber.

b) Estimate the heat in kJ that must be transferred from the absorber if the product solution is to emerge at 45° C.

c) What would the final solution temperature be if the process were adiabatic?

\[ 1 \text{L} \cdot 1.12 \text{g/cm}^3 \cdot 1000 = 1120 \text{ g of solution;} \ (1 \text{L solution} \cdot 6 \text{ mol HCl/L solution} \cdot 36.47 \text{ g HCl/mole HCl} = 219 \text{ g HCl}; \ 901.18 \text{ g of water} = 50.1 \text{ moles H}_2\text{O}. \ r = 50.1/6 = 8.34 \]

\[ V = 6\times293\times0.08206/(780/760) = 141 \text{ L gas feed} \]

b)

\[
\begin{array}{c|cc}
\text{Substance} & n_{\text{in}} & H_{\text{in}} \\
\hline
\text{H}_2\text{O (l)} & 50.1 & 0 \\
\text{HCl (g)} & 6 & -0.15 \\
\text{HCl (n=8.34)} & 0 & -57.5 \\
\end{array}
\]

at \( r = 8.34 \), \( \Delta H_s = -67.8 \text{ kJ/mole HCl} \)

\( \Delta H \) from 25 to 45 = 2.76 \text{ J/g} \cdot \text{°C} \cdot 1120 \text{ g} \cdot (45-25) / 6 = 10.3 \text{ kJ/mole HCl} \)

\[ Q = (6\times-57.5 - (6\times-.15)) = -344 \text{ kJ/L product} \]

c) \( Q = 0 \text{ H}_{\text{in}} = H_{\text{out}} \text{ H}_{\text{in}} = -0.9 \text{ H}_{\text{out}} = 6\times(-67.8 + .5152\times(T - 25)) \]

\( -0.9 = -406.8 + 3.1T - 77.28 \quad T = 156^\circ \text{ C} \)
4. The reaction \( \text{CH}_3\text{OH}(l) \rightarrow \text{HCHO} \ (g) + \text{H}_2 \ (g) \) has a heat of reaction of 245.4 kJ/mole. What is the heat of reaction for: \( 2 \text{CH}_3\text{OH} + \text{O}_2 (g) \rightarrow 2 \text{HCHO}(g) + 2 \text{H}_2\text{O}(l) \) if the heat of formation for liquid water is -285.8 kJ/mole? (10 pts)

\[
\text{H}_2(g) + \frac{1}{2} \text{O}_2 \ (g) \rightarrow \text{H}_2\text{O} \ (l) \quad \Delta H_r = -285.8 \text{ kJ/mole}
\]

\[
2*( \text{CH}_3\text{OH}(l) \rightarrow \text{HCHO} \ (g) + \text{H}_2 \ (g)) = 2*245.4 = 490.8 \\
2*( \text{H}_2(g) + \frac{1}{2} \text{O}_2 \ (g) \rightarrow \text{H}_2\text{O} \ (l)) = 2*-285.8
\]

The heat of reaction for \( 2 \text{CH}_3\text{OH}(l) + \text{O}_2(g) \rightarrow 2 \text{HCHO}(g) + 2 \text{H}_2\text{O}(l) \) = -80.8