EXAM PET550 – NATURAL GAS PROCESSING & TRANSPORTATION; MAY 8th 2015

(ANSWERS)

Exercise 1

a) $$\mu_{JT} = \frac{1}{c_p}\left[T\left(\frac{\partial v}{\partial T}\right)_p - v\right]$$

Ideal gas: $p(v,T) = \frac{RT}{v} \rightarrow v(p,T) = \frac{RT}{p}$

$$\Rightarrow \left(\frac{\partial v}{\partial T}\right)_p = \frac{R}{p}\frac{\partial T}{\partial T} = \frac{R}{p}$$

(p is held constant)

$$\Rightarrow \mu_{JT} = \frac{1}{c_p}\left[\underbrace{T \cdot \frac{R}{p}}_{=v} - v\right] = 0 \quad \text{QED}$$

b) Van der Waals: $$a = \frac{27}{64}\cdot\frac{(8.3144\cdot 305.4)^2}{48.8\cdot 10^5} = 0.55740$$

$$b = \frac{1}{8}\cdot\frac{8.3144\cdot 305.4}{48.8\cdot 10^5} = 6.5041\cdot 10^{-5}$$

$$\Rightarrow \left(\frac{\partial v}{\partial T}\right)_p = \frac{8.3144\cdot 3.33\cdot 10^{-4}}{3\cdot 50\cdot 10^5\cdot 3.33\cdot 10^{-4} - 2\cdot(8.3144\cdot 323.15 + 50\cdot 10^5\cdot 6.5041\cdot 10^{-5}) + \frac{0.5574}{3.33\cdot 10^{-4}}}$$

$$= 4.29\cdot 10^{-6}$$

c) $\mu_{JT} = \left(\frac{dT}{dp}\right)_h \approx \left(\frac{\Delta T}{\Delta p}\right)_h$

$$\Rightarrow \Delta T \approx \mu_{JT}(T,p) \cdot \Delta p$$

$$\mu_{JT} = \frac{1}{108 \frac{J}{mol\,K}} \cdot \left[323.15\,K \cdot 4.29 \cdot 10^{-6} \frac{m^3}{mol\,K} - 3.33 \cdot 10^{-4} \frac{m^3}{mol} \right]$$

$$= 9.253 \cdot 10^{-6} \frac{m^3\,K}{J}$$

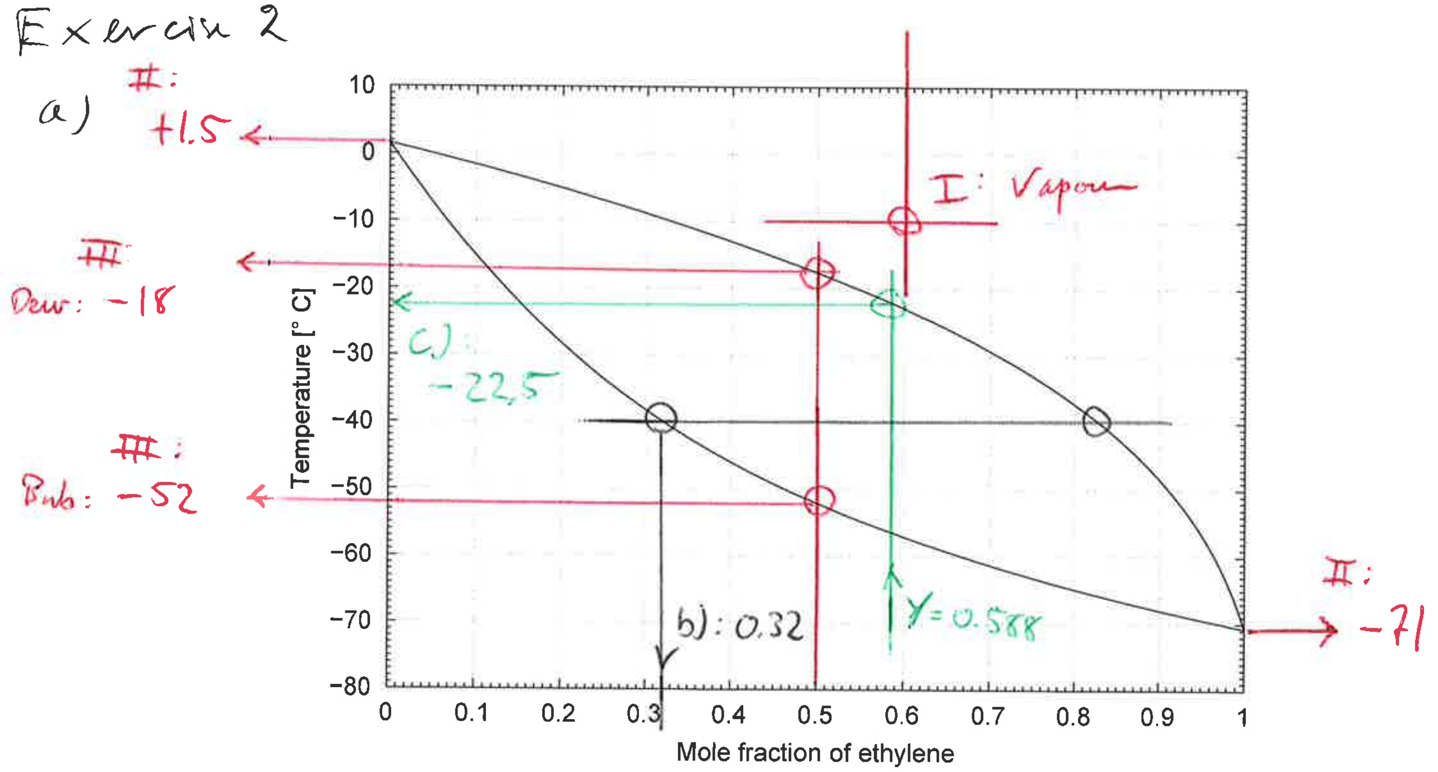
$$\frac{m^3\,K}{J} = \frac{m^3\,K}{N\,m} = \frac{K}{N/m^2} = \frac{K}{Pa}$$

$\Delta p = 1$ bar $= 100\,000$ Pa :

$$\Delta T = 9.253 \cdot 10^{-6} \cdot 10^{5} \approx \underline{\underline{0.925\,K}}$$

) Exercise 2

a)



I: Vapour phase

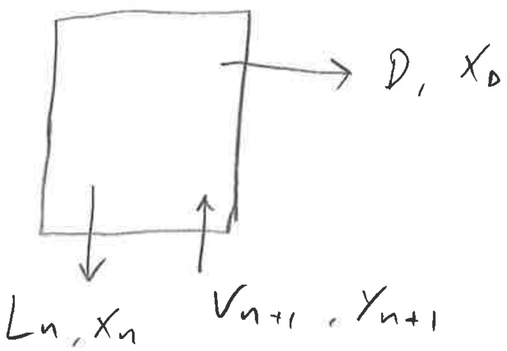
II: Ethylene: $T_B \approx -71°C$, Propane $T_B \approx +1.5°C$

III: Mixture: $T_B \approx -52°C$, $T_D \approx -18°C$

b) The liquid leaving the tray has the liquid equilibrium composition at the current temp.

$$X_n = 0.32$$

c) Mass and component balance around the top:



Mass: $V_{n+1} = L_n + D$

Comp: $V_{n+1} \cdot Y_{n+1} = L_n X_n + D X_D$

$$\Rightarrow (L_n + D) \cdot Y_{n+1} = L_n X_n + D X_D$$

Also, since $L_n = L$, and $R = \frac{L}{D} \Rightarrow L_n = R \cdot D$

$$\Rightarrow (R \cdot D + D)\, Y_{n+1} = R \cdot D\, X_n + D X_D$$

$$\rightarrow Y_{n+1} = \frac{R \cdot X_n + X_D}{R+1} = \frac{1.5 \cdot 0.32 + 0.99}{1.5 + 2} = 0.588$$

From the diagram: $T \approx -22.5\,°C$

(equilibrium vapour at the tray below)

Exercise 3

a) The content of the most "heavy" (i.e. least volatile) components controls the dew point. These are also the components that go with the condensate stream from the LTS.

b) Due to the extraction of condensate in the LTS, the flow rate in II will be less than in I, whereas the specific heat capacity is of comparable size. The temperature rise in II is therefore larger than the temperature fall in I.

c) It should bring the pressure down, creating lower temperature, and large amount of heavy components will drop out in the LTS.

d) 1. Expansion through a turbine
2. External refrigeration

Exercise 4

a) Reading off the diagram:

h_{in} (T = 25 °C, p = 50 bar) ≈ 830 kJ/kg

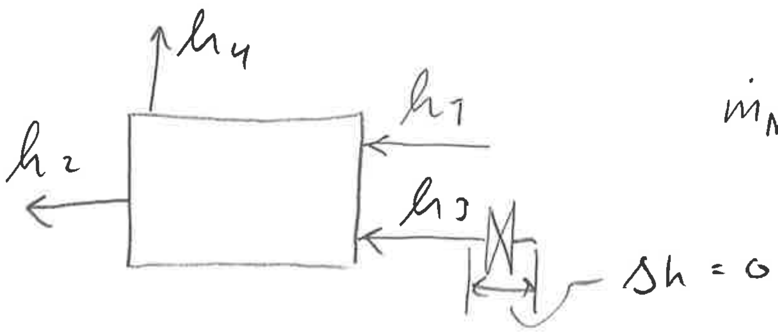
h_{out} (T = −155.8 °C, p = 50 bar) ≈ 25 kJ/kg

(Refrigerant temp. = −160.3 + 4.5 K = −155.8)

⇒ Δh = 830 − 25 = 805 kJ/kg

* h_{out} = 5 kJ/kg is also correct. Δh = 825 kJ/kg

b) Heat balance on heat exchanger:



$\dot{m}_{NG} \cdot (h_1 - h_2) = \dot{m}_{R} \cdot (h_4 - h_3)$

h_1: NG @ −141.5 °C / 50 bar ≈ 72 kJ/kg

h_2 = h_{out} ≈ 25 kJ/kg

h_3 = R @ −145.6 °C / 3.18 bar ≈ 52 kJ/kg

h_4 = R @ −160.3 / 1.1 bar / x_v = 1 ≈ 525 kJ/kg

Unit conversion: $\dot{m}_{NG}$ = 1 mtpa = $\dfrac{10^6 \cdot 10^3 \text{ kg/y}}{365 \text{ d/y} \cdot 24 \text{ h/d} \cdot 3600 \text{ s/h}}$

= 31.7 kg/s

$$\Rightarrow \dot{m}_{R1} = \dot{m}_{NG} \cdot \frac{h_1 - h_2}{h_4 - h_3} = \frac{72 - 25}{525 - 52} \cdot 31.2 \, kg/s$$

$$= 3.15 \, kg/s$$

c) Same kind of heat balance as in b, only we know the duty.

$$\dot{Q} = \dot{m}_{R2} \cdot (h_6 - h_5)$$

h_5 = R @ −126.2 °C / 9.19 bar ≈ 125 kJ/kg

h_6 = R @ −145.6 °C / 3.18 bar / $x_v = 1$ ≈ 540 kJ/kg

$$\dot{m}_{R2} = \frac{2190 \, kW}{(540 - 125) \, kJ/kg} = 5.28 \, kg/s$$

Assume isentropic compression from saturated vapor:

$h_6 = 540 \, kJ/kg$

h_{7s} ≈ R @ 9.19 bar / S = const. ≈ 618 kJ/kg work stage 2: $W = (\dot{m}_{R1} + \dot{m}_{R2}) \cdot \dfrac{h_{7s} - h_6}{\eta_{is}}$

$$= (3.15 + 5.28)\,\mathrm{kg/s} \cdot \frac{(618 - 540)\,\mathrm{kJ/kg}}{0.8} = \underline{\underline{822\ \mathrm{kW}}}$$

Attachent 2: log$p$-h diagram for methane