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ENGG 201 – WINTER 2017 – QUIZ (January 31, 2017)
Total marks: 60
Time allowed: 60 minutes

- Closed book, closed notes
- Schulich calculators only
- Show all work, and box the final answer

Question 1

PART A

In distillation column, vapour and liquid are contacted for separation of a mixture. The velocity of small liquid droplets carried-up by vapour jets is given by the following equation:

$$\rho_L\left(\frac{\pi d^3}{6}\right)g-\rho_V\left(\frac{\pi d^3}{6}\right)g=C_D\left(\frac{\pi d^2}{4}\right)\frac{u^2}{2}\rho_V \quad \cdots (1)$$

A capacity parameter is defined in the following manner

$$C=\left(\frac{4dg}{3C_D}\right)^{1/2} \quad \cdots (2)$$

where, ρ_L = Density of liquid
d = Diameter of liquid droplet
ρ_V = Density of vapour
u = Velocity of liquid droplet
g = Gravitational acceleration
C_D = Drag coefficient
C = Capacity parameter

(i) Determine the dimensions of drag coefficient (/4)

Each additive term has same dimensions.

$$\left[C_D \frac{\pi d^2}{4}\frac{u^2}{2}\rho_v\right]=\left[\rho_v \frac{\pi d^3}{6} g\right]$$

$$\Rightarrow [C_D u^2]=[dg]$$

$$\Rightarrow [C_D]=\left[\frac{dg}{u^2}\right]=\left[\frac{L\cdot L}{t^2}\cdot\frac{t^2}{L^2}\right]=[1], \quad \boxed{C_D \text{ is dimensionless.}}$$

(ii) Determine the dimensions of capacity parameter (C) in terms of fundamental dimensions. Also give its typical units. (/4)

$$[C]=\left[\left(\frac{dg}{C_D}\right)^{1/2}\right]=\left[(dg)^{1/2}\right]=\left[\left(L\cdot\frac{L}{t^2}\right)^{1/2}\right]=\left[\frac{L}{t}\right]$$
$$=\boxed{[L][t]^{-1}}$$

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PART B

(iii) Determine the dimensions of thermal diffusivity in terms of fundamental dimensions from the following heat transfer equation. (/3)

$$\frac{1}{r}\frac{\cancel{\partial}}{\cancel{\partial} r}\left(r\frac{\cancel{\partial} T}{\cancel{\partial} r}\right)=\frac{1}{\alpha}\frac{\cancel{\partial} T}{\cancel{\partial} t}$$

Where,
T = Temperature
t = Time
r = Radial distance
α = Thermal diffusivity

$$\left[\frac{1}{L}\cdot\frac{1}{L}\cdot\cancel{L}\cdot\frac{\cancel{T}}{\cancel{L}}\right]=\left[\frac{1}{\alpha}\cdot\frac{\cancel{T}}{t}\right]$$

$$\Rightarrow\left[\frac{1}{L^2}\right]=\left[\frac{1}{t\alpha}\right]$$

$$\Rightarrow[t\alpha]=[L^2]$$

$$\Rightarrow[\alpha]=\boxed{[L]^2[t]^{-1}}$$

(iv) If the following quantity is dimensionless, determine the dimensions of the quantity k in terms of fundamental dimensions . (/3)

$$k\left(\frac{\rho}{\mu g}\right)^{1/3}$$

Where,
ρ = Density
g = Gravitational acceleration
μ = Viscosity $\left(\frac{kg}{m.s}\right)$

$$\left[k\left(\frac{\rho}{\mu g}\right)^{1/3}\right]=[1]$$

$$\Rightarrow[k]=\left[\left(\frac{\mu g}{\rho}\right)^{1/3}\right]$$

$$=\left[\left(\frac{\cancel{M}}{\cancel{L}\cdot t}\cdot\frac{\cancel{L}}{t^2}\cdot\frac{L^3}{\cancel{M}}\right)^{1/3}\right]$$

$$=\left[\frac{L}{t}\right]$$

$$=\boxed{[L][t]^{-1}}$$

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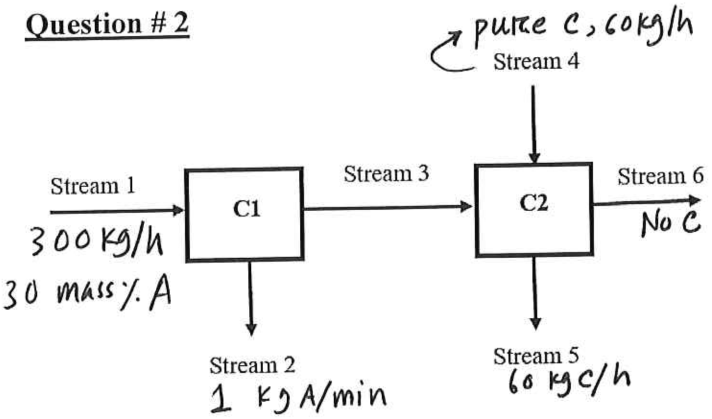
Question # 2

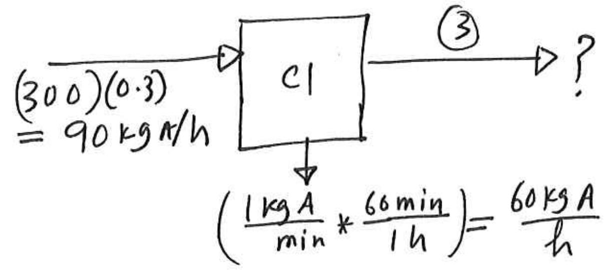


The schematic of a steady-state separation process, for the separation of a gas mixture of components A and B, is shown to the left. Stream 1, which contains 30 mass percent component A, with the balance being component B, is fed to a cooler (C1) at a rate of 300 kg/h. Pure Component A leaves the cooler (C1) as liquid condensate via Stream 2 at a rate of 1 kg/min. Stream 3 is sent to an extraction column (C2). Stream 4 which contains a pure component C also enters into the extraction column (C2) at a rate of 60 kg/h. Stream 5 contains 25 mass percent A, and the balance C. Stream 6 contains no C.

(i) Determine the mass flow rate (kg/h) of component B in stream 1 (/2)

$$\left(300 \frac{kg}{h}\right)(70\%) = \left(300 \frac{kg}{h}\right)(0.7) = \boxed{210 \text{ kg B/h}}$$

(ii) Calculate the mass flow rate (kg/h) of component A in stream 3. (/2)

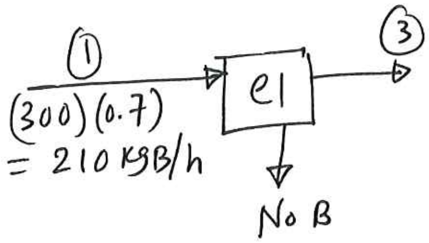


Flow rate of A in 3

$$= 90 - 60 = \boxed{30 \frac{\text{kg A}}{h}}$$

(iii) Calculate the mass fraction of component B in stream 3. (/2)

B in 1 = B in 3



210 kg B/h

30 kg A/h [from part (ii)]

Total = 240 kg/h

Mass fraction of B $= \frac{\cancel{210} \text{ kg B/h}}{\cancel{240} \text{ kg total/h}} = \cancel{\frac{7}{8}} = \cancel{\boxed{0.125}}$

$$= \frac{21\cancel{0}}{24\cancel{0}} = \frac{7}{8} = \boxed{0.875}$$

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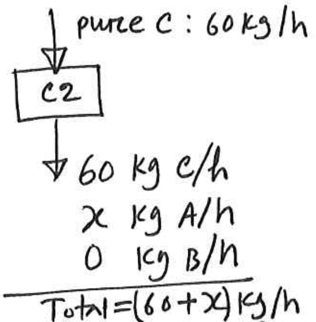
(iv) Calculate the total mass flow rate (kg/h) of stream 5. (/4)



$25\% = 0.25 = \frac{x}{60+x}$

$\Rightarrow 15 + 0.25x = x \Rightarrow 15 = 0.75x$

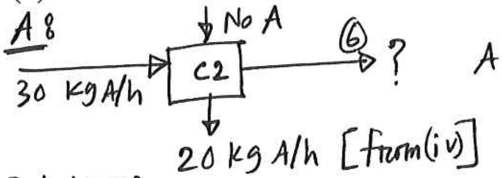
$\Rightarrow \boxed{x = 20\ \text{kg/h}}$

Alternatively: $\frac{x}{60} = \frac{25\%}{75\%} = \frac{1}{3}$

$\Rightarrow \boxed{x = 20\ \text{kg A/h}}$

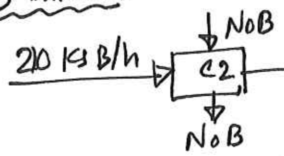
(v) Calculate the mass percent of component A in stream 6. (/4)

A 8



A in ⑥ $= 30 - 20 = 10$ kg A/h

B balance:



B in ⑥ $= 210$ kg B/h

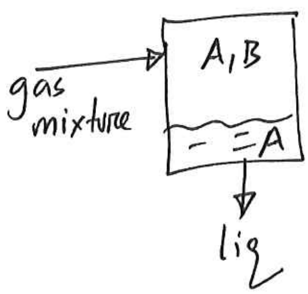
Total ⑥ $= 10 + 210 = 220$ kg total/h

Mass% A $= \frac{10\ \text{kg/h}}{220\ \text{kg/h}} \times 100\% = \boxed{4.545\%}$

(vi) Calculate the molar flow rate (in mol /min) of stream 4. The molar mass of component C is 18 kg/kmol. (/2)

$$\frac{60\ \text{kg}}{\text{h}} \left| \frac{1\ \text{h}}{60\ \text{min}} \right| \frac{\text{kmol}}{18\ \text{kg}} \left| \frac{10^3\ \text{mol}}{1\ \text{kmol}} \right. = \boxed{55.56\ \frac{\text{mol}}{\text{min}}}$$

(vii) Calculate the degree of freedom in the cooler (C1) assuming the phases present in the cooler are in equilibrium. (/2)



$C = 2$

$P = 2$

$F = 2 + C - P = 2 + \cancel{2} - \cancel{2} = 2$

$\boxed{F = 2}$

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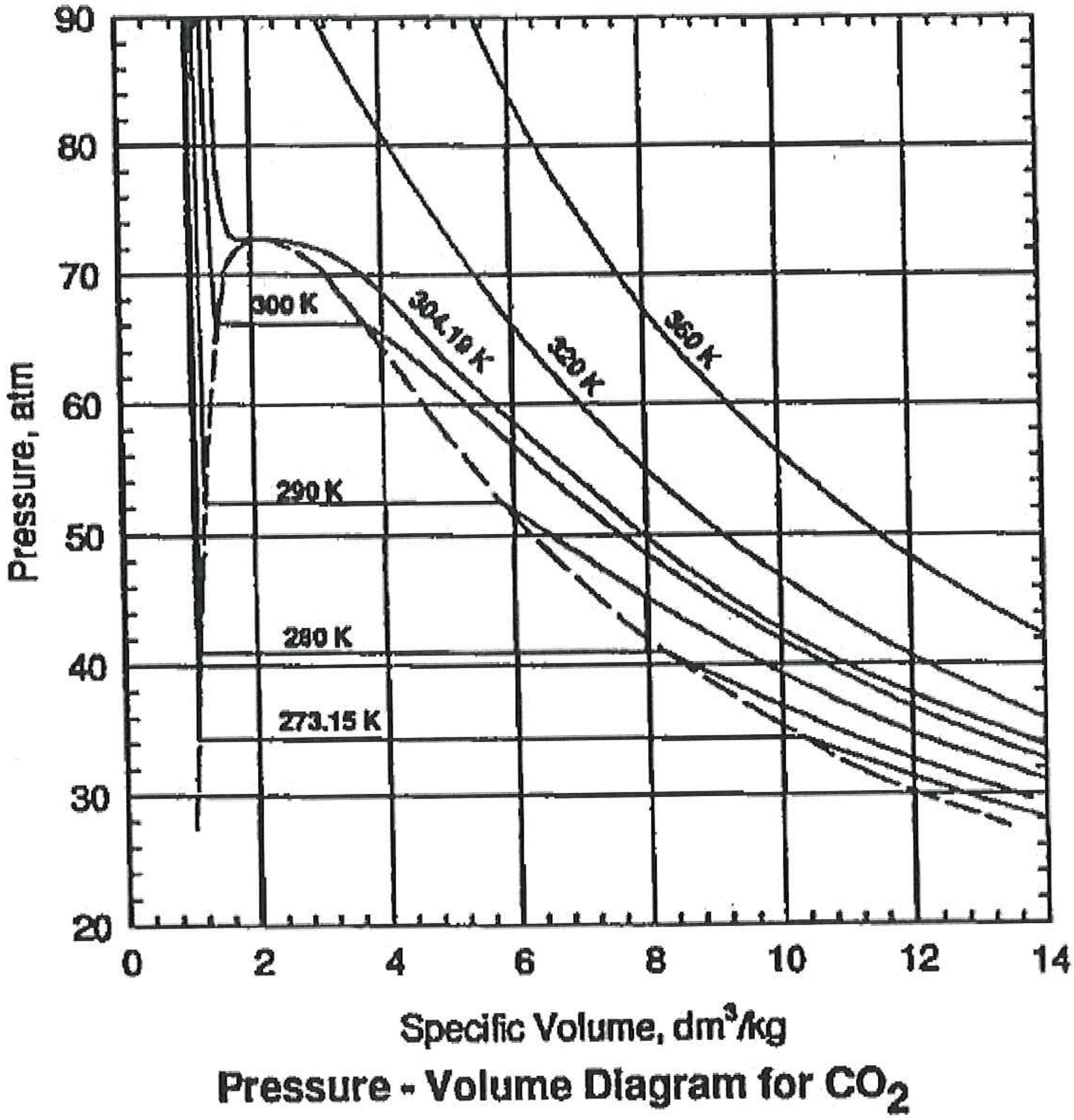
Question 3
Use the phase diagram for the vapour-liquid region of CO_2 to answer the following questions. Show all your work for full marks.



PART A (/10)

(i) What is the critical temperature of CO_2. (1)

$\boxed{304.19 K}$

(ii) At critical conditions, what is the volume of 2 kg carbon dioxide? (/2)

$\left(2.1 \frac{dm^3}{kg}\right)(2\ kg) \simeq \boxed{4.2\ dm^3}$ ± error in reading graph.

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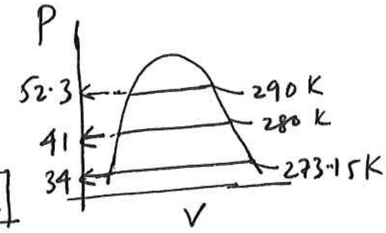
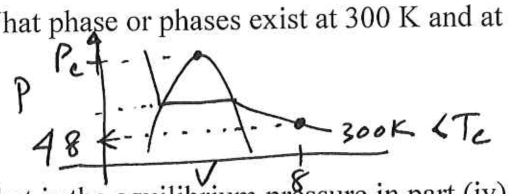
(iii) Estimate the vapor pressure of CO_2 at 273.15 K, 280 K, and at 290 K. (/3)

$\simeq \boxed{34\ atm}$ $\simeq \boxed{41\ atm}$ $\simeq \boxed{52.3\ atm}$



(iv) What phase or phases exist at 300 K and at a specific volume of 8 dm^3/kg? (/2)



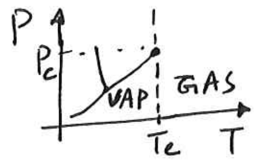
$\boxed{VAPOUR}$

(v) What is the equilibrium pressure in part (iv)? (/1)

$\simeq \boxed{48\ atm}$

(vi)What phase or phases exist at 360 K and at 60 atm? (/1)

~~36~~ $360 > T_c$
$60 < P_c \Rightarrow \boxed{GAS}$



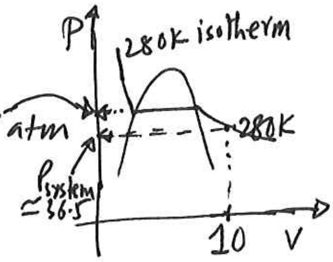
PART B (/18)

(vii) Is the pressure of the system at the following conditions (T = 280 K, specific volume = 10 dm^3/kg) greater or less or equal to the vapor pressure of CO_2 at 280 K (/4)

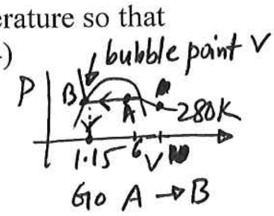
$T = 280K,\ V = 10\ dm^3/kg \Longrightarrow P_{sys} \simeq 36.5\ atm$

VAPOUR pressure of CO_2 at $280K \Rightarrow P_{vap} \simeq 41.5\ atm$

$\boxed{P_{system} \text{ is LESS than } P_{vap}}$



(viii) A rigid container of volume 600 dm^3 contains 100 kg of CO_2 at a temperature of 280K. Determine how much CO_2 (kg) would have to be added or removed to the container at the same temperature so that the specific volume of CO_2 become equal to the bubble point specific volume at 280 K? (/4)



Bubble point specific volume at $280K \simeq 1.15\ dm^3/kg$

$\left(1.15\ \frac{dm^3}{kg}\right) * (m_{new}\ kg) = 600\ dm^3$ $[mV = v]$

$\Rightarrow m_{new} = \frac{600}{1.15} = 522\ kg > 100\ kg$

So, $\boxed{422\ kg \text{ have to be added.}}$

[± error reading graph]

(ix) Another rigid container of volume 600 dm^3 contains 100 kg of CO_2 at a temperature of 280K. Determine how much CO_2 (kg) would have to be added or removed to the container so that the specific volume of CO_2 become equal to the dew point specific volume at 50 atm? (/4)

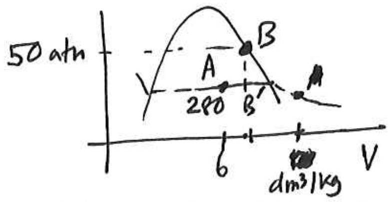
Dew point specific volume at 50 atm $\simeq$ 6.3 dm^3/kg [± error in reading graph]

Then, $(6.3\ \frac{dm^3}{kg}) * (m_{new}\ kg) = 600\ dm^3$

$\Rightarrow\ m_{new} = 600/6.3 \simeq 95.2\ kg < 100\ kg$

So, $100 - 95.2 \simeq$ $\boxed{4.8\ \text{kg have to be REMOVED}}$

point A → B'



(x) A separate variable-volume container contains 100 kg of CO_2. The volume of the container is adjusted isothermally at 300 K and the substance is allowed to reach equilibrium. The density of the substance at equilibrium is 0.167 kg/dm^3. What is the internal volume of the container at these conditions? (/2)

$$V = \frac{1}{\rho} = \frac{1}{0.167\ kg/dm^3} = 5.988\ dm^3/kg$$

$$\mathcal{V} = mV = (100\ kg)(5.988\ \frac{dm^3}{kg}) = \boxed{598.8\ dm^3}$$

(xi) Following part (x) the temperature of the container is brought to 273.15 K. What is the specific volume of each phase present inside the container at these new conditions at equilibrium? (/4)

part (x): $V = 5.988\ dm^3/kg$, $T = 300K$, $P \simeq 57$ atm

solution #1: Go to 273.15 K isobarically. New conditions: $T = 273.15$, $P \simeq 57$ atm

Then, only liquid is present, $\boxed{V_{liq} \simeq 0.9\ dm^3/kg}$

Alternatively,
Solution #2: Go to 273.15 K keeping specific volume constant.

New conditions: $T = 273.15K$, $V = 5.988\ dm^3/kg$

Then, both liquid and vapoure are present, with

$$\boxed{\begin{aligned} V_{liq} &\simeq 1\ dm^3/kg \\ V_{vap} &\simeq 10.2\ dm^3/kg \end{aligned}}$$

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Question	Total Marks	Marks Obtained
1	14	
2	18	
3	28	