

Name: INSTRUCTOR SOLUTIONS

University of Calgary
Schulich School of Engineering
ENGG 201: Behaviour of Liquids, Gases and Solids

Quiz INSTRUCTOR SOLUTIONS

Closed Book / Closed Notes / Sanctioned Calculators Allowed Only

October 3, 2013

Time Allowed: 60 minutes

1. Do not turn this cover page until instructed to begin.
2. Provide answers to the questions in the space provided. If you require more space on a given page, you may use the back of that page to complete your answers.
3. Please write clearly and legibly.
4. You must show all of your work and include units to receive full marks.
5. Possible marks are listed in the left margin.
6. Please ensure that your name is written at the top of every page.

Question 1 (8 Marks)

Extensive studies have shown that when a fluid flows over a flat, solid surface under conditions where the flow is defined as “laminar”, the velocity of the fluid at the surface is zero, and the velocity increases linearly with distance away from the surface. In certain fluids, the fluid viscosity (μ) can be related to shear stress (τ) through the relationship shown in Equation 1:

$$\tau = \underbrace{-\mu}_{\text{TERM A}} \underbrace{\left(\frac{du}{dy}\right)}_{\text{TERM B}} + \underbrace{C}_{\text{TERM C}} \quad \text{Equation 1}$$

where: τ = shear stress which is defined as the force per unit area parallel to the surface

μ = viscosity

C = yield stress

$\left(\frac{du}{dy}\right)$ = change in velocity (u) over a distance y away from the surface

The viscosity can also be used to determine kinematic viscosity (ν) using the ratio shown in Equation 2:

$$\nu = \frac{\mu}{\rho} \quad \text{Equation 2}$$

where: ρ = density (kg/m^3)

(a) Express yield stress in terms of fundamental dimensions (show all your work)

3

In order for an equation to be valid, each term in an equation has to have the same dimensions. In this case, in Equation 1, the dimensions of terms A, B and C have to be the same

$$[\text{TERM A}] = [\text{TERM B}] = [\text{TERM C}]$$

$$\therefore [\tau] = [C]$$

We are told that $[\tau] = \frac{[\text{FORCE}]}{[\text{AREA}]} = \frac{[M][L]/[t]^2}{[L]^2} = \frac{[M]}{[L][t]^2}$

$$\therefore [C] = \frac{[M]}{[L][t]^2}$$

Question 1 (Contd.)

(b) Express kinematic viscosity in terms of fundamental dimensions (show all your work)

4 We are being asked to find $[\nu]$ and we know that $[\nu] = \frac{[\mu]}{[\rho]}$

We can find $[\mu]$ from Equation 1:

$$(\text{Term B}) = (\text{Term A})$$

$$[\mu] \frac{[u]}{[L]} = [\tau]$$

$$[\mu] = \frac{[\tau][L]}{[u]} = \frac{\left(\frac{[\mu]}{[L][t]^2}\right)([L])}{\left(\frac{[L]}{[t]}\right)} = \frac{[\mu]}{[L][t]}$$

We can find $[\rho]$ by using the units provided

$$[\rho] = \frac{[M]}{[L]^3}$$

$$\text{Therefore: } [\nu] = \frac{[\mu]}{[\rho]} = \frac{\left(\frac{[\mu]}{[L][t]}\right)}{\left(\frac{[M]}{[L]^3}\right)} = \boxed{\frac{[L]^2}{[t]}}$$

(c) Provide typical metric units for kinematic viscosity.

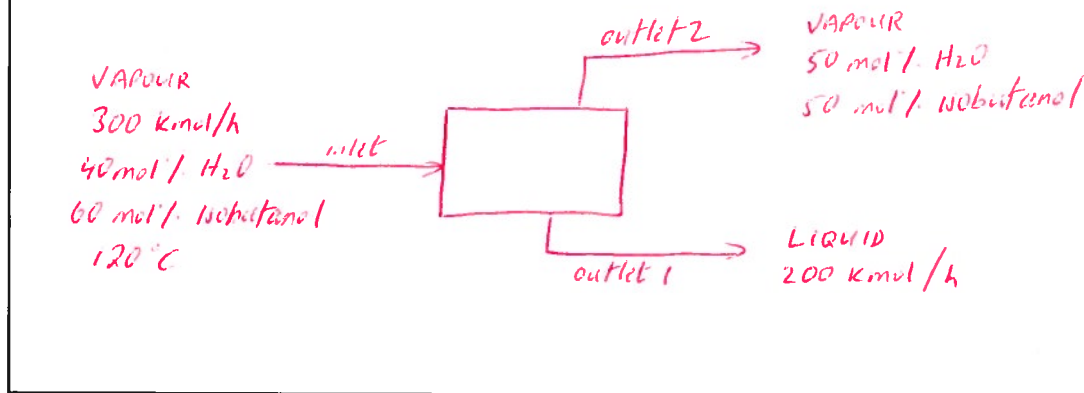
1

$$\boxed{\frac{m^2}{s}}$$

Question 2 (10 marks)

A 120°C vapour containing 60 mol% isobutanol ($C_4H_{10}O$; molar mass = 74.12 kg/kmol) and 40 mol% water (H_2O ; molar mass = 18.02 kg/kmol) enters a tank at a rate of 300 kmol/h where it is cooled to 95°C, causing a portion of it to condense. The condensed liquid leaves through outlet 1 at the bottom of the tank at a rate of 200 kmol/h. The remaining vapour leaves the tank through outlet 2 at the top of the tank. An analysis of the vapour leaving the tank shows that it has a composition of 50 mol% isobutanol.

Space to draw a figure if needed (no marks associated with this)



Assuming that the process operates at steady state, and no reactions are occurring, answer the following questions:

- (a) Calculate the molar flow rate (in kmol/h) of the vapour leaving through outlet 2.

1

Since the process operates at steady state, there is no accumulation.

Since there is no reaction, there is no generation term and moles are conserved

$$\therefore \text{in} = \text{out}$$

$$\text{vapour flow rate in} = \text{vapour flow rate out} + \text{liquid flow rate out}$$

$$300 \text{ kmol/h} = \text{vapour flow rate out} + 200 \text{ kmol/h}$$

$$\therefore \text{vapour flow rate out} = 300 \text{ kmol/h} - 200 \text{ kmol/h} = \boxed{100 \text{ kmol/h}}$$

- (b) Calculate the molar flow rate (in kmol/h) of isobutanol in the inlet stream of the tank.

1

$$\text{molar flow rate of isobutanol in inlet} = \left(\text{mol fraction of isobutanol} \right) \left(\text{total molar flow rate of inlet stream} \right)$$

$$= (0.6) (300 \text{ kmol/h})$$

$$= \boxed{180 \text{ kmol/h}}$$

Question 2 (Contd.)

(c) Calculate the molar composition of the liquid leaving the tank through outlet 1.

3

We can determine this by performing a component balance on the isobutanol

$$\text{isobutanol in} = \text{isobutanol out of outlet 1} + \text{isobutanol out of outlet 2}$$

Let x = mol fraction of isobutanol in outlet 1

$$180 \text{ kmol/h} = (x)(200 \text{ kmol/h}) + (0.5)(100 \text{ kmol/h})$$

$$x = 0.65$$

∴ composition of liquid leaving through outlet 1 : 0.65 mol fraction isobutanol
(1-0.65) = 0.35 mol fraction water

(d) Calculate the mass flow rate (in kg/h) of liquid leaving the tank through outlet 1.

4

- First we should calculate the molar flow rate of each component in outlet 1

$$\text{molar flow rate of isobutanol} = (0.65)(200 \text{ kmol/h}) = 130 \text{ kmol/h}$$

$$\text{molar flow rate of water} = (0.35)(200 \text{ kmol/h}) = 70 \text{ kmol/h}$$

- Next we need to convert these molar flow rates to mass flow rates by using molar mass

$$\text{mass flow rate of isobutanol} = (130 \text{ kmol/h})(74.12 \text{ kg/kmol}) = 9635.6 \text{ kg/h}$$

$$\text{mass flow rate of water} = (70 \text{ kmol/h})(18.02 \text{ kg/kmol}) = 1261.4 \text{ kg/h}$$

- Sum the mass flow rates of all components to get the total mass flow rate

$$\text{total mass flow rate through outlet 1} = 9635.6 \text{ kg/h} + 1261.4 \text{ kg/h} = \boxed{10897 \text{ kg/h}}$$

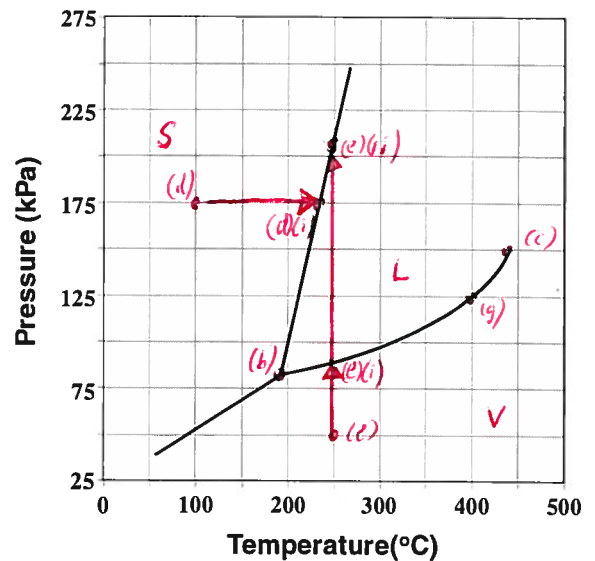
(e) What is the mass fraction of isobutanol in the liquid exiting through outlet 1?

1

$$\text{mass fraction of isobutanol} = \frac{\text{mass flow rate of isobutanol}}{\text{total mass flow rate}} = \frac{9635.6 \text{ kg/h}}{10897 \text{ kg/h}} = 0.88$$

Question 3 (12 marks)

Shown to the right is a PT diagram for a newly discovered pure substance called Ficshunium. Use this diagram to answer the questions below.



- 1.5 (a) On the diagram, clearly label the solid (S), liquid (L) and vapour (V) regions.

- 1 (b) What is the temperature (in °C) and pressure (in kPa) at the triple point?

- see point (b) on the graph

$$T = 190^{\circ}\text{C}$$

$$P = 82 \text{ kPa}$$

- 2 (c) What is the temperature (in K) and pressure (in atm) at the critical point? Show all calculations. (Note that $1 \text{ atm} = 101325 \text{ Pa}$).

- see point (c) on the graph

$$T_c = (440 + 273.15) \text{ K} = 713.15 \text{ K}$$

$$P_c = (150 \text{ kPa}) \left(\frac{1000 \text{ Pa}}{\text{kPa}} \right) \left(\frac{1 \text{ atm}}{101325 \text{ Pa}} \right) = 1.48 \text{ atm}$$

- 1 (d) Starting at a temperature of 100°C and pressure of 175 kPa , you isobarically increase the temperature of Ficshunium. At what temperature would you expect to see a phase change? What is the term used to describe this phase change?

- see point (d) on curve for starting point and follow the arrow to the phase change (point (d)(i))

$$T = 235^{\circ}\text{C}$$

Solid to liquid phase change is called **MELTING**.

- 3 (e) Starting at a temperature of 250°C and pressure of 50 kPa , you isothermally increase the pressure to a new equilibrium pressure of 250 kPa . Describe the pressure (in kPa) and temperature (in °C) for each phase change that occurs during this process. Provide the term used to describe each of the phase changes.

- see point (e) on graph for starting point and follow arrows for phase changes at points (e)(i) and (e)(ii)

At point (e)(i): $P = 85 \text{ kPa}, T = 250^{\circ}\text{C} \rightarrow$ **condensation**

At point (e)(ii): $P = 205 \text{ kPa}, T = 250^{\circ}\text{C} \rightarrow$ **freezing**

Question 3 (Contd.)(f) Calculate the degrees of freedom at the triple point (*show all of your work*).

1.5

$$C = 1 \quad (\text{P-T diagram is for a pure substance})$$

$$P = 3 \quad (\text{at the triple point, a solid, liquid and vapor coexist at equilibrium})$$

$$\therefore F = C - P + 2 = 1 - 3 + 2 = \boxed{0}$$

(g) You place pure Ficshunium into a container, seal the container and then change the pressure to 125 kPa and the temperature to 673.15 K.

(i) Describe the phases present at equilibrium

1

$$T = 673.15 \text{ K} - 273.15 = 400^\circ \text{C}$$

see point (g) on the graph. \rightarrow this lies right on the line separating the liquid and vapor regions.

\therefore phases present at equilibrium are LIQUID and VAPOR.

(ii) Calculate the number of intensive variables that you could manipulate without changing the number of phases present.

1

- this is just another way of asking how many degrees of freedom are available

$$C = 1$$

$$P = 2$$

$$\therefore F = C - P + 2 = 1 - 2 + 2 = \boxed{1}$$