# CBE 20255

# HW 9

## 1. All roads lead to Rome

(1) From Perry's handbook, water

| | $\hat{H}$ |
|---|---|
| 800K/10 bar | 63.729 kJ/mol |
| 900K/10 bar | 67.710 kJ/mol |
| 370K/0.905 bar | 48.111 kJ/mol |
| 380K/~~0.72~~ 1.29 bar | 48.393 kJ/mol |

By interpolation,

$\hat{H}$ (873K, 10 bar) = 66.635 kJ/mol

$\hat{H}$ (373, 1atm) = 48.196 kJ/mol

So $\dot{q}$ = (48.196 kJ/mol − 66.635 kJ/mol) · 250 mol/h

= −4609 kJ/h

(2) From Table B2 in text book

$C_p$ of water $= a + bT + cT^2 + dT^3$

$a = 33.46 \times 10^{-3}$  $b = 0.6680 \times 10^{-5}$  $c = 0.7604 \times 10^{-8}$  $d = -3.593 \times 10^{-12}$

So $\Delta \hat{H} = \int_{600°C}^{100°C} C_p \, dT = -18.33$ kJ/mol

$\dot{q} = -18.33$ kJ/mol $\cdot$ 250 mol/h $= -4583$ kJ/h

(3) I believe more in part (1).

Reason: Part (2) assumes the water vapor to be ideal gas, where low enough pressures are required. Part (1) does not require this assumption.

2. In with the cold, out with the hot

(1) Assume ideal gas law,

6500 SLM

$\longrightarrow 1\,atm \cdot 6500\,L/min = \dot{n} R\, 273K$

$\longrightarrow \dot{n} = 290.2\,mol/min$

From Table B2 in text book,

$C_p = a + bT + cT^2 + dT^3$ of methanol

$a = 42.93\times10^{-3}$ $b = 8.301\times10^{-5}$ $c = -1.87\times10^{-8}$ $d = -8.03\times10^{-12}$

$$\Delta\hat{H}_m = \int_{65°C}^{260°C} C_p\, dT = 10.885\ kJ/mol$$

$\Delta\hat{H}_{H_2O} = \hat{H}_{H_2O}(90°C) - \hat{H}_{H_2O}(300°C)$ From Perry's Hand book

$= 6.78\ kJ/mol - 49.53\ kJ/mol$

$= -42.75\ kJ/mol$

$\Delta\hat{H}_m \cdot \dot{n}_m + \Delta\hat{H}_{H_2O} \cdot \dot{n}_{H_2O} = 0$

$\longrightarrow \dot{n}_{H_2O} = 73.9\ mol/min$

~~$\dot{V} = \frac{\dot{n}RT}{P}$ 73.9 mol/min~~

$\dot{V} = \dot{n}_{H_2O} \cdot \hat{V} = 73.9\,mol/min \cdot 0.392\,dm^3/mol = 0.03\,m^3/min$

2. $\dot{q} = \Delta\hat{H}_m \cdot \dot{n}_m$

$= 10.885\ kJ/mol \cdot 290.2\ mol/min$

$= 52.6\ kW$

3. ① Steam flow rate is lower than required value

② Outlet liquid water is higher than 90°C

③ Inlet saturated steam is lower than 300°C

4. ① Stream flow rate is higher than required value

② Outlet liquid water is ~~higher~~ lower than 90°C

③ Inlet saturated steam is higher than 300°C

3. Please be specific

(1) n-pentane

200°C 2 atm vapor

↓ ①

200°C 1 atm vapor

↓ ②

$T_b$(1atm) 1 atm vapor

↓ ③

$T_b$(1atm) 1atm liquid

↓ ④

20°C 1atm liquid

↓ ⑤

20°C 5atm liquid

$\Delta\hat{H}_{①} = 0$ assuming ideal gas

$$\Delta\hat{H}_{②} = \int_{200°C}^{T_b(1atm)} C_p\, dT$$

$T_b(1atm) = 36.07\,°C$

$C_p = 114.8\times10^{-3} + 34.09\times10^{-5}T - 18.99\times10^{-8}T^2 + 42.26\times10^{-12}T^3$

$\rightarrow \Delta\hat{H}_{②} = -24.93\ kJ/mol$

$\Delta\hat{H}_{③} = -\Delta\hat{H}_v = -25.77\,kJ/mol$

$$\Delta\hat{H}_{④} = \int_{36.07°C}^{20°C} C_p\, dT = \int_{36.07°C}^{20°C} 155.4\times10^{-3} + 43.68\times10^{-5}T\, dT$$

$= -2.69\ kJ/mol$

$\Delta \hat{H}_{⑤} \approx 0$ for liquid

So $\Delta \hat{H} = \Delta \hat{H}_{①} + \Delta \hat{H}_{②} + \Delta \hat{H}_{③} + \Delta \hat{H}_{④} + \Delta \hat{H}_{⑤}$

$= 0 + (-24.93 \text{ kJ/mo}) + (-25.77 \text{ kJ/mol}) + (-2.69 \text{ kJ/mol}) + 0$

$= -53.39 \text{ kJ/mo}$

Set 20°C 5atm liquid as reference,

$\hat{H}(200°C, 2atm, vapor) = 53.39 \text{ kJ/mol}$

(2) $\Delta \hat{H} = \Delta \hat{U} + \Delta (PV)$

Assume initial vapor n-pentane as ideal gas and PV term for liquid is negligible compared to vapor

$\Delta \hat{H} = \Delta \hat{U} + RT$

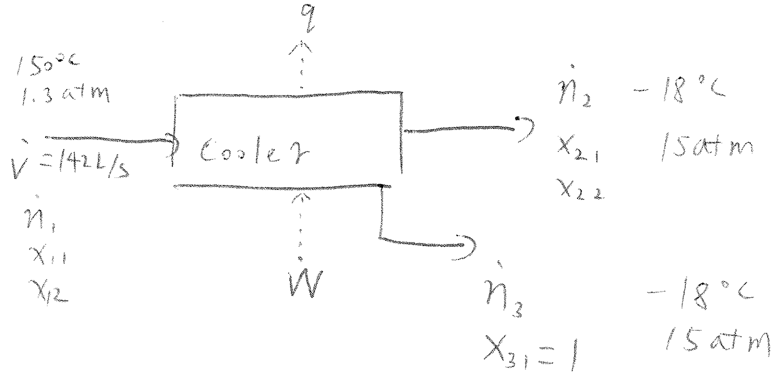
So $\Delta U = -53.39 \text{ kJ/mol} + 8.314 \cdot 473 \text{ J/mol}$

$= -49.46 \text{ kJ/mol}$

So $\hat{U}(200°C, 2atm, vapor) = 49.46 \text{ kJ/mol}$

# 4. Cold compression

(1)




1 = acetone

2 = air

O(3) Assume gas stream is ideal gas,

$$P\dot{V} = \dot{n}RT$$

$$\dot{n}_1 = \frac{P\dot{V}}{RT} = \frac{1.3\,atm \cdot 142L/s}{R \cdot 423K} = 5.32\ mol/s$$

In a 3L sample,

$$n_{total} = \frac{PV}{RT} = \frac{1.3\,atm \cdot 3L}{R \cdot 423K} = 0.1124\ mol$$

$$n_1 = \frac{m_1}{MW_1} = \frac{0.957g}{58.1g/mol} = 0.01647\,mol$$

So $$x_{11} = \frac{n_1}{n_{total}} = \frac{0.01647\,mol}{0.1124\,mol} = 14.65\%$$

$$x_{12} = 1 - x_{11} = 85.35\%$$

(4) The outlet stream only contains acetone so

$$P_{acetone} = P^*_{acetone}(-18°C)$$

$P^*_{acetone}(-18°C)$ can be calculated using Antoine equation

$$P^*(-18°C) = 10^{A-(B/255+C)}$$

$A = 4.42448 \quad B = 1312.253 \quad C = -32.445$ from Nist

$$P^*_{acetone}(-18°c) = 10^{4.42448 - \frac{1312.253}{255-32.445}}$$

$$= 0.0337 \text{bar} = 0.03326 \text{ atm}$$

So $P_{acetone} = 0.03326$ atm

$$X_{21} = \frac{P_{acetone}}{P_{total}} = \frac{0.03326}{5} = 0.67\%$$

(2) DOF analysis,

Unknown : $\dot{n}_2$, $\dot{n}_3$, $\dot{q}$

Equations : 2 mass balance (total and acetone/air)

1 energy balance

DOF = 3 - 3 = 0 solvable

(5)
$$\begin{cases} \dot{n}_1 = \dot{n}_2 + \dot{n}_3 \\ \dot{n}_1 X_{11} = \dot{n}_2 X_{21} + \dot{n}_3 \end{cases} \longrightarrow \begin{cases} \dot{n}_2 = 4.571 \text{ mol/s} \\ \dot{n}_3 = 0.749 \text{ mol/s} \end{cases}$$

(6) $\dot{H}_1 + \dot{q} + \dot{W} = \dot{H}_2 + \dot{H}_3$

$$\dot{q} = \dot{H}_2 + \dot{H}_3 - \dot{H}_1 - \dot{W}$$

$$\dot{H}_2 + \dot{H}_3 - \dot{H}_1 = \Delta \dot{H}_{air} + \Delta \dot{H}_{acetone}$$

① $\Delta \dot{H}_{air} = \int_{150°C}^{-18°C} C_p \, dT \cdot \dot{n}_{12}$

$= \int_{150°C}^{-18°C} 28.94\times10^{-3} + 0.4147\times10^{-5}T + 0.3191\times10^{-8}T^2 - 1.965\times10^{-12} \, dT \cdot \dot{n}_{12}$

$= -4.91 \text{ kJ/mol} \cdot 5.32 \cdot 85.35\%$

$= -22.29 \text{ kJ/s}$

~~$\Delta \dot{H}_{acetone} = \Delta \hat{H}_{acetone} \cdot \dot{n}$~~

② Acetone

150°C 1.3 atm vapor

↓ ①

150°C 1.0 atm vapor

↓ ②

$T_b$(1atm) 1 atm vapor

↓ ③

$T_b$(1atm) 1 atm liquid

↓ ④

$T_b$ −18°C 1 atm liquid

↓ ⑤

−18°C 5 atm liquid

⑥

−18°C 1 atm vapor

↓ ⑦

−18°C 5 atm vapor

$\Delta \hat{H}_{①} = 0$

$T_b(1atm) = 56.0°C$

$$\Delta \hat{H}_{②} = \int_{150°C}^{56°C} C_p \, dT$$

$$C_p = 71.96\times10^{-3} + 20.10\times10^{-5}T - 12.78\times10^{-8}T^2 + 34.76\times10^{-12}T^3$$

$\rightarrow \Delta \hat{H}_{②} = -8.58 \text{ kJ/mol}$

$$\Delta \hat{H}_{③} = -\Delta \hat{H}_v(T_b) = -30.2 \text{ kJ/mol}$$

$$\Delta \hat{H}_{④} = \int_{56°C}^{-18} 123.0\times10^{-3} + 18.6\times10^{-5}T \, dT$$

$$= -9.36 \text{ kJ/mol}$$

$\Delta \hat{H}_{⑤} \approx 0$

$\Delta \hat{H}_{⑥} = -5.6 \text{ kJ/mol}$

$\Delta \hat{H}_{⑦} = 0$

$$\text{So } \Delta \dot{H}_{acetone} = (\Delta \hat{H}_{①} + \Delta \hat{H}_{②})\dot{n}_{11} + (\Delta \hat{H}_{③} + \Delta \hat{H}_{④} + \Delta \hat{H}_{⑤})\dot{n}_3 + (\Delta \hat{H}_{⑥} + \Delta \hat{H}_{⑦})\dot{n}_{21}$$

$$= -8.58 \text{ kJ/mol} \cdot 5.32 \text{ mol/s} \cdot 14.65\%$$
$$+ (-30.2 \text{ kJ/mol} - 9.36 \text{ kJ/mol}) \cdot 0.749 \text{ mol/s}$$
$$+ (-5.6 \text{ kJ/mol} \cdot 4.571 \text{ mol/s} \cdot 0.67\%)$$
$$= -36.49 \text{ kJ/s}$$

So $\dot{q} = \Delta\dot{H}_{air} + \Delta\dot{H}_{acetone} - \dot{W}$

$= (-22.29 - 36.49 - 25.2)\ kJ/s$

$= \boxed{-83.98\ kJ/s}$ cooling rate

5. Psychro

(1) $T_{dry} = 78°F$  $RH = 40\%$

From Psychrometric chart in EngineeringToolBox.com,

$T_{wet} = 62°F$

(2) From Psychrometric chart,

when $T_{dry} = 35°C$  $T_{wet} = 29°C$

$RH \sim 65\%$

At $T_{dry} = 35°C$,

$$e_s = 6.11 \times 10^{(7.5 \times 35)/(273.3+35)} = 42.18 \text{ mmHG}$$

$$e = 42.18 \text{ mmHG} \cdot 65\% = 27.4 \text{ mmHG}$$

$$\cancel{T_{dew} = \log_{10}\left(\frac{e}{6.11}\right)} \quad e = 6.11 \times 10\left(\frac{7.5 \times T_d}{273.3 + T_d}\right)$$

So $T_d = 27.4°C$

(3) At $RH = 65\%$ and ~~Da~~ $T_{dry} = 35°C$, $\hat{H} = 94 \text{ kJ}/(\text{kg-dry air})$

At $RH = 40\%$ and $T_{dry} = 78°F$, $\hat{H} = 46 \text{ kJ}/(\text{kg} \cdot \text{dry air})$

$$\Delta\hat{H} = (94 - 46) \text{ kJ}/(\text{kg dry air}) = 48 \text{ kJ}/(\text{kg dry air})$$