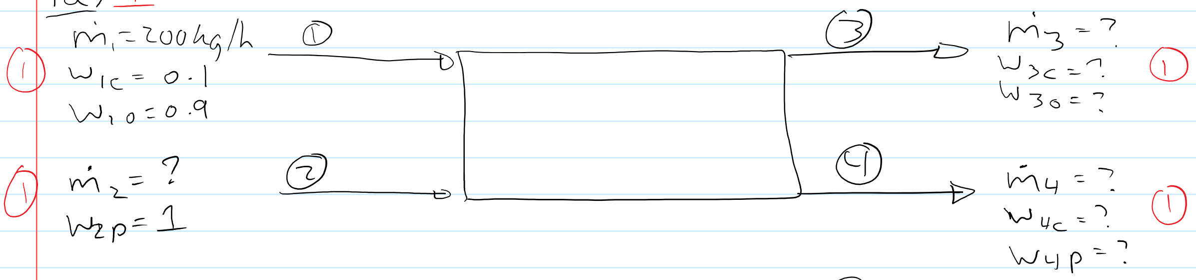
Final 2017W Solutions

December 1, 2017 12:53 PM

1a) 4



$K = 0.05 = \frac{w_{3c}}{w_{4c}}$ Ⓐ ① →b

95% extraction: $\dot m_1 w_{1c} \cdot 0.95 = \dot m_4 w_{4c}$ Ⓑ ① →b

b) DOF

10

7 unknowns ($\dot m_2, \dot m_3, w_{3c}, w_{3o}, \dot m_4, w_{4c}, w_{4p}$)

− 3 independent MB (C, O, P)

− 2 Extra equations (above as A, B)

− 2 mole fraction summations (stream ③ and ④)

② 0

MB's: overall $\dot m_1 + \dot m_2 = \dot m_3 + \dot m_4$ ①

C: $\dot m_1 w_{1c} = \dot m_3 w_{3c} + \dot m_4 w_{4c}$ ①

O: $\dot m_1 w_{1o} = \dot m_3 w_{3o}$ ①

P: $\dot m_2 = \dot m_4 w_{4p}$ ①

Mass fraction summations: ③ $w_{3c} + w_{3o} = 1$ ①

④ $w_{4c} + w_{4p} = 1$ ①

CBal + Ⓐ

c) 6

$\dot m_1 w_{1c} = \dot m_3 w_{3c} + \dot m_1 w_{1c} \cdot 0.95$

$0.05 m_1 w_{1c} = \dot m_3 w_{3c}$

Result + O bal

$m_1 w_{1o} = m_3 (1 - w_{3c})$

$m_1 w_{1o} = m_3 - m_3 w_{3c} = m_3 - 0.05 m_1 w_{1c}$

$\dot m_3 = m_1 w_{1o} + 0.05 m_1 w_{1c} = (200 kg/h)(0.9) + 0.05(200 kg/h)(0.10)$

$\dot m_3 = 181$ kg/h ②

$w_{3o} = \frac{m_1 w_{1o}}{m_3} = \frac{(200)(0.9)}{(181)} = 0.9945$ ①

$w_{3c} = 1 - w_{3o} = 1 - 0.9945 = 5.52 \times 10^{-3}$

$w_{4c} = \frac{w_{3c}}{0.05} = 0.11$ ①

$W_{4p} = 1 - W_{4c} = 0.89$

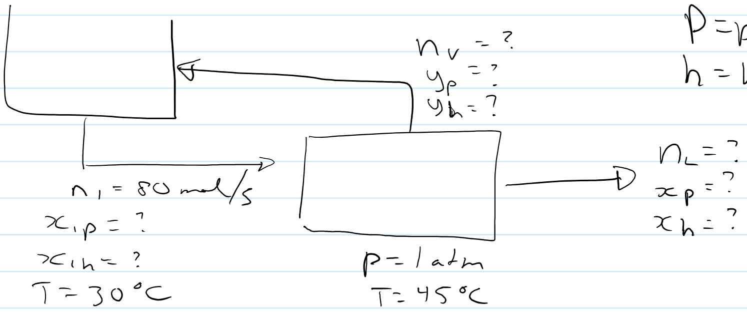
C bal $\quad 0.95\, m_1 W_{1c} = \dot{m}_4 W_{4c}$

$$\dot{m}_4 = \frac{0.95(200)(0.1)}{0.11} = 172.7 \text{ kg/h}$$ ①

①

$$\dot{m}_2 = \dot{m}_4 + \dot{m}_3 - \dot{m}_1 = 181 \text{ kg/h} + 172.7 \text{ kg/h} - 200 \text{ kg/h} = 154 \text{ kg/h}$$

2)



P = pentane
h = hexane

$n_L : n_v$
$0.7 : 1$

$n_L = 0.7\, n_v$

a) 10

Raoult's law $\quad y_p P = x_p p_p^*$ ①

$y_h P = x_h p_h^*$ ①

$$P = y_p P + y_h P = x_p p_p^* + x_h p_h^* = x_p p_p^* + (1 - x_p) p_h^*$$

$$P = x_p (p_p^* - p_h^*) + p_h^*$$

$$x_p = \frac{P - p_h^*}{p_p^* - p_h^*} \text{ @ } 45°\text{C} = \frac{760 \text{ mmHg} - 338 \text{ mmHg}}{1020 \text{ mmHg} - 338 \text{ mmHg}}$$

$x_p = 0.62$ ⑤

$x_h = 1 - x_p = 0.38$

$$y_p = \frac{x_p\, p_p^*}{P} = \frac{(0.62)(1020 \text{ mmHg})}{760 \text{ mmHg}} = 0.83$$ ①

$y_h = 0.17$

$n_1 = n_v + n_L = 1.7\, n_v$

$n_v = 80/1.7 = 47$ mol/s ①

$n_L = 80 - 47 = 33$ mol/s ①

$n_1 x_{1p} = y_p n_V + x_p n_L$

$x_{1p} = \dfrac{(0.83)(47) + (0.62)(33)}{80} = 0.74$ ②

$x_{1h} = 1 - 0.74 = 0.26$

b)

Substance	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (J/mol)	n_{out} (mol/s)	$\hat{H}_{out}$ (J/mol)
p (l)		0	$\dot{n}_1$	$\hat{H}_1$
h (l)		0	$\dot{n}_2$	$\hat{H}_2$
p (V)			$\dot{n}_3$	$\hat{H}_3$
h (v)			$\dot{n}_4$	$\hat{H}_4$

Choose reference to be entering stream, 30°C, liquid for P+h

$\hat{H}_1 = \int_{30}^{45} Cp_{p(l)}\, dT = (155\ J/mol\ h)(45-30) = 2325\ J/mol$ ②

$\hat{H}_2 = (216)(45-30) = 3240\ J/mol$ ②

$\hat{H}_3 = \int_{30}^{36} Cp_{p(l)}\, dT + H_{vap_p} + \int_{36}^{45} Cp_{(v)}\, dT = 155(6) + 25800 + (115)(9) = 27{,}765\ J/mol$ ②

$\hat{H}_4 = \int_{30}^{69} Cp_{h(l)}\, dT + H_{v_h} + \int_{69}^{45} Cp(v)\, dT = (216)(39) + 28900 + (137)(-24) = 34{,}036\ J/mol$ ②

$\dot{n}_1 = 0.62 \cdot 33\ mol/s = 20.5\ mol/s$

$\dot{n}_2 = 33 - 20.5 = 12.5\ mol/s$

$\dot{n}_3 = 0.83 \cdot 47\ mol/s = 39\ mol/s$

$\dot{n}_4 = 47 - 39 = 8\ mol/s$

$\dot{Q} = \Delta H = \Sigma n_{out} H_{out} - \Sigma n_{in} \cancel{H_{in}}^{0}$

$\dot{Q} = (20.5)(2325) + (12.5 \times 3240) + (39)(27{,}765) + 8(34{,}036)$

$\dot{Q} = 1.44 \times 10^6\ J/s = 1.44 \times 10^6\ W$ ③ **4** c)

substance	min (kg/s)	$\hat{H}_{in}$ (kJ/kg)	$\dot{m}_{out}$ (kg/s)	$\hat{H}_{out}$ (kJ/kg)
steam	3	2827 ②	ms	2776.2 ②
liq water			$(3-\dot{m}_s)$	762.6 ②

$\hat{H}_{in} \Rightarrow$ steam at 200°C, 10 bar

$\hat{H}_{out} \Rightarrow$ sat steam + water at 10 bar

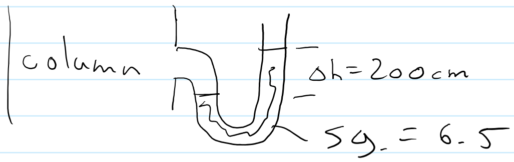
$\dot{Q} = \Delta\dot{H} = \dot{m}_s(2776.2) + (3-\dot{m}_s)(762.6) - 3(2827)$ ②

$-1440 \text{ kJ/s} + 8481 \text{ kJ/s} - 3 \cdot 762.6 = \dot{m}_s(2776.2 - 762.6)$

$\dot{m}_s = \frac{4753}{2014} = 2.36$ ②

$w_s = \frac{2.36}{3} = 0.79$ ①

d)



$\rho = 6.5 \times 1000 \text{ kg/m}^3 = 6500 \text{ kg/m}^3$ ①

$P_0 = 700 \text{ mmHg} \cdot \frac{101.3 \text{ kPa}}{760 \text{ mmHg}} = 93.3 \text{ kPa}$

$P = P_0 + \rho g(h_0 - h)$ ①

$P = 93.3 \text{ kPa} + 6500 \text{ kg/m}^3 \cdot 9.8 \text{ N/kg}(2 \text{ m}) \cdot \frac{1 \text{ kPa}}{1000 \text{ N/m}^2}$

$P = 93.3 \text{ kPa} + 127.4 \text{ kPa}$

$P_{abs} = 220.7 \text{ kPa}$ ①

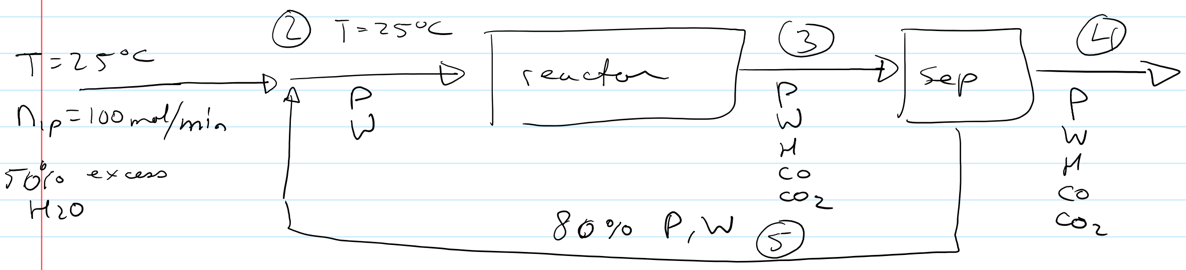
$P_{gauge} = P_{abs} - P_{atm} = 127.4 \text{ kPa}$ ②- 1

Since P abs > p* for either compound, we will have a liquid rather than any gas exiting. 1

3) $3H_2O + C_3H_8 \rightarrow 7H_2 + 3CO$

$CO + H_2O \rightarrow H_2 + CO_2$

$\underline{P = 1 atm}$



Overall conversion = 85%

$CO : CO_2$ 1:5

a) $n_{4p} = n_{1p} \times (1 - conv) = 100\ (0.15) = 15$ mol/min ①

$n_{4p} = 0.2\, n_{3p}$ so $n_{3p} = \frac{15}{0.2} = 75$ mol/min

$n_{5p} = 75 - 15 = 60$ mol/min ①

$n_{2p} = 100 + 60 = 160$ mol/min ①

single pass conv. propane $= \frac{160-75}{160} \times 100\% = 53\%$ ②

b) $n_{1W} = 3\, n_{1p} \times 1.5 = 450$ mol/min ②

$n_1 = 450 + 100 = 550$ mol/min

③

$V_1 = \frac{550 \text{ mol/min} \times (0.08206 \frac{L\,atm}{mol \cdot K})(273.15)}{1 atm} = 1.23 \times 10^4$ L/min

c) Atomic balances on overall system

C: $3 \cdot n_{1p} = 3 \cdot n_{4p} + n_{4co} + n_{4co_2}$

know $n_{4co} = 5 n_{4co_2}$

$$3\cdot(100) = 3\cdot(15) + 6n_{4CO_2}$$

$$n_{4CO_2} = \frac{100-15}{2} = 42.5\,\text{mol/min} = n_{3CO_2}$$ ② ①

$$n_{4CO} = 5n_{4CO_2} = 212.5\,\text{mol/min} = n_{3CO}$$ ② ①

O: $n_{1W} = n_{4W} + n_{4CO} + 2n_{4CO_2}$

$$n_{4W} = 450 - 212.5 - 42.5\times 2 = 152.5\,\text{mol/min}$$ ②

H: $2n_{1W} + 8n_{1P} = 2\cdot n_{4W} + 8n_{4P} + 2n_{4H}$

$$n_{4H} = n_{1W} + 4n_{1P} - n_{4W} - 4n_{4P}$$

$$n_{4H} = 450 + 4\cdot 100 - 152.5 - 4(15) = 637.5\,\text{mol/min}$$ ②

$$n_{3H} = n_{4H} = 637.5\,\text{mol/min}$$ **2**

$$n_{3W} = \frac{n_{4W}}{0.2} = 762.5\,\text{mol/min}$$ ②

$$n_{5W} = 762.5 - 152.5 = 610\,\text{mol/min}$$ ②

$$n_{2W} = n_{5W} + n_{1W} = 610 + 450 = 1060\,\text{mol/min}$$ ②

d)

Compound	$\dot{n}_{in}$ (mol/min)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$ (mol/min)	$\hat{H}_{out}$ (kJ/mol
P (g)	160	−104 ①	75	−104 ①
W (ℓ)	1060	−286 ①	762.5	−286 ①
H_2 (g)			637.5	0 ①
CO (g)			212.5	−110 ①
CO_2 (g)			42.5	−393 ①

Set Tref = 25°C, all compounds in gas except water in liquid

So $\hat{H}$ will be heat of formation since products + reactants @ 25°C

$$\dot{Q} = \Delta H = \Sigma_{out}\,\dot{n}\hat{H} - \Sigma_{in}\,\dot{n}\hat{H}$$ ①

$$Q = (75)(-104) + (762.5)(-286) + (212.5)(-110) + (42.5)(-393)$$

$$- 160 \cdot (-104) - 1060 \cdot (-286)$$ ①

$$\dot{Q} = -265952 \quad + 319,800 \ \text{kJ/min}$$

$$\dot{Q} = 53848 \ \text{kJ/min} \times \frac{1\text{min}}{60\text{s}} = 897 \ \text{kW}$$ ③