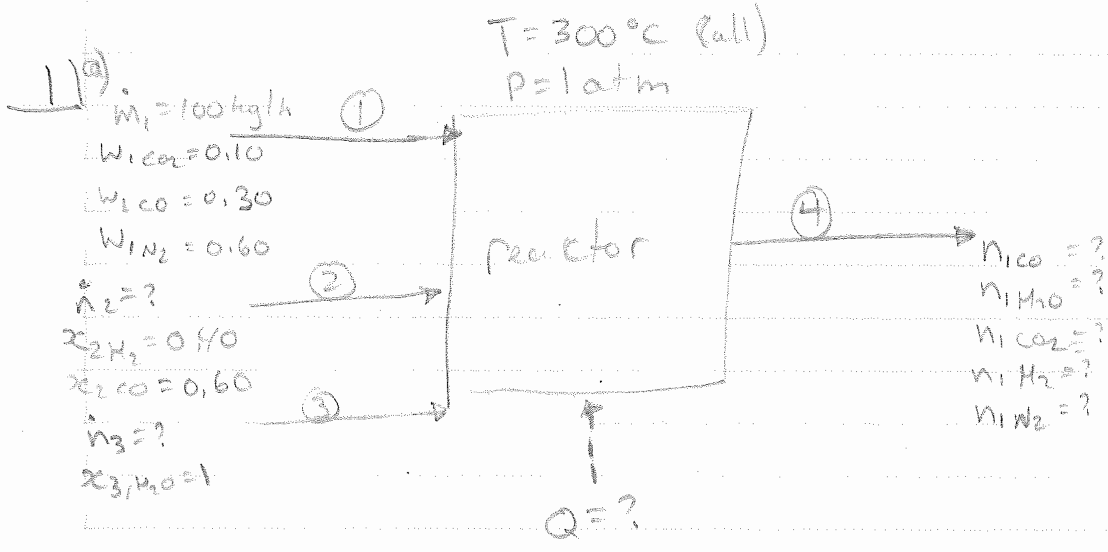
11) a)



conversion = 0.8

b) Molar flow conversion for stream 1

$\dot{n}_{1CO_2} = \dot{m}_{1CO_2} \div MW_{CO_2} = 10\ kg/h / 44\ kg/kmol = 0.227\ kmol/h$

$\dot{n}_{1CO} = 30\ kg/h / 28\ kg/kmol = 1.07\ kmol/h$

$\dot{n}_{1N_2} = 60\ kg/h / 28\ kg/kmol = 2.14\ kmol/h$

$\dot{n}_{tot} = 3.437\ kmol/h$

$y_{CO_2} = 0.227\ kmol/h \div 3.437\ kmol/h = 0.066$

$y_{CO} = 1.07\ kmol/h \div 3.437\ kmol/h = 0.311$

$y_{N_2} = 2.14\ kmol/h \div 3.437\ kmol/h = 0.623$

c) Atomic balance

DOF = unknowns : 8

atomic balances : 3 (C, O, H)

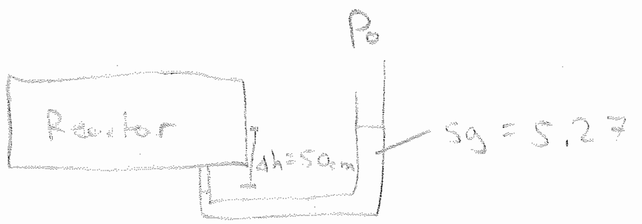
molecular balances : 1 (N_2)

extra equations : 1 (conversion)

energy balance : 1

[2]

d)



$$SG = \frac{\rho}{\rho_{ref}} \quad \text{so} \quad \rho = 5.27 \times 1\,g/cm^3 = 5.27\,g/cm^3$$

$$\rho = 5.27\,g/cm^3 \times (100\,cm/m)^3 \times (1\,kg/1000\,g) = 5270\,kg/m^3$$

$$P_{reactor} = P_0 + \rho \cdot g \cdot (h_0 - h)$$

$$= 100\,kPa + 5270\,kg/m^3 \cdot 9.81\,m/s^2 \cdot (0.5\,m) \cdot \frac{1\,N}{1\,\frac{kg\,m}{s^2}} \cdot \frac{1\,Pa}{1\,\frac{N}{m^2}} \cdot \frac{1\,kPa}{1000\,Pa}$$

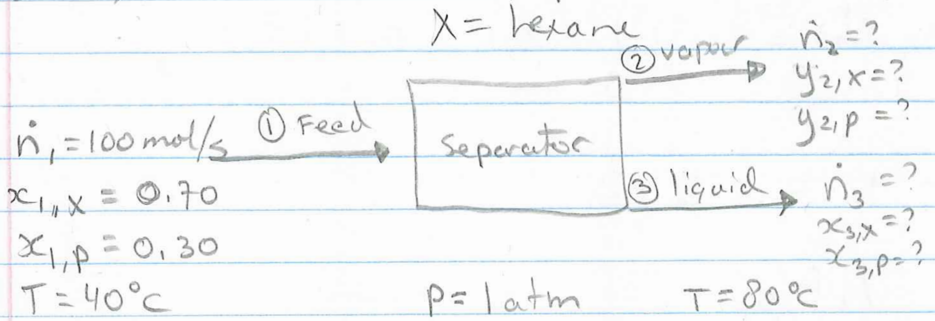
$$= 100\,kPa + 25.85\,kPa$$

$$= 125.85\,kPa$$

{11:13}

2|

P = heptane
X = hexane



$$p^*_x = 10^\wedge(6.87601 - 1171.17/(80°c + 224.41))$$

$$= 1068 \text{ mmHg} \times \frac{1 \text{atm}}{760 \text{mmHg}} = 1.406 \text{ atm}$$

$$p^*_p = 10^\wedge(6.89677 - 1264.90/(80°c + 216.54))$$

$$= 427.8 \text{mmHg} \times \frac{1 \text{atm}}{760 \text{mmHg}} = 0.563 \text{ atm}$$

Using Raoult's law.

$$P = y_x P + y_p P = x_x p^*_x + x_p p^*_p$$

know also $x_x + x_p = 1$ so $x_p = (1 - x_x)$

$$P = x_x p^*_x + (1 - x_x) p^*_p$$

$$P - p^*_p = x_x (p^*_x - p^*_p)$$

$$x_x = \frac{1 \text{atm} - 0.563 \text{ atm}}{(1.406 \text{atm} - 0.563 \text{ atm})} = 0.518$$

$$x_p = 1 - x_x = 0.482$$

$$y_x = \frac{x_x P^*_x}{P} = \frac{(0.518)(1.406)}{1} = 0.728$$

$$y_p = 1 - y_x = 0.272$$

so using MB's

Overall: $\dot{n}_2 = \dot{n}_1 - \dot{n}_3$

hexane: $\dot{n}_1 x_{1x} = \dot{n}_2 y_{2x} + \dot{n}_3 x_{3x}$

$$\dot{n}_1 x_{1x} = (\dot{n}_1 - \dot{n}_3) y_{2x} + \dot{n}_3 x_{3x}$$

$$\dot{n}_1 x_{1x} - \dot{n}_1 y_{2x} = \dot{n}_3 (x_{3x} - y_{2x})$$

$$\dot{n}_3 = \frac{(100\ mol/s)(0.7 - 0.728)}{(0.518 - 0.728)} = \text{~~13.3~~ } 13.8\ mol/s \text{ (Liquid)}$$

[15 mins] $\dot{n}_2 = 100 - 13.3 = $ ~~86.7~~ 86.2 mol/s (Vapor)

b) E bal:

Take reference as liquids at 40°C.

Substance	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$	$\hat{H}_{out}$
hex (l)	70	0	7.17	$\hat{H}_1$ =
hept (l)	30	0	6.65	H_2
hex (v)			62.8	H_3
hept (v)			23.3	H_4

$$\hat{H}_1 = \int_{40°C}^{80°C} c_p\,dT = (0.150\ \text{kJ/mol K})(80-40)°C \cdot \frac{K}{°C} = 6\ \text{kJ/mol}$$

$$\hat{H}_2 = 0.180 \cdot 40 = 7.2\ \text{kJ/mol}.$$

$$\hat{H}_3 = \int_{40}^{80} c_p\,dT + H_{v_x} = 6\ \text{kJ/mol} + 28.85\ \text{kJ/mol} = 34.85$$

$$\hat{H}_4 = 7.2\ \text{kJ/mol} + 31.69\ \text{kJ/mol} = 38.89$$

$$\dot{Q} = \Delta\dot{H} = \sum \dot{n}_{out}\hat{H}_{out} - \sum \dot{n}_{in}\hat{H}_{in}$$

$$= (7.17 \times 6) + (6.65 \times 7.2) + (62.8 \times 34.85) + (23.3 \times 38.89)$$

(11:37) $= 3188\ \text{kW}$

24 mins

3)

$P = 5\ bar$

① → 1 tonne/h. liquid + vapour

↑ Q

② → 1 tonne/h = 1000 kg/h. Vapour $T = 300°C$

③ C_3H_8 → $\dot{n}_3 = 1\ kmol/h$

④ Air → $\dot{n}_4 = ?$
$x_{4,O_2} = 0.21$
$x_{4,N_2} = 0.79$
100% excess.

$T_3 = T_4 = 200°C$

$\Delta H_c = -2220\ kJ/mol\ C_3H_8$ @ 400°C

fractional conversion = 1

⑤ → $\dot{n}_{5C_3H_8} = ?$
$\dot{n}_{5O_2} = ?$
$\dot{n}_{5CO_2} = ?$
$\dot{n}_{5H_2O} = ?$
$\dot{n}_{5N_2} = ?$

From question $Q = W = \Delta E_k = \Delta E_p = 0$

a) Combustion

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Theoretical air $= 5 \cdot n_{C_3H_8} = 5\ kmol/h$

$$\boxed{\dot{n}_{4O_2} = 5\ kmol/h \times 2 = 10\ kmol/h.}$$

$$\boxed{\dot{n}_{N_2} = \dot{n}_{4O_2} \times \frac{0.79}{0.21} = 37.62\ kmol/h.}$$

b) $\dot{n}_{5C_3H_8} = \dot{n}_{4C_3H_8} - \xi = 0$ (100%) conversion,
so $\xi = 1\ kmol/h.$

$\dot{n}_{5O_2} = \dot{n}_{4O_2} - 5\xi = 20\ kmol/h - 5 \times 1\ kmol/h = 5\ kmol/h.$
$\dot{n}_{5N_2} = \dot{n}_{4N_2} = 37.62\ kmol/h.$
$\dot{n}_{5H_2O} = 4\xi = 4\ kmol/h.$
$\dot{n}_{5CO_2} = 3\xi = 3\ kmol/h.$
$\dot{n}_{total} = 49.62\ kmol/h.$

$y_{O_2} = 5/49.62 = 0.101$

$y_{N_2} = 37.62/49.62 = 0.758$

$y_{CO_2} = 3/49.62 = 0.060$

$y_{H_2O} = 4/49.62 = 0.081$

c)

Species	n_{in} (kmol/h)	$\hat{H}_{in}$ (kJ/kmol)	n_{out}	$\hat{H}_{out}$
C_3H_8	1		0	0
O_2	10		5	0
N_2	37.62		37.62	0
CO_2	0		3	0
H_2O	0		4	0

Reference will be 400°C, [illegible] for all species in the gas phase.

$H_{C_3H_8} = \int_{400}^{200} C_p \, dT = 68 \text{ kJ/kmol K} \cdot -200\text{K} = -13\,600 \text{ kJ/kmol}$

$H_{O_2} = 29 \text{ kJ/kmol K} \times -200\text{K} = -5800 \text{ kJ/kmol}$

$H_{N_2} = H_{O_2} = -5800 \text{ kJ/kmol}$

$\dot{Q} = \Delta \dot{H} = \xi H_r + \sum \dot{n}_{out} \hat{H}_{out} - \sum \dot{n}_{in} \hat{H}_{in} =$

$= 1 \text{ kmol/h} \cdot -2220 \text{ kJ/mol} \cdot \frac{1000 \text{ mol}}{\text{kmol}} - (-13\,600)(1) - (-5{,}800)(10) - (-5800)(37.62)$

$= -2.22 \times 10^6 \text{ kJ/h} + 13\,600 + 58000 + 218196$

$= -1.930 \times 10^6 \text{ kJ/h}$

d)

Species	$\dot{m}_{in}$ (kg/h)	$\hat{H}_{in}$ (kJ/kg)	$\dot{m}_{out}$	$\hat{H}_{out}$
$H_2O(l)$	m_l	640.1	—	—
$H_2O(v)$	$1000-m_l$	2747.5	1000	3065

$$Q = \Delta \dot{H} = \sum \dot{m}_{out} \hat{H}_{out} - \sum \dot{m}_{in} \hat{H}_{in}$$

$$Q = 1.930 \times 10^{6}\ \text{kJ/h} = (3065)(1000) - (m_l)(640.1) - (1000-m_l)(2747.5)$$

$$1.930 \times 10^{6}\ \text{kJ/h} - 3065(1000) + 1000(2747.5) = m_l\,(2747.5 - 640.1)$$

$$1.613 \times 10^{6}\ \text{kJ/h} = 2107.4\, m_l$$

$$m_l = 765\ \text{kg/h}$$