Question Number III *(16 Marks ~ 29 minutes)* 11:43

The normal boiling point ① of n-pentane is 36.1°C. At a temperature of 75°C the vapour pressure of n-pentane is 310.5 kPa. The latent heat of vaporization of benzene at its normal boiling point of 80.1°C is 30.7 MJ/kmol. You have been given a liquid mixture ② containing 10 mol% benzene (M =78 g/mol) and 90 mol% n-pentane (M = 72.15 g/mol). Use the information provided to answer the following questions:

a) Determine the vapour pressure (in kPa) of pure n-pentane at 65°C. (/3)

① $T_1 = 36.1°C = 309.25\ K$ $P_1 = 101.325\ kPa$

② $T_2 = 75°C = 348.15\ K$ $P_2 = 310.5\ kPa$

$\ln P = -\frac{A}{T} + C$ for ① and ②

$\ln 101.325 = -\frac{A}{309.25} + C$

$\ln 310.5 = -\frac{A}{348.15} + C$

$\ln\left(\frac{101.325}{310.5}\right) = -A\left(\frac{1}{309.25} - \frac{1}{348.15}\right)$

$A = 3099.46$

$\ln 101.325 = -\frac{3099.46}{309.25} + C$

$C = 14.64$

$\ln P = -\frac{3099.46}{338.15} + 14.64$ ← 338.15 K

$P = 238.4281\ kPa$

b) Estimate the vapour pressure (in kPa) of pure benzene at 65°C. (/3)

$\Delta H_v = 30.7 \times 10^3\ kJ/kmol$

$T_{b_1} = 80.1°C = 353.25\ K$ $P_1 = 101.325\ kPa$ $T_2 = 65°C = 338.15\ K$

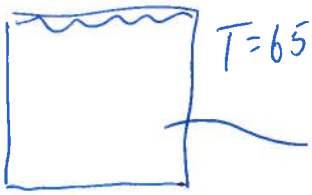
$\ln\frac{P_2}{P_1} = \frac{\Delta H_v}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

$\ln P_2 = \ln(101.325) + \frac{30.7 \times 10^3\ kJ/kmol}{8.314\ kJ/kmol\,K}\left(\frac{1}{353.25} - \frac{1}{338.15}\right)$

$P = 63.53\ kPa$

Question Number III *(Continued)*

c) Calculate the bubble point pressure (in kPa) of the liquid mixture at 65°C. (/4)



$T = 65°C$

$x_1 = 0.90$

$x_2 = 0.10$

(1) pentane (2) benzene

$P_{v_1} = 238.428$ $P_{v_2} = 63.53$

$\Sigma y_i = 1.0$ $P_{v_i} x_i = P y_i$

$y_i = \frac{P_{v_i} x_i}{P}$

$$\frac{P_{v_1} x_1}{P} + \frac{P_{v_2} x_2}{P} = 1$$

$$P = P_{v_1} x_1 + P_{v_2} x_2$$

$$P = (238.428)(0.90) + (63.53)(0.10)$$

$$P = 220.938 \text{ kPa}$$

d) Determine the composition of the vapour phase in equilibrium with the liquid at 65°C. (/2)

$$y_1 = \frac{P_{v_1} x_1}{P} = \frac{238.428 \times 0.90}{220.938} = 0.971 = y_{pent}$$

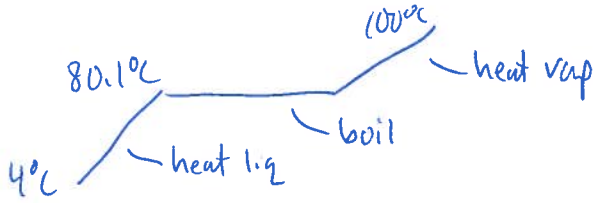
$$y_2 = 1 - y_1 = 0.029 = y_{benz}$$

Question Number III *(Continued)*

e) You now have 10 kg of pure liquid benzene at a temperature of 4°C at a pressure of 1 atm. Determine the total heat energy required (kJ) to boil the substance entirely to a vapour at 100°C. *Note:* Cp_L for benzene is 134.8 kJ/kmolK and Cp_V for benzene is 82.4 kJ/kmolK. (/4)

benzene $P = 1\ atm = 101.325\ kPa$ $m = 10\ kg$

need boiling $T = 80.1°C$ $M = 78\ \frac{kg}{kmol}$



$n = \frac{m}{M} = 0.1282\ kmol$

$E = n\left(Cp_L \Delta T_1 + \Delta H_v + Cp_V \Delta T_2\right)$

$E = n\left(134.8 \frac{kJ}{kmol}(80.1-4) + 30.7\times10^3 \frac{kJ}{kmol} + 82.4(100-80.1)\right)$

$E = n\left(10258.28 + 30.7\times10^3 + 1639.76\right)$

$E = n\left(42598\ kJ/kmol\right)$

$E = 0.1282 \times 42598$

$E = 5461\ kJ$