Question 1: [10 points]

(a) **[4 pts]** The rate of substance diffusion through a membrane, D (cm²/s), varies with temperature, T (K), according to the Arrhenius equation:

$$D = D_0 exp(-E/RT)$$

where D_0 = the pre-exponential factor

E = the activation energy for diffusion

R = 1.987 cal/(mol.K)

1. What are the units of D_0 and E?

$D_0 \rightarrow cm^2/s$

$E \rightarrow cal/mol$

2. What plot would yield a straight line that would enable you to determine the values of D_0 and E?

$D = D_0 e^{(-E/RT)}$

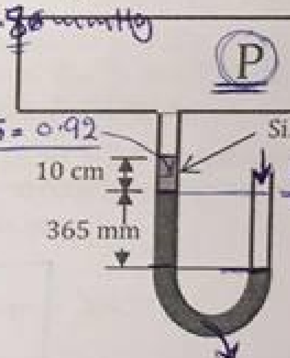
$\ln y = \ln D_0 + \frac{-E}{RT}$

$\ln y$ vs $\frac{1}{T} \Rightarrow$ slope $= \frac{-E}{R}$, intercept $= \ln D_0$

(b) **[6 pts]** An open-end mercury manometer is to be used to measure the pressure is an apparatus containing a vapor that reacts with mercury. A 10 cm layer of silicon oil (SG = 0.92) is placed on top of the mercury in the arm attached to the apparatus. Atmospheric pressure is 765 mm Hg.

a. If the level of mercury in the open end is 365 mm below mercury level in the other arm, as shown in the figure, what is the pressure P (mm Hg) in the apparatus? **Use correct significant figures.**

P = 808.26 mmHg



$P + \rho g h_{silicon} = \rho g h_{Hg} + P_2$

$SG_{Hg} = 13.6$

$P_2 = 765$ mmHg

b. Why do you think the instrumentation specialist chose silicon oil to put on top of mercury in the manometer?

...stion 2: [10 points]

3

Two aqueous sulfuric acid solutions containing 25.0 wt% H_2SO_4 (SG=1.168) and 65.0 wt% H_2SO_4 (SG=1.524) are mixed to form a 5.00 M solution (SG=1.305).

Additional Information: M.W (H_2SO_4) = 98

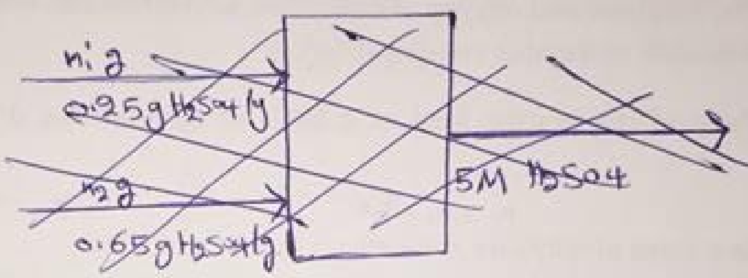
(a) Draw and fully label a flowchart of this process, and do degree-of-freedom analysis.
(b) Calculate the mass fraction of sulfuric acid (wt%) in the product solution.
(c) What amount of 65% solution would be required to produce 125 kg of the product?

c) $X = \frac{mass}{total}$

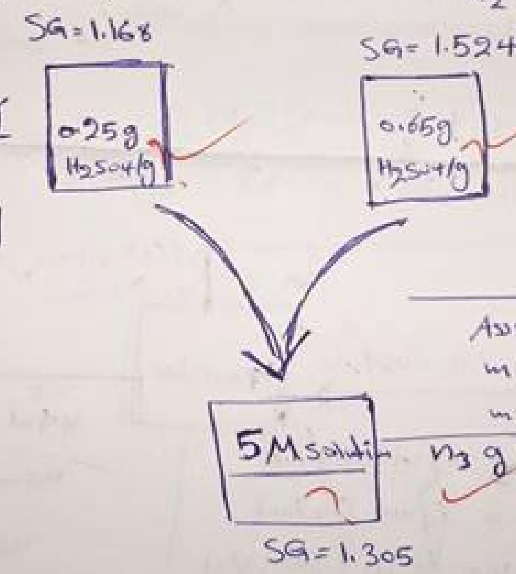
$0.65 = \frac{m}{125 \text{ kg}}$

$m = 81.25$ kg

$n = 0.829$ kmol



a)



Mw = 98 H_2SO_4

d = 1.524 kg/m3

Assume Basis 100 g.
$m_1 = 25$ g
$m_2 = 65$ g

DoF ⇒ # of unkown − # of equation

3 − 1 (H_2SO_4) − 1 (SG) − 1 (5M solution)

DoF = zero

b) X = ??

$X = \frac{mass}{total\ mass} = \frac{6.525}{6.525 + 25 + 65} = 0.98$ g/g total

$d = \frac{m}{V} \Rightarrow m = \frac{1305 \text{ kg}}{m^3} \Big| 5k \Big| \frac{1 m^3}{1000 k} = 6.525$ kg Solution

d = SG × dref ⇒ d = 1.305 × 10³ kg/m³

d = 1305 kg/m³

Question 3: [10 points]

35

Ethylene oxide (C_2H_4O) is produced by the catalytic oxidation of ethylene (C_2H_4):

$$C_2H_4 + O_2 \rightarrow C_2H_4O$$

An undesired competing reaction is the combustion of ethylene:

$$C_2H_4 + O_2 \rightarrow CO_2 + H_2O$$

The feed to the reactor contains 3 moles of ethylene per mole of oxygen. The single-pass conversion of ethylene is 20%, and for every 100 moles of ethylene consumed in the reactor, 80 moles of ethylene oxide emerges in the reactor products. A multiple-unit process is used to separate the products: ethylene and oxygen are recycled to the reactor, ethylene oxide is sold as a product, and carbon dioxide and water are discarded.

(a) Take 100 mole/min of the reactor feed as a basis of calculations, draw and fully label the flowchart.

(b) Calculate:

(i) the molar flow rates of ethylene and oxygen in the fresh feed.

(ii) the production rate of ethylene oxide.

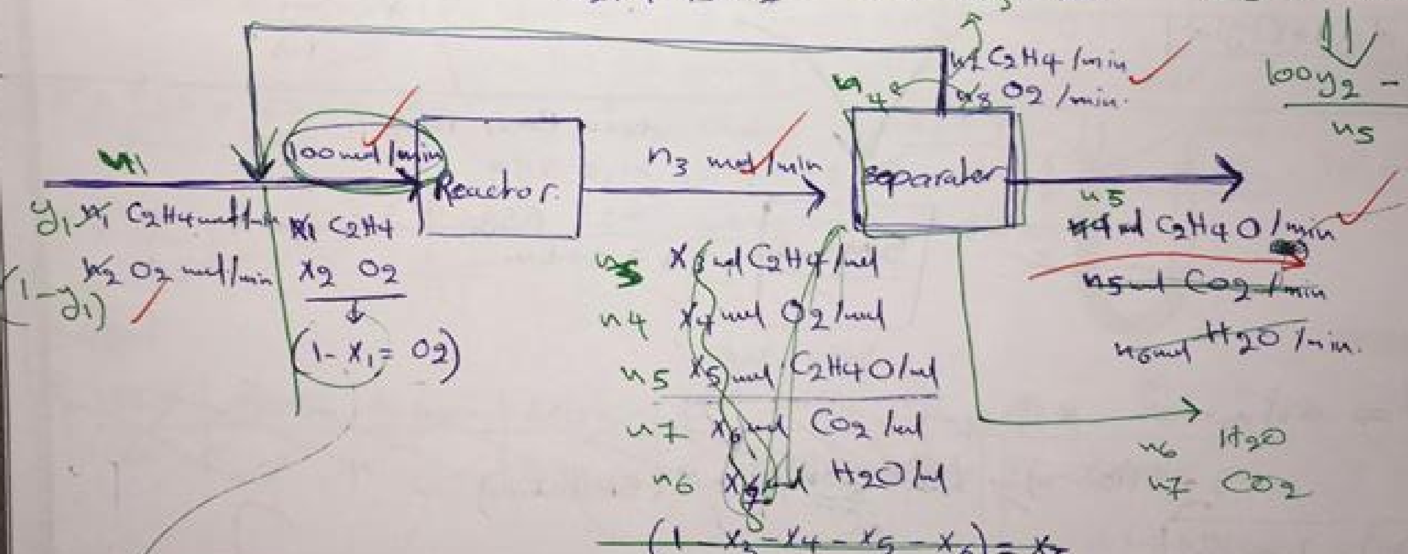
(iii) the overall conversion of ethylene.

(iv) the selectivity of ethylene oxide to carbon dioxide production.

- $\frac{3 \text{ mol } C_2H_4}{1 \text{ mol } O_2}$ reactor
- Sing pass con = 20% C_2H_4
- 100 mol C_2H_4 → 80 mol C_2H_4 reactor prod

$$2C_2H_4 + O_2 \rightarrow 2C_2H_4O$$

$$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$$



$$\frac{x_1 \times 100}{x_2 \times 100} = \frac{3}{1}$$

- Single pass conve = $\frac{\text{in Reactor} - \text{out Reactor}}{\text{in}}$

- $0.2 = \frac{x_1 \times 100 - x_3 n_3}{x_1 \times 100}$

Useful information:

$$\rho_{H_2O(l)}(4°C) = 1.000\frac{g}{cm^3} = 1000.\frac{kg}{m^3} = 62.43\frac{lb_m}{ft^3}$$

$$g = 9.8066\ m/s^2 = 980.66\ cm/s^2 = 32.174\ ft/s^2$$

$$\bar{M} = \sum_{\substack{all \\ components}} y_i M_i$$

$$\frac{1}{\bar{M}} = \sum_{\substack{all \\ components}} \frac{x_i}{M_i}$$

$$\frac{1.8°F}{1°C}, \frac{1.8°R}{1\ K}, \frac{1°F}{1°R}, \frac{1°C}{1\ K}$$

$$T(K) = T(°C) + 273.15$$

$$T(°R) = T(°F) + 459.67$$

$$T(°R) = 1.8T(K)$$

$$T(°F) = 1.8T(°C) + 32$$

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28.317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/$in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp