Chemical Engineering Principles (2)

HW1

Instructor: Prof. Naim M. Faqir

Chemical Engineering Principles (2)

HW1

Q1.

A truck has a mass of 3000 kg breaks to a stop from a speed of 80 km/hr. Calculate the energy dissipated as heat (J, cal, ft, ft-Ib$_f$, and Btu) by the friction of the breaking process.

80 km	10^3 m	hr
hr	km	3600 s

= **22.22 m/s**

$$\Delta E_K + \cancel{\Delta E_P} + \cancel{\Delta U} = Q + \cancel{W}$$

$$\Delta E_K = Q \rightarrow \frac{1}{2} m (u_2^2 - u_1^2) = Q$$

$$= \frac{1}{2} * 3000 * (0^2 - 22.22^2) = \boxed{-740593\ J}$$

-740593 J	0.23901 cal
	1 J

= **-177009 cal**

-740593 J	0.7376 ft.Ib$_f$
	1 J

= **-546 * 10^3 ft.Ib$_f$**

-740593 J	9.486 * 10^{-4} Btu
	1 J

= **-702.7 Btu**

Q2.

Liquid benzene is pumped from a large storage tank through a 2 cm. ID pipe at a rate of 3.00 gal/min. Calculate the rate of kinetic energy (W, hp, and ft.Ib$_f$/s).

$SG_{\text{Benzene}} = 0.879$ $\qquad$ $\rho_{\text{Benzene}} = 0.879*1000 = 879\ \text{kg/m}^3$

$$\begin{array}{l|l|l} 3\ \text{gal} & 1\ \text{m}^3 & 1\ \text{min} \\ \hline \text{min} & 264.17\ \text{gal} & 60\ \text{s} \end{array} = \boxed{\mathbf{1.89 * 10^{-4}\ m^3/s}}$$

$$A = (1 * 10^{-2})^2 * \pi = \boxed{\mathbf{3.14*10^{-4}\ m^2}}$$

$$u = \frac{\dot{V}}{A} = \frac{1.89*10^{-4}}{3.14*10^{-4}} = \boxed{\mathbf{0.6\ m/s}}$$

$$\dot{m} = \dot{V} * \rho = 1.89 * 10^{-4} * 879 = \boxed{\mathbf{0.166\ kg/s}}$$

$$\dot{E_K} = \frac{1}{2}\,\dot{m}\ u^2 = \frac{1}{2} * 0.166 * (0.6)^2 = \boxed{\mathbf{0.03\ W}}$$

$$\begin{array}{l|l} 0.03\ \text{W} & 1.341*10^{-3}\ \text{hp} \\ \hline & 1\ \text{W} \end{array} = \boxed{\mathbf{4*10^{-5}\ hp}}$$

$$\begin{array}{l|l} 0.03\ \text{W} & 0.7376\ \ \text{ft.Ib}_f\text{/s} \\ \hline & 1\ \text{W} \end{array} = \boxed{\mathbf{0.02\ ft.Ib_f/s}}$$

Q3.

Air at 400 °C and 1 bar flows through a 5 cm-ID pipe at a velocity of 59 m/s.

a) Calculate the rate of kinetic energy (assume ideal gas behavior).

b) Calculate the change in the rate of kinetic energy if the air is heated at constant pressure from 400 to 500 °C. Report your answers in W.

a) $\dot{V}_1 = A*u_1 \rightarrow \dot{V}_1 = (2.5*10^{-2})^2 * \pi * 59 = \boxed{\mathbf{0.12\ m^3/s}}$

$P_1\dot{V}_1 = \dot{n}RT_1 \rightarrow \dot{n} = \frac{10^5 * 0.12}{8.314 * (400+273.15)} = \boxed{\mathbf{2.14\ gmol}}$

$\dot{m} = \dot{n} * \text{Mwt} = 2.14 * 29 = 62.06\text{g/s} = \boxed{\mathbf{0.062\ kg/s}}$

$\dot{E}_K = \frac{1}{2}\dot{m}\,u_1{}^2 \rightarrow \dot{E}_K = \frac{1}{2} * 0.062 * 59^2 = \boxed{\mathbf{107.9\ W}}$

b) $P_2\dot{V}_2 = \dot{n}RT_2 \rightarrow \dot{V}_2 = \frac{2.14*8.314*(500+273.15)}{10^5} = \boxed{\mathbf{0.14\ m^3/s}}$

$u_2 = \frac{\dot{V}_2}{A} = \frac{0.14}{1.96* 10^{-3}} = \boxed{\mathbf{71.4\ m/s}}$

$\Delta\dot{E}_K = \frac{1}{2}\dot{m}\,(u_2{}^2 - u_1{}^2) = \frac{1}{2} * 0.062\ (71.4^2 - 59^2) = \boxed{\mathbf{50.13\ W}}$

Q4.

Methane enters a 4-cm ID pipe at 400 K and 5 bar with an average velocity of 10 m/s and emerges at a point 100 m lower than the inlet at 420 K and 8 bar. Calculate the change in the rate of potential and the kinetic energy of methane. Assume ideal gas behavior and report your answer in W.

$\dot{V}_1 = A*u_1 \rightarrow \dot{V}_1 = (2*10^{-2})^2 * \pi * 10 = \boxed{\mathbf{0.013\ m^3/s}}$

$P_1\dot{V}_1 = \dot{n}RT_1 \rightarrow \dot{n} = \frac{5*10^5 * 0.013}{8.314 * 400} = \boxed{\mathbf{1.95\ gmol}}$

$\dot{m} = \dot{n} * Mwt = 1.95 * 16 = 31.2\ g/s = \boxed{\mathbf{0.0312\ kg/s}}$

$P_2\dot{V}_2 = \dot{n}RT_2 \rightarrow \dot{V}_2 = \frac{1.95*8.314*420}{8*10^5} = \boxed{\mathbf{8.5*10^{-3}\ m^3/s}}$

$u_2 = \frac{\dot{V}_2}{A} = \frac{8.4*10^{-3}}{1.26*10^{-3}} = \boxed{\mathbf{6.75\ m/s}}$

$\Delta\dot{E}_K = \frac{1}{2}\dot{m}\,(u_2{}^2 - u_1{}^2) = \frac{1}{2} * 0.03\ (6.75^2 - 10^2) = \boxed{\mathbf{-0.82\ W}}$

$\Delta\dot{E}_P = \dot{m}g\,(z_2 - z_1) = 0.03 * 9.81 * (-100 - 0) = \boxed{\mathbf{-29.43\ W}}$

Chemical Engineering Principles (2)

HW 2

Instructor: Prof. Naim M. Faqir

Chemical Engineering Principles (2)

HW2

Q1.

Air at 122 kPa absolute and temperature 25 ˚C has a flow rate of 1.25 m^3/min is heated to 150 ˚C. The change in specific enthalpy of the Air from 25 ˚C to 150 ˚C is 3640 J/mole. Calculate the heat requirement (kW).

$$\cancel{\Delta\dot{E}_k} + \cancel{\Delta\dot{E}_P} + \Delta\dot{H} = \dot{Q} + \cancel{\dot{W}_s}$$

$$\Delta\dot{H} = \dot{Q} \longrightarrow \dot{n}\Delta\hat{H} = \dot{Q}$$

$$\dot{n} = \frac{122 * 10^3\ \text{Pa}}{} \left| \frac{1.25\ \text{m}^3}{\text{min}} \right| \frac{\text{mol.K}}{8.314\ \text{m}^3\text{.Pa}} \left| \frac{}{298\ \text{K}} \right. = 61.6\ \text{mol/min}$$

$$\dot{Q} = \dot{n}\Delta\hat{H} = \frac{61.6\ \text{mol}}{\text{min}} \left| \frac{1\ \ \text{min}}{60\ \ \text{s}} \right| \frac{3640\ \text{J}}{\text{mol}} \left| \frac{1\ \text{KW}}{1000\ \text{W}} \right. = 3.74\ \text{KW}$$

Q2.

The specific internal energy of liquid n-Hexane at 1 atm varies linearly with temperature and equals 25.8 kJ/kg at 30 ˚C and 129.8 kJ/kg at 50˚C.

a) Determine the equation that relates U to T.

b) Derive an equation that relates H to T.

c) Calculate the heat transfer rate to cool 30 kg/min of liquid n-Hexane from 75 to 25 ˚C.

a) $\hat{U} = bT + a$

$\hat{U}_1 = 25.8$ kJ/kg $\qquad T_1 = 30$ °C

$\hat{U}_2 = 129.8$ kJ/kg $\qquad T_2 = 50$ °C

$$b = \text{slope} = \frac{\hat{U}_2 - \hat{U}_1}{T_2 - T_1} = \frac{129.8 - 25.8}{50 - 30} = 5.2$$

$$a = \text{intercept} \longrightarrow 25.8 = (5.2 * 30) + a \longrightarrow a = 25.8 - 156 = -130.2$$

$\hat{U}$(kJ/kg) = 5.2T – 130.2

b) $\hat{H} = \hat{U} + p\hat{V}$

$$P = \frac{1\ \text{atm} \;\Big|\; 1.01325 * 10^5\ \text{Pa}}{1\ \ \text{atm}} = 1.01325 * 10^5\ \text{Pa}$$

$$SG_{\text{n-Hexane}} = 0.659 \longrightarrow \rho = 0.659 * 1000 = 659\ \text{kg/m}^3$$

$$\hat{V} = \frac{1}{\rho} = \frac{1}{659} = 1.52 * 10^{-3}\ \text{m}^3/\text{kg}$$

$$\hat{H} = \hat{U} + p\hat{V} = 5.2T - 130.2 + (1.01325 * 10^5 * 1.52 * 10^{-3} * 10^{-3})$$

$\hat{H}$(kJ/kg) = 5.2T – 130

c) $\cancel{\Delta\dot{E}_k} + \cancel{\Delta\dot{E}_P} + \Delta\dot{H} = \dot{Q} + \cancel{\dot{W}_s}$

$\Delta\dot{H} = \dot{Q}$

$\hat{H}(75)$ = (5.2 * 75) + 130 = 520 kJ/kg

$\hat{H}(25)$ = (5.2 * 25) + 130 = 260 kJ/kg

$\dot{Q} = \Delta\dot{H}$ = m $\Delta\hat{H}$ = 30 * (260 – 520) = -7800 kJ/min = -130 kW

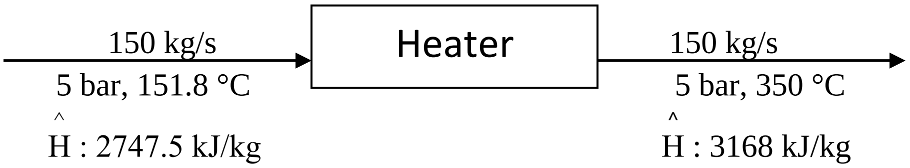
Q3.

Saturated steam at 5 bars is heated to 350 °C at constant pressure. Calculate the heat requirement for the following cases:

a) A continuous steam is flowing at 150 kg/s.

b) A closed container has 150 kg.

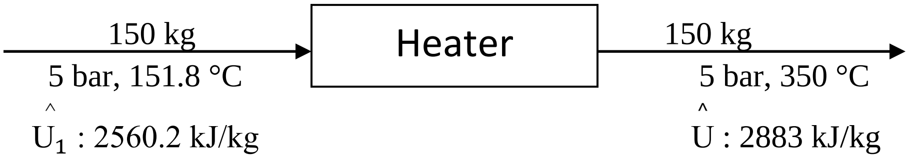
a) Open System



$$\cancel{\Delta \dot{E}_k} + \cancel{\Delta \dot{E}_P} + \Delta \dot{H} = \dot{Q} + \cancel{\dot{W}_s}$$

$\dot{Q} = \Delta \dot{H} = \dot{m}\ \Delta \hat{H} = 150 * (3168 - 2747.5) = 63075$ kW

b) Closed System

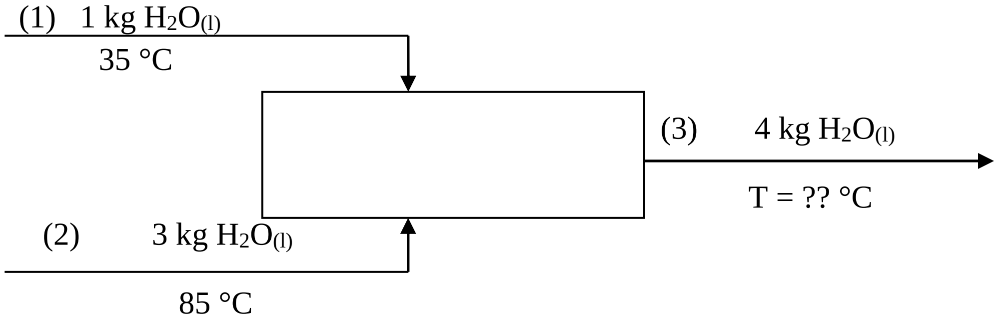


$$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta U = Q + \cancel{W}$$

$Q = \Delta U = m\ \Delta \hat{U} = 150 * (2883 - 2560.2) = 48420$ kJ

Q4.

Liquid water at 35 ˚C and liquid water at 85 ˚C are mixed adiabatically in a ratio (1 kg cold water/3 kg hot water) .Find the final temperature of the mixture.



$\hat{U} \longrightarrow$ Interpolation

$$\frac{\hat{U}_f - \hat{U}_i}{T_f - T_i} = \frac{\hat{U} - \hat{U}_i}{T - T_i} \longrightarrow \hat{U} = \frac{\hat{U}_f - \hat{U}_i}{T_f - T_i}(T - T_i) + \hat{U}_i$$

$$\hat{U}_1 = \frac{150.7 - 142.4}{36 - 34} * (35 - 34) + 142.4 = 146.6 \text{ kJ/kg}$$

$$\hat{U}_2 = \frac{360 - 351.6}{86 - 84} * (85 - 84) + 351.6 = 355.8 \text{ kJ/kg}$$

$$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta U = \cancel{Q} + \cancel{W}$$

$$\Delta U = 0 \longrightarrow U_f - U_i = m3\,\hat{U}_3 - \sum m_i \hat{U}_i = 4\hat{U}_f - (1 * 146.6 + 3 * 355.8) = 0$$

$$\hat{U}_3 = 303.5 \text{ kJ/kg}$$

T → Interpolation

$$\frac{T_f - T_i}{\hat{U}_f - \hat{U}_i} = \frac{T - T_i}{\hat{U} - \hat{U}_i} \longrightarrow T = \frac{T_f - T_i}{\hat{U}_f - \hat{U}_i} (\hat{U} - \hat{U}_i) + T_i$$

$$T_3 = \frac{74 - 72}{309.8 - 301.4} * (303.5 - 301.4) + 72 = 72.5\ ^\circ\mathrm{C}$$

Chemical Engineering Principles (2)

HW 3

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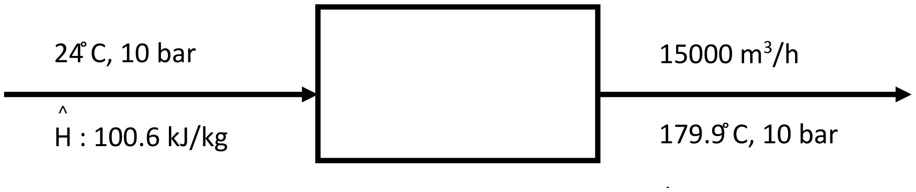
Chemical Engineering Principles (2)

HW3

Q1.

Liquid water is fed to a boiler at **24 ˚C** and **10.0 bar** and is converted at constant pressure to saturated steam. **Calculate** the heat input required to produce **15000** **m^3/h** of steam at the exiting conditions. Assume that the kinetic energy of the entering liquid is negligible and that the steam is discharged through a **15-cm** ID pipe.



$$\Delta\dot{E}_k + \cancel{\Delta\dot{E}_P} + \Delta\dot{H} = \dot{Q} + \cancel{\dot{W}_s}$$

$$\Delta\dot{E}_k + \Delta\dot{H} = \dot{Q}$$

$$\dot{m} = \frac{15000\ m^3}{h}\left|\frac{kg}{0.1943\ m^3}\right|\frac{1\ h}{3600\ s} = \mathbf{21.44\ kg/s}$$

$$u = \frac{\dot{V}}{A} = \frac{15000\ m^3}{h}\left|\frac{}{\pi\,(7.5)^2\ cm^2}\right|\frac{1\ h}{3600\ s}\left|\frac{10^4\ cm^2}{1\ m^2}\right. = \mathbf{235.8\ m/s}$$

$$\Delta\dot{E}_k = \dot{E}_{k\,final} - \dot{E}_{k\,initial}$$

$$= \frac{1}{2}\,\dot{m}\,u^2 - 0 = \frac{1}{2} * 21.44 * 235.8^2 - 0 = \mathbf{596\ k\,W}$$

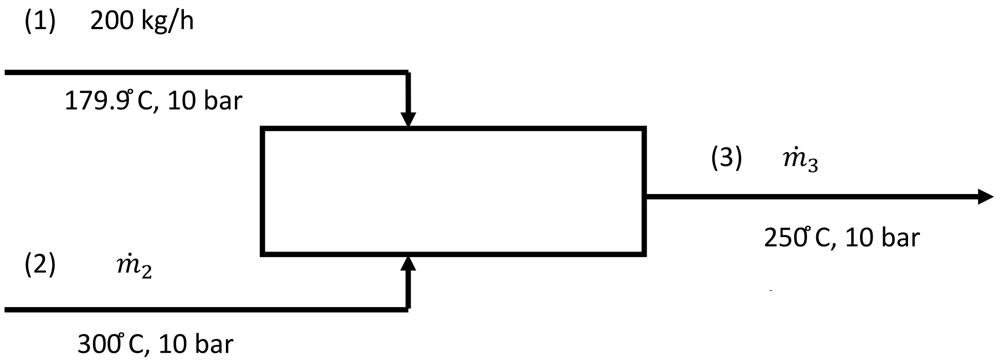
$$\Delta\dot{H} = \dot{m}\,\Delta\hat{H} = 21.44 * (2776.2 - 100.6) = \mathbf{5.7 * 10^4\ kW}$$

$$\Delta\dot{E}_k + \Delta\dot{H} = \dot{Q} = 596 + 5.7 * 10^4 = \mathbf{5.8 * 10^4\ kW}$$

Q2.

A turbine discharges **200 kg/h** of saturated steam at **10.0** bar absolute. It is desired to generate steam at **250°C** and **10.0 bar** by mixing the turbine discharge with a second stream of superheated steam of **300°C** and **10.0 bar**.

1. If **300 kg/h** of the product steam is to be generated, **how much** heat must be added to the mixer?



$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$ = 200 + $\dot{m}_2$ = 300 $\longrightarrow$ $\dot{m}_2$ = **100 kg/h**

$\cancel{\Delta\dot{E}_k} + \cancel{\Delta\dot{E}_P} + \Delta\dot{H} = \dot{Q} + \cancel{\dot{W}_s}$

$\Delta\dot{H} = \dot{Q} = \dot{m}_3\hat{H}_3 - \dot{m}_1\hat{H}_1 - \dot{m}_2\hat{H}_2$ = 300 * 2943 – 200 * 2776.2 – 100 * 3052 = **6.24 kW**

2. If instead the mixing is carried out adiabatically, at **what rate** is the product steam generated?

$\dot{m}_1 + \dot{m}_2 = \dot{m}_3 = 200 + \dot{m}_2 = \dot{m}_3$ …….. (1)

$\cancel{\Delta \dot{E}_k} + \cancel{\Delta \dot{E}_P} + \Delta \dot{H} = \cancel{\dot{Q}} + \cancel{\dot{W}_s}$

$\Delta \dot{H} = 0 = \dot{m}_3 \hat{H}_3 - \dot{m}_1 \hat{H}_1 - \dot{m}_2 \hat{H}_2 = \dot{m}_3 * 2943 - 200 * 2776.2 - \dot{m}_2 * 3052$

$= 2943\dot{m}_3 - 3052\,\dot{m}_2 =$ **$5.6 * 10^5$** ….. (2)

From (1) and (2) :

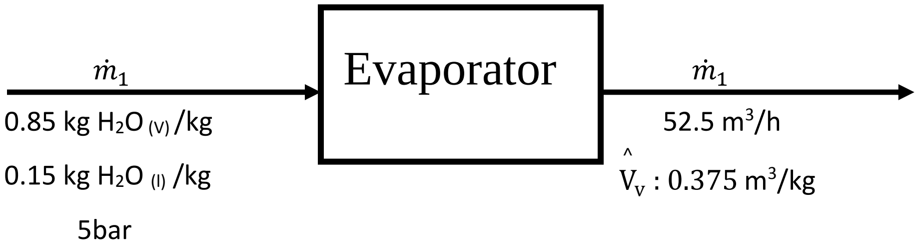
$\dot{m}_2 = 306$ kg/h

$\dot{m}_3 = 506$ kg/h

Q3.

A wet stream at a pressure of **5.0** bar with a quality of **0.85** is isothermally dried by evaporating the entrained liquid. The quality of a wet stream is defined as the fraction of the mixture by mass that is vapor. The flow rate of the dried steam is **52.5** m^3/h.

1. **Determine** the temperature at which this operation occurs.
2. **Determine** the total mass flow rate.
3. **Calculate** the heat input in kW required for the evaporation process.



1-

From table B.6

T = 151.8℃

2-

$$\dot{m} = \frac{52.5\ m^3}{h}\bigg|\frac{kg}{0.375\ m^3}\bigg|\frac{1\ h}{3600\ s} = \mathbf{0.039\ kg/s}$$

$$\cancel{\Delta\dot{E}_k} + \cancel{\Delta\dot{E}_P} + \Delta\dot{H} = \dot{Q} + \cancel{\dot{W}_s}$$

$\dot{m}_{water}$ = 0.039 * 0.15 = 5.85 * 10^{-3} kg/s

$\hat{H}_{Evaporation}$ = 2107.4 kJ/kg

$$\Delta\dot{H} = \dot{Q} = \frac{5.85 * 10^{-3}\ kg}{s}\bigg|\frac{2107.4\ kJ}{kg} = \mathbf{12.3\ kW}$$

Chemical Engineering Principles (2)

HW 4

Prof. Naim M. Faqir

Chemical Engineering Principles (2)

HW4

Q1.

The specific internal energy of formaldehyde (HCHO) vapor at 1 atm and moderate temperature is given by the formula

$$\hat{U}(\mathrm{J/mol}) = 25.96T + 0.0213T^2$$

Where T is in℃.

(a) Calculate the specific internal energies of formaldehyde vapor at 0℃ and 100℃. What reference temperature was used to generate the given expression for $\hat{U}$?

$$\hat{U}(0) = 25.96(0) + 0.0213(0)^2 = 0$$

$$\hat{U}(100) = 25.96(100) + 0.0213(100)^2 = 2809\, J/mol$$

The reference temperature is T= 0℃

(c) Use the closed system energy balance equation to calculate the heat (J) required to raise the temperature of 3 mol HCHO at constant volume from 0℃ to 100℃.

$$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta U = Q + \cancel{W}$$

$$\Delta U = Q \rightarrow n\,\Delta\hat{U} = n\,(\hat{U}_2 - \hat{U}_1) = 3\,(2809 - 0) = 8427\ \mathrm{J}$$

(d) From the definition of heat capacity at constant volume, derive a formula for C_v (T) [J/mol.℃]. Then use this formula and equation 8.3-6 to calculate the heat (J) required to raise the temperature of 3.0 mol of HCHO (v) at constant volume from 0℃ to 100℃.

$$C_v = \frac{d\hat{U}}{dT} = 25.96 + 0.04268T$$

$$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta U = Q + \cancel{W}$$

$$\Delta U = Q \rightarrow n\,\Delta\hat{U} = n\int_{T_1}^{T_2} C_v\ dT = n\int_0^{100} 25.96 + 0.04268T\ \ dT$$

$$= n\,[25.96T + 0.04268\frac{T^2}{2}]_0^{100} = 3 * 2809 = 8427\ \mathrm{J}$$

Q.2

The heat capacity at constant volume of hydrogen sulfide at low pressure is:

$$C_v\ [\text{kJ}/(\text{mol.℃})] = 0.0252 + 1.547 * 10^{-5}T - 3.012 * 10^{-9}T^2$$

Where T is in ℃. A quantity of H_2O is kept in a piston-fitted cylinder with initial temperature, pressure, and volume equal to 25℃, 2.00 atm, and 3.00 liters, respectively.

(a) Calculate the heat (kJ) required to raise the gas temperature from 25℃ to 1000℃ if the heating takes place at constant volume(i.e., if the piston does not move), retaining successively one term, two terms, and all three terms of the heat capacity formula. Determine the percentage errors in Q that result from retaining only one and two terms of the heat capacity formula, assuming that the full expression yields the correct result.

$n = \frac{PV}{RT} = \frac{2*3}{0.08206*298} = 0.245\ mol$

$$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta U = Q + \cancel{W}$$

$$\Delta U = Q$$

(1) $\Delta U = Q \rightarrow n\,\Delta\hat{U} = n\int_{25}^{1000} C_v\ dT = n\int_{0}^{100} 0.0252\ dT = n\,[0.0252\,T]_{25}^{1000}$

Q = 0.245 * 24.57 = 6.02 J

(2) $\Delta U = Q \rightarrow n\,\Delta\hat{U} = n\int_{25}^{1000} C_v\ dT = n\int_{0}^{100} 0.0252 + 1.547 \text{ x } 10^{-5}\text{T}\ \ dT$

$Q = n[0.0252T + 1.547 * 10^{-5}\frac{T^2}{2}]_{25}^{1000} = 0.245 * 32.3 = 7.91$ J

(3) $\Delta U = Q \rightarrow n\,\Delta\hat{U} = n\int_{25}^{1000} C_v\ dT = n\int_{0}^{100} 0.0252 + 1.547 * \text{T} - 3.012 * 10^{-9}T^2\ dT$

$Q = n[0.0252T + 1.547 * 10^{-5}\frac{T^2}{2} - 3.012 * 10^{-9}\frac{T^3}{3}]_{25}^{1000} = 0.245 * 31.3 = 7.67$ J

Error in (1) = $\left|\frac{6.02-7.67}{7.67}\right| * 100\% = 21.5\%$

Error in (2) = $\left|\frac{7.91-7.67}{7.67}\right| * 100\% = 3.13\%$

Q3.

The heat capacity at constant pressure of hydrogen cyanide is given by the expression:

$$C_p[J/(mol.{}^0C)] = 35.3 + 0.0291 * T({}^0C)$$

1. **Write an expression for the heat capacity at constant volume for HCN, assuming ideal gas behavior.**
2. **Calculate $\Delta \hat{H}(J/mol)$ for the constant-pressure process:**
   HCN (v, 25 °C, 0.80 atm) $\rightarrow$ HCN (v, 100 °C, 0.80 atm)
3. **Calculate $\Delta \hat{U}(J/mol)$ for the constant-volume process**
   HCN (v, 25 °C, 50 m^3/kmol) $\rightarrow$ HCN (v, 100 °C, 50 m^3/kmol)

1. $C_v = C_p - R \rightarrow C_v = 35.3 + 0.0291\ T - 8.314 = 27 + 0.0291\ T$

2. $\Delta\hat{H} = \int_{25}^{100} C_p\ dT = \int_{25}^{100} (35.3 + 0.0291\ \mathrm{T})\ \mathrm{dT} = 2784 \frac{\mathrm{J}}{\mathrm{mol.°C}}$

3. $\Delta\hat{U} = \int_{25}^{100} C_v\ dT = \int_{25}^{100} (27 + 0.0291\ \mathrm{T})\ \mathrm{dT} = 2161 \frac{\mathrm{J}}{\mathrm{mol.°C}}$

Q4.

Use data in Table B.2 to calculate the following:

1. **The heat capacity (C_p) of liquid benzene at 40 ˚C.**

$C_p = 126.5 * 10^{-3} + 23.4 * 10^{-5}\ T = 126.5 * 10^{-3} + 23.4 * 10^{-5}\ (40) = 0.136$ kJ/mol.℃
$= 126.5 * 10^{-3} + 23.4 * 10^{-5}\ (40) = 0.136$ kJ/mol.℃

2. **The heat capacity (C_p) of benzene vapor at 40 ˚C.**

$C_p = 74.06 * 10^{-3} + 32.95 * 10^{-5}\ T - 25.2 * 10^{-8}\ T^2 + 77.57 * 10^{-12}\ T^3$
$= 74.06 * 10^{-3} + 32.95 * 10^{-5}\ (40) - 25.2 * 10^{-8}\ (40)^2 + 77.57 * 10^{-12}\ (40)^3 = 0.087$ kJ/mol.℃

3. **The heat capacity (C_p) of solid carbon at 40 ˚C.**

$C_p = 11.18 * 10^{-3} + 1.095 * 10^{-5}\ T - 4.891 * 10^{2}\ T^2$
$= 11.18 * 10^{-3} + 1.095 * 10^{-5}\ (313) - 4.891 * 10^{2}\ (313)^2 = 9.6 * 10^{-3}$ kJ/mol.℃

4. $\Delta\hat{H}(kJ/mol)$ **For benzene vapor going from 40 ˚C to 300˚C.**

$$\Delta\hat{H} = \int_{40}^{300} 74.06 * 10^{-3} + 32.95 * 10^{-5}\ T - 25.2 * 10^{-8}\ T^2 + 77.57 * 10^{-12}\ T^3\ \ dT$$

= 31.71 kJ/mol

5. $\Delta\hat{H}(kJ/mol)$ **For solid carbon going from 40 ˚C to 300˚C.**

$$\Delta\hat{H} = \int_{313}^{673} 11.18 * 10^{-3} + 1.095 * 10^{-5}\ T - 4.891 * 10^{2}\ T^2\ \ dT$$

= 5.13 kJ/mol

Q5.

A stream of steam flowing at a rate of 100 kg/min is cooled from 600 ˚C and 10 bar to 100 ˚C and 1 bar. Calculate the cooling duty (kW) using:

1) Steam Tables.

$\dot{m}$ = 100 kg/min = 1.67 kg/s

From B.7

$\Delta\dot{H} = \dot{Q} \rightarrow \dot{m}\Delta\hat{H} = \dot{Q}$

H_2O (v, 600 ˚C, 10 bar) → H_2O (v, 100 ˚C, 1 bar)

$\dot{Q} = \dot{m}\Delta\hat{H}$ = 1.67 (2676 – 3697) = -1702 kW

2) Table B.8

$\dot{n} = \frac{1.67}{18} * 1000 = 92.78\ mol$

From B.8

$\Delta\dot{H} = \dot{Q} \rightarrow \dot{n}\Delta\hat{H} = \dot{Q}$

H_2O (v, 600 ˚C, 10 bar) → H_2O (v, 100 ˚C, 1 bar)

$\dot{Q} = \dot{n}\Delta\hat{H}$ = 92.78 (2.54 – 20.91) = -1704.4 kW

3) Heat capacity data for water reported in Table B.2

From B.2

$\Delta\dot{H} = \dot{Q} \rightarrow \dot{n}\Delta\hat{H} = \dot{Q}$

H_2O (v, 600 ˚C, 10 bar) → H_2O (v, 100 ˚C, 1 bar)

$$\dot{Q} = \dot{n}\Delta\hat{H} = \dot{n}\int_{600}^{100}(33.46 * 10^{-3} + 0.6880 * 10^{-5}\,T + 0.7604 * 10^{-8}\,T^2 - 3.593 * 10^{-12}\,T^3)\ dT$$

= 92.78 * -18.36 = -1703.44 kW

Chemical Engineering Principles (2)

HW 5

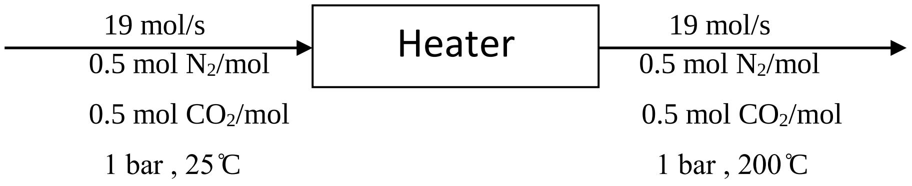
Prof. Naim M. Faqir

Chemical Engineering Principles (2)

HW5

Q1.

1000 SCFM of an equimolar gas mixture of nitrogen and carbon dioxide is heated at constant pressure of 1 bar from 25 ˚C to 200 ˚C. Calculate the heating duty of the process (kW).



$$\dot{n} = \begin{array}{c|c|c|c|c|c|c} 1000\ ft^3 & 1\ m^3 & 1\ bar & 101325\ Pa & mol.K & & 1\ min \\ \hline min & 35.3145\ ft^3 & & 1.01325\ bar & 8.314\ Pa.m^3 & 298.15\ K & 60\ s \end{array} = 19\ mol/s$$

$$\cancel{\Delta\dot{E}_k} + \cancel{\Delta\dot{E}_P} + \Delta\dot{H} = \dot{Q} + \cancel{\dot{W}_s}$$

$$\Delta\dot{H} = \dot{Q} \longrightarrow \dot{n}\Delta\hat{H} = \dot{Q}$$

Ref : N_2 (g , 1 atm , 25℃) CO_2 (g , 1 atm , 25℃)

Substance	$\dot{n}_{in}$	$\hat{H}_{in}$	$\dot{n}_{out}$	$\hat{H}_{out}$
N_2	9.5	0	9.5	5.13
CO_2	9.5	0	9.5	7.08

$$\Delta\dot{H} = \dot{Q} = \dot{n}_{N_2 2}\hat{H}_{N2} + \dot{n}_{CO_2 2}\hat{H}_{CO_2 2} - \dot{n}_{N_2 1}\hat{H}_{N_2 1} - \dot{n}_{CO_2 1}\hat{H}_{CO_2 1}$$

$$= 9.5 * 5.13 + 9.5 * 7.08 - 9.5 * 0 - 9.5 * 0 = 115.995\ kW$$

Q2.

Estimate the heat of evaporation of water (kJ/kg) at 200 ˚C using:

- **a) Chen's equation in association with Watson's correlation.**
- **b) Trouton's equation in association with Watson's correlation.**
- **c) Clapeyron's equation (use the normal boiling point and the critical point of water) in association with Watson's correlation.**
- **d) Steam Table.**

a) Chen's equation:

$$\Delta\hat{H}_v = \frac{T_b\,[0.0331\,(T_b/T_c) - 0.0327 + 0.0297\,\log_{10} P_c]}{1.07 - (T_b/T_c)}$$

$$\Delta\hat{H}_v = \frac{373.15\,[0.0331\,(373.15/647.4) - 0.0327 + 0.0297\,\log_{10} 218.3]}{1.07 - (373.15/647.4)} = 42.22 \text{ kJ/mol}$$

Watson's correlation:

$$\Delta\hat{H}_v(T_2) = \Delta\hat{H}_v(T_1)\,\left(\frac{T_c - T_2}{T_c - T_1}\right)^{0.38}$$

$$\Delta\hat{H}_v(473.15) = 42.22\,\left(\frac{647.4 - 473.15}{647.4 - 373.15}\right)^{0.38} = 35.54 \text{ kJ/mol} = 1974.44 \text{ kJ/kg}$$

b) Trouton's equation:

$\Delta\hat{H}_v$ = 0.109 T_b = 0.109 * 373.15 = 40.67 kJ/mol

Watson's correlation:

$$\Delta\hat{H}_v(T_2) = \Delta\hat{H}_v(T_1)\,\left(\frac{T_c - T_2}{T_c - T_1}\right)^{0.38}$$

$$\Delta\hat{H}_v(473.15) = 40.67\,\left(\frac{647.4 - 473.15}{647.4 - 373.15}\right)^{0.38} = 34.23 \text{ kJ/mol} = 1901.74 \text{ kJ/kg}$$

c) Clapeyron's equation:

$$\ln P^* = -\frac{\Delta\hat{H}_v}{RT} + B$$

$$\Delta\hat{H}_v = -R\,\frac{\ln(P_2/P_1)}{[(1/T_2)-(1/T_1)]} = -0.008314\,\frac{\ln(221.2/1.01325)}{[(1/647.4)-(1/373.15)]} = 39.44 \text{ kJ/mol}$$

Watson's correlation:

$$\Delta\hat{H}_v(T_2) = \Delta\hat{H}_v(T_1)\,\left(\frac{T_c - T_2}{T_c - T_1}\right)^{0.38}$$

$$\Delta\hat{H}_v(473.15) = 39.44\,\left(\frac{647.4 - 473.15}{647.4 - 373.15}\right)^{0.38} = 33.2 \text{ kJ/mol} = 1844.23 \text{ kJ/kg}$$

d) Steam Table.

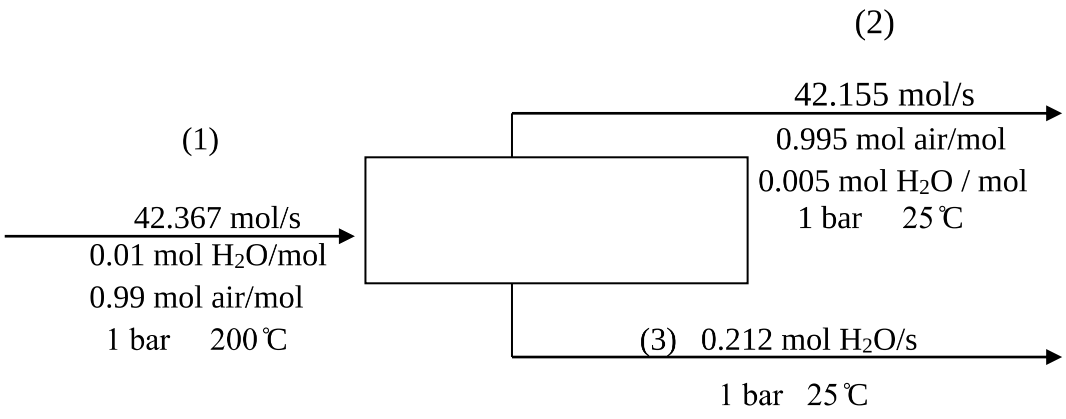
Interpolation:

$$\Delta\hat{H}_v = \frac{\Delta\hat{H}_v\,f - \Delta\hat{H}_v\,i}{T_f - T_i}\,(T - T_i) + \Delta\hat{H}_{vi}$$

$$\Delta\hat{H}_v = \frac{1933.2 - 1945.2}{201.4 - 198.3}\,(200 - 198.3) + 1945.2 = 1938.62 \text{ kJ/kg}$$

Q3.

100 m^3/min of a gas mixture containing 1 mol % water and 99 mol % air is cooled at constant pressure of 1 bar from 200 $^\circ$C to 25 $^\circ$C. 50 % of the water in the inlet stream is condensed during this process. Calculate the cooling duty of the process (kW).



$\dot{n}$ =	100 m^3	1 bar	101325 Pa	mol.K		1 min	= 42.367mol/s
	min		1.01325 bar	8.314 m^3.Pa	473.15 K	60 s	

Ref: H_2O (g , 1 atm , 25℃)   Air (g , 1 atm , 25℃)

Substance	$\dot{n}_{in}$	$\hat{H}_{in}$	$\dot{n}_{out}$	$\hat{H}_{out}$
H_2O v	0.42	6.01	12.71	0
H_2O l	…..	…….	0.21	-43.767
Air	41.94	5.15	41.94	0

$$\hat{H}_{out\ H2O\ l} = \int_{25}^{100} 0.03346 + 0.688 * 10^{-5}T + 0.7604 * 10^{-8}\ T^2 - 3.593 * 10^{-12}\ T^3 + \Delta\hat{H}_v + \int_{100}^{25} 0.0754$$

= 2.594 – 40.656 – 5.655 = -43.767 kJ/mol

$$\cancel{\Delta\dot{E}_k} + \cancel{\Delta\dot{E}_P} + \Delta\dot{H} = \dot{Q} + \cancel{\dot{W}_s}$$

$$\Delta\dot{H} = \dot{Q} \longrightarrow \dot{n}\Delta\hat{H} = \dot{Q}$$

$$\Delta\dot{H} = \dot{Q} = \dot{n}_{H_2O3}\hat{H}_{H_2O3} + \dot{n}_{H_2O2}\hat{H}_{H_2O2} + \dot{n}_{Air2}\hat{H}_{Air2} - \dot{n}_{H_2O1}\hat{H}_{H_2O1} - \dot{n}_{Air1}\hat{H}_{Air1}$$

= 0.21 * -43.767 + 12.71 * 0 + 41.94 * 0 – 0.42 * 6.01 – 41.94 * 5.15 = -227.7 kW

Chemical Engineering Principles (2)

HW 6

Instructor: Prof. Naim M. Faqir

Chemical Engineering Principles (2)

HW6

Q1.

For air at 30 ^{0}C and 60% relative humidity, find the following:

1. **Absolute humidity**

   0.016 kg/kg Dry air

2. **Wet-bulb temperature**

$$T_{wb} = \frac{T_{wbf} - T_{wbi}}{T_f - T_i}\ (T - T_i) + T_{wbi}$$

$$= \frac{24 - 23}{30.4 - 29.2}\ (30 - 29.2) + 23 = 23.67\ \mathring{C}$$

3. **Humid volume**

$$V = \frac{V_f - V_i}{T_f - T_i}\ (T - T_i) + V_i$$

$$= \frac{0.9 - 0.85}{44.6 - 26.8}\ (37.6 - 26.8) + 26.8 = 0.880\ m^3/kg \text{ Dry air}$$

4. **Enthalpy**

$$\hat{H}_{saturated} = 71.5 \text{ kJ/kg Dry air}$$

$$\text{Diviation} = \frac{-0.4 - -0.2}{33.6 - 28.2}\ (30 - 28.2) + -0.2 = -0.27$$

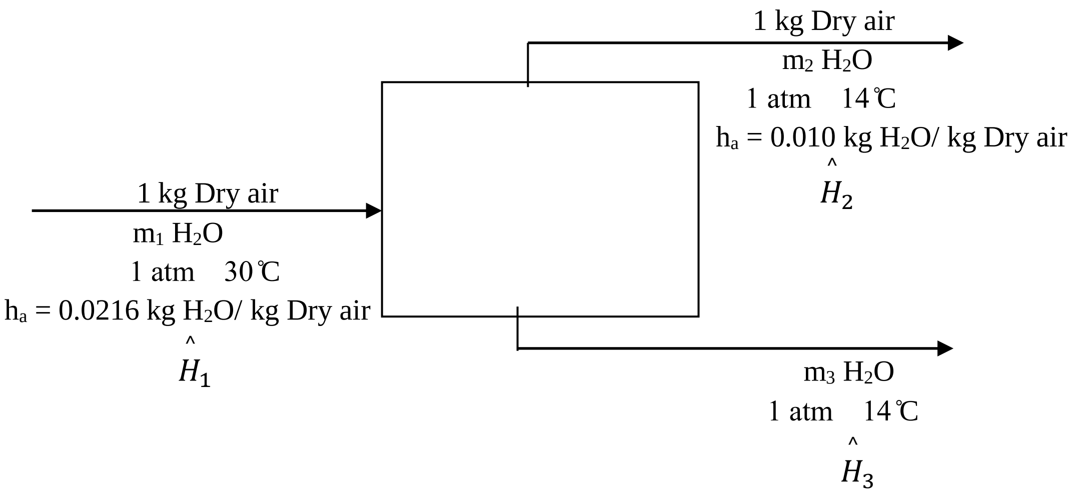
$$\hat{H} = 71.5 - 0.27 = 71.23 \text{ kJ/kg Dry air}$$

5. **At what temperature condensation will start?**

   21.4 $\mathring{C}$

Q2.

air enters a window air conditioner at 1 atm, 30 deg C, and 80% relative humidity at a rate of 10 cubic meters per min, and it leaves as saturated air at 14 deg C. Part of the moisture in the air which condenses during the process is also removed at 14 deg C. Determine the rates of heat and moisture removal from the air.



m_1 = 0.0216 kg H_2O/ kg Dry air * 1 kg Dry air = 0.0216 kg H_2O

m_2 = 0.010 kg H_2O/ kg Dry air * 1 kg Dry air = 0.010 kg H_2O

$m_3 = m_1 - m_2$ = 0.0216 – 0.010 = 0.0116 kg H_2O

Ref: H_2O (l , 1 atm , 0℃) Dry Air (1 atm , 0℃)

Substance	$\dot{m}_{in}$	$\hat{H}_{in}$	$\dot{m}_{out}$	$\hat{H}_{out}$
Humid air	1 kg dry air	85.36	1 kg dry air	40.5
H_2O_l	…..	…….	0.0116	58.64

$\hat{H}_3 = \int_0^{14} 0.0754$ = 1.0556 kJ/mol H_2O = 58.64 kJ/ kg H_2O

$$\cancel{\Delta \dot{E}_k} + \cancel{\Delta \dot{E}_P} + \Delta \dot{H} = \dot{Q} + \cancel{\dot{W}_s}$$

$$\Delta \dot{H} = \dot{Q} \longrightarrow \dot{m}\Delta \hat{H} = \dot{Q}$$

$$\Delta \dot{H} = \dot{Q} = 0.0116 * 58.64 + 40.5 * 1 - 85.36 * 1 = -44.18 \text{ kJ}$$

Scaling:

Humid volume = 0.888 m^3/ kg Dry air

$$\begin{array}{l|l} 1\ \text{kg DA} & 0.888\ \text{m}^3\ \text{humid air} \\ \hline & 1\ \text{kg DA} \end{array} = 0.888\ \text{m}^3\ \text{humid air}$$

Scale: $\frac{10\ m^3/min}{0.888\ m^3}$

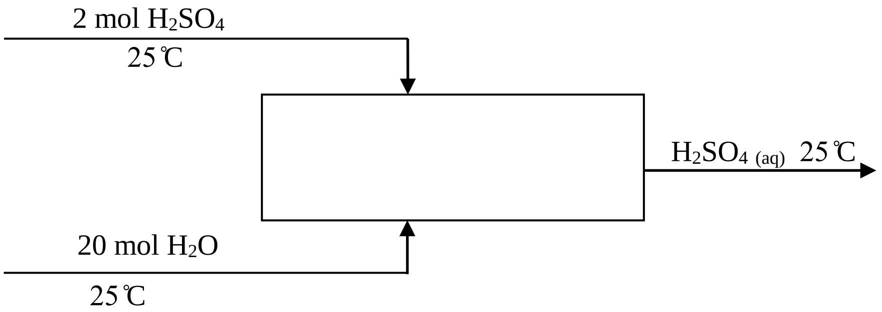
Q = -44.18 kJ * $\frac{10\ m^3/min}{0.888\ m^3} * \frac{1\ min}{60\ s}$ = -8.3 kJ/s

m_3 = 0.0116 *$\frac{10\ m^3/min}{0.888\ m^3} * \frac{1\ min}{60\ s}$ = 0.0022 kg H_2O/s

Q3.

196 grams of sulfuric acid at 250C are mixed with 360 grams of water at 25 oC to form a solution at 25 oC.

Find the amount of heat which should be removed in KJ.



$$n_{H_2SO_4} = 196 \text{ g } H_2SO_4 \left| \frac{\text{mol}}{98 \text{ g}} \right. = 2 \text{ mol } H_2SO_4$$

$$n_{H_2O} = 360 \text{ g } H_2O \left| \frac{\text{mol}}{18 \text{ g}} \right. = 20 \text{ mol } H_2O$$

Ref: H_2O_l , H_2SO_4 (25℃)

Substance	n_{in}	$\hat{H}_{in}$	n_{out}	$\hat{H}_{out}$
H_2O_l	20	0	…….	…….
H_2SO_4	2	0	…….	…….
$H_2SO_{4\,(aq)}$	……	…….	2	-67.03

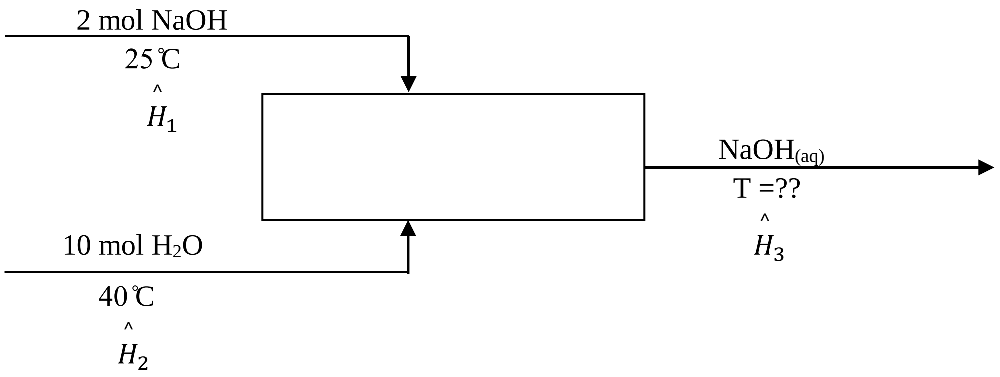
$r = \frac{20}{2} = 10 \text{ mol } H_2O/\text{mol } H_2SO_4$

$$\Delta\dot{H} = \dot{Q} \longrightarrow \dot{n}\Delta\hat{H} = \dot{Q}$$

$$\Delta\dot{H} = \dot{Q} = -67.03 * 2 - 20 * 0 - 20 * 0 = -134.06 \text{ kJ}$$

Q4.

2 moles of solid NaOH at 25℃ are dissolved in 10 moles of liquid water at 40℃ in a flask of a mass 200 grams. The heat capacity (CP) of the flask and the solution is 3.5 J/g.0c .The whole mixing is adiabatic, calculate the final temperature.



Ref: H_2O_l , $NaOH_s$ (25℃)

Substance	n_{in}	$\hat{H}_{in}$	n_{out}	$\hat{H}_{out}$
H_2O_l	10	$\hat{H}_2$	…….	…….
$NaOH_s$	2	0	…….	…….
NaOH $_{(aq)}$	……	…….	2 mol NaOH	$\hat{H}_3$

$\hat{H}_2 = \int_{25}^{40} 0.0754 = 1.131$ kJ/mol

$\hat{H}_3 = \frac{-37.74\ kJ}{mol\ NaOH} + \frac{(80+180+200)g}{2\ mol\ \text{NaOH}} * \frac{3.5\ j}{g.C} * (T-25) * 10^{-3} = -57.865 + 0.805\ T$

$\Delta\dot{H} = 0$ =2*(-57.865 + 0.805 T) – 10 * 1.131 – 0 * 2 =0

T = 78.9℃