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ENGG 201 – T02 - WINTER 2017 - QUIZ (/60) [60 min.]

- Closed book, closed notes, Schulich Calculator Only.
- Show all work, and box final answer.
- Use the back of pages if needed and indicate with an arrow if you do so

1. The following equation is used to determine the power required to achieve laminar or turbulent flow in a stirred tank reactor:

$$\frac{P\,g_c}{\rho n^3 d^5} = A\left(\frac{d^2 n \rho}{\mu}\right)^{-1} = \frac{A}{Re}$$

Where:

P = power (W)
d = diameter of impeller (m)
μ = fluid viscosity (kg/ms)
g_c = gravitational acceleration (kgm/Ns^2)
Re = (ρ n d^2) / μ
ρ = fluid density (kg/m^3)
n = agitation rate (s^{-1})

Determine the DIMENSIONS of A starting from the given information. Show all your work. (/5)

$$\left[\frac{P g_c}{\rho n^3 d^5}\right] = \left[\frac{A}{Re}\right]$$

$$[P] = \frac{[\text{Energy}]}{[\text{time}]} = \frac{[F][L]}{[t]} = \frac{[M]^1[L]^1[L]^1}{[t]^2\,[t]^1}$$

$$[Re] = \frac{[\rho][n][d^2]}{[\mu]} = \frac{\cancel{[M]^1}\cancel{[L]^{-3}}\cancel{[t]^{-1}}\cancel{[L]^2}}{\cancel{[M]^1}\cancel{[L]^{-1}}\cancel{[t]^{-1}}} = [1]$$

$$\left[\frac{P g_c}{\rho n^3 d^5}\right] = [A] \quad \text{since } [Re] = [1]$$

$$\frac{[P][g_c]}{[\rho][n^3][d^5]} = \frac{[M]^1[L]^2[t]^{-3}\,[1]}{[M]^1[L]^{-3}[t]^{-3}[L]^5}$$

$= [1]$ dimensionless

$$\boxed{[A] = 1}$$

$g_c = \frac{kgm}{s^2}\cdot\frac{1}{N}$

$$[g_c] = \frac{[M]^1[L]^1}{[t]^{-2}} \cdot \frac{[t]^{-2}}{[M]^1[L]^1} = [1]$$

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2. The following formula is used to describe unsteady heat transfer in cylindrical geometry with no generation. The quantity T is the temperature, r is radial distance, φ is radial angle, z is axial length, k is thermal conductivity (W/mK) and C_p is the heat capacity (J/kgK).

$$\underbrace{\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)}_{A}+\underbrace{\frac{1}{r^2}\frac{\partial}{\partial \phi}\left(k\frac{\partial T}{\partial \phi}\right)}_{B}+\underbrace{\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)}_{C}=\underbrace{\rho C_p\frac{\partial T}{\partial t}}_{D}$$

Determine the DIMENSIONS of φ the radial angle. Show all your work. (/5)

$[B]=[D]$

$[D]=[\rho C_p \frac{\partial T}{\partial t}]=[\rho][C_p]\frac{[T]}{[t]}=\frac{[M]^1}{[L]^3}\frac{[E]}{[M]^1[T]^1}\frac{[T]^1}{[t]^1}$

$[E]=[F][L]=[M]^1[L]^1[t]^{-2}[L]^1=[M]^1[L]^2[t]^{-2}$

$[D]=\frac{\cancel{[M]^1}}{[L]^3}\frac{\cancel{[M]^1}[L]^2}{[t]^{-2}\cancel{[M]^1}\cancel{[T]^1}}\frac{\cancel{[T]^1}}{[t]^1}=\boxed{[M]^1[L]^{-1}[t]^{-3}}$

$[B]=[\frac{1}{r^2}][\frac{\partial}{\partial\phi}][k][\frac{\partial T}{\partial\phi}]$ $\boxed{[\partial]=1}$

$[k]=\frac{[M]^1[L]^2[t]^{-2}}{[t]^1[L]^1[T]^1}$

$[B]=[L]^{-2}[\phi]^{-1}[k][T]^1[\phi]^{-1}$

$[B]=[L]^{-2}[\phi]^{-2}[M]^1[L]^1[t]^{-3}\cancel{[T]^{-1}}\cancel{[T]^1}$

$[B]=[M]^1[L]^{-1}[t]^{-3}[\phi]^{-2}=[D]\Rightarrow\boxed{[\phi]=1}$

3. What force will a 17000 g copper block exert on an object if it is accelerated at a rate of 4000 cm/h²? Express your answer in base SI units. (/3)

$\to$ kg m s (N)

$F=ma$

$M=17000\,g=17\,kg$

$F=(17)(3.084\times10^{-6})$

$a=4000\frac{cm}{h^2}\times\left(\frac{1h}{60min}\right)^2\cdot\left(\frac{1min}{60s}\right)^2\left(\frac{1m}{100cm}\right)$

$a=3.0864\times10^{-6}\,m/s^2$

$\boxed{F=5.25\times10^{-5}\,\frac{kg\,m}{s^2}}$

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4. A liquid mixture of B_2, B_2D and D_2 exist at conditions where reactions do not occur.

   a. Calculate the degrees of freedom in this system (/3)

$F + P = C + 2 \qquad F = C + 2 - P$

$C = 3 \rightarrow B_2, \rightarrow B_2D, \rightarrow D_2$

$F = 3 + 2 - 1 = \boxed{4}$

$P = 1 \rightarrow$ Liq

   b. Give a set of intensive variables to fix the state of the system. (/2)

T, P, x_1, x_2, x_3] $\rightarrow$ any 4 (but not all 3 x_i values, MAX two of these)

$\rho, \mu,$

   c. The mixture is brought to 500°C and a vapour phase is produced. It is also known that reactions may be occurring at this temperature. How many intensive variables can be specified? (/3)

T = specified $\qquad P = 2$ (V + L)

reactions $\rightarrow C = 2$ – B, – D

$F = C + 2 - P$

$F = 2 + 2 - 2$

$F = 2$ but since T = specified, $\boxed{F = 1}$

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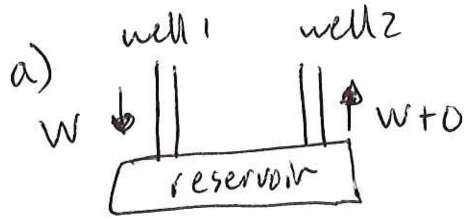
5. A process uses steam to heat oil from an underground reservoir and carry it to the surface (SAGD – Steam Assisted Gravity Drainage). The steam is injected in one well, flows to the reservoir hundreds of meters below the surface, and hot oil and water are produced out of another well (production well). You can assume that the reservoir is so large that for this calculation, steady state can be assumed.

   At one site, steam (pure vapour H_2O) is injected into a well at a rate of 400 kg/h.

   a. If the Steam-to-Oil ratio is 2.5 (for every one kg of oil produced, 2.5 kg of steam are injected), how much oil could theoretically be produced assuming no losses of water in the system? (/3)
   b. It is known that 20% of the water is lost down in the rock around the reservoir. What is the ~~concentration~~ fraction of oil in the production well stream coming to the surface? (/4)
   c. If the water/oil mixture in part b is sent to a separator where 90% of the water is recovered for re-use, how much make-up water should be added if we want to be injecting at 400kg/h? (/3)

a)



well 1 → W = 400 kg/h

oil produced : water → 1 : 2.5

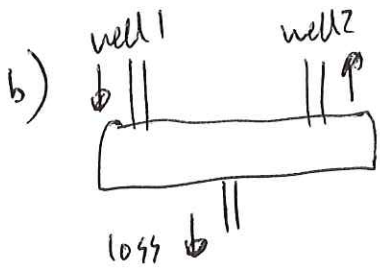
TOTAL MASS BALANCE

$I + \cancel{G} = O + A$ oil from reservoir

$400\ \text{kg/h} = (400\ \text{kg/h} + O) - 160\ \text{kg/h}$

Production = $\boxed{160\ \text{kg/h oil}}$

b)



$\text{loss} = 0.20(400\ \text{kg/h}) = 80\ \text{kg/h}$

oil produced = 160 kg/h

water balance

$I + \cancel{G} = O + \cancel{A}$ → 320 kg/h

$400\ \text{kg/h} = 80\ \text{kg/h} + \text{Out with oil}$

$\text{OUT well 2} = \underset{w}{320\ \text{kg/h}} + \underset{o}{160\ \text{kg/h}} = 480\ \text{kg/h}$

oil fraction = $160/480 = \boxed{0.33}$

c) well 2 → 320 kg/h → [separator] → oil + 10% water

↓ 90% water recovered

$0.90(320) = 288\ \text{kg/h}$

$400 - 288 = \boxed{122\ \text{kg/h}}$

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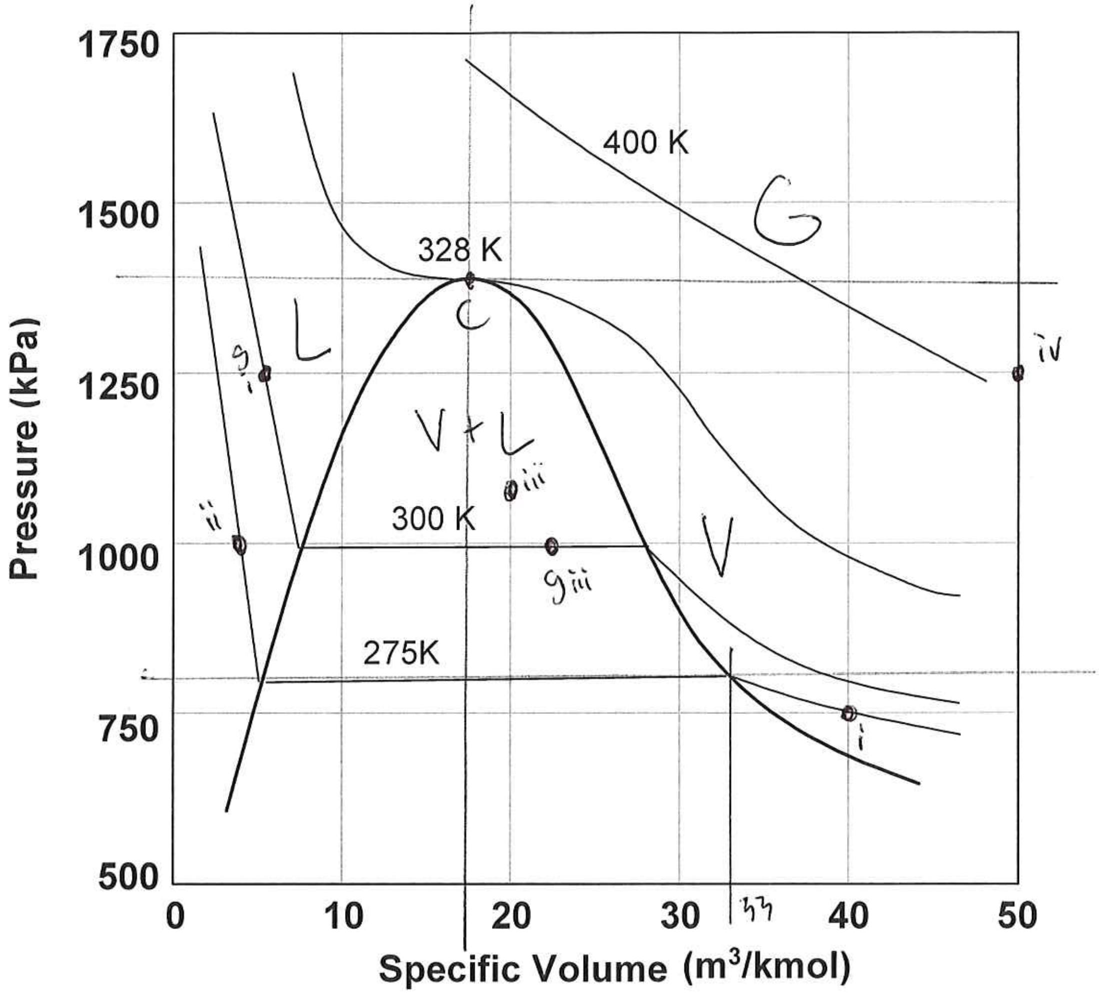
6. A newly discovered substance Sallokium has been discovered. It is known that the molecular mass is 50 kg/kmol. Use the phase diagram shown below to answer the following questions. Show all your work for full marks.



a) Estimate the critical temperature (K), pressure (MPa), and density (kg/m³) of Sallokium. (/3)

$\boxed{T_c = 328\,K}$ $P_c = 1340\,kPa = \boxed{1.34\,MPa}$

$\rho_c = \frac{M}{V_{mc}} = \frac{50\,kg/kmol}{17.3\,m^3/kmol} = \boxed{2.89\,kg/m^3}$

b) What is the vapour pressure of Sallokium at 275 K? (/2)

$P_v \simeq 800\,kPa$ (chart)

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c) At the following conditions, please state the names of all of the phases present (/8)

i) T=275K, P=0.75 MPa $\boxed{\text{VAPOUR}}$

ii) T=275K, P=1.0 MPa $\boxed{\text{LIQUID}}$

iii) T=310K, V_m=20 m^3/kmol

$\boxed{\text{VAPOUR + LIQUID}}$

iv) P=1.25 MPa, ρ=1 kg/m^3

$$\rho = \frac{M}{V_m} \rightarrow V_m = \frac{M}{\rho} = \frac{50\ \text{kg/kmol}}{1\ \text{kg/m}^3} = 50\ \text{m}^3\text{/kmol} \quad \boxed{\text{GAS}}$$

d) What phase or phases would be present if Sallokium is just below the dew point pressure at a specific temperature? (/2)

$\boxed{\text{VAPOUR}}$

e) At a given temperature, if a Sallokium has a slightly higher density than the bubble point density, which phase or phases would exist? (/2)

– higher ρ = lower V_m $\boxed{\text{LIQUID}}$

f ~~d~~) What size (volume) container would you have to build so that 50 g of Sallokium at 275K exists as a saturated vapour at it's dew point? (/4)

T = 275 K , Dew point $V_m = 33\ \text{m}^3\text{/kmol}$

$$m = 50\,g = 0.05\ \text{kg}$$

$$M = \frac{m}{n} \rightarrow n = \frac{m}{M} = \frac{0.05\ \text{kg}}{50\ \text{kg/kmol}} = 0.001\ \text{kmol}$$

$$V_m = \frac{V}{n} \rightarrow V = V_m n = \left(33\ \frac{\text{m}^3}{\text{kmol}}\right)(0.001\ \text{kmol}) = \boxed{0.033\ \text{m}^3}$$

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~~8)~~ 9) Fifty (50) moles of Sallokium are held at 300K and 1250 kPa in a container of volume v_1.

i) Identify the name(s) of the phase(s) that are present. (/1)

$\boxed{\text{LIQUID}}$

ii) Determine the volume v_1 that the Sallokium occupies. (/3)

$V_m = 5.5\ m^3/kmol \qquad n = 50\ mol = 0.05\ kmol$

$V_m = \frac{v}{n} \rightarrow v = V_m n = \left(5.5\frac{m^3}{kmol}\right)(0.05\ kmol) = \boxed{0.275\ m^3}$

iii) Keeping the temperature constant, the volume of the container is increased by a factor of 4 (i.e. $v_2 = 4x(v_1)$). What is the new pressure in the container? (/2)

$v_1 = 0.275\ m^3 \rightarrow v_2 = 1.1\ m^3 \qquad V_m = \frac{v_2}{n} = \frac{1.1\ m^3}{0.05\ kmol} = 22\ \frac{m^3}{kmol}$

now L+V

$P = P_v = \boxed{1000\ kPa}$

iv) At the new increased volume conditions, identify the phase or phases present. (/2)

$\boxed{\text{LIQUID + VAPOUR}}$