SCHULICH
School of Engineering

FINAL EXAMINATION
(FALL 2014)
ENGG 201 - Behaviour of Liquids, Gases and Solids

December 13, 2014 Time Allowed: 180 minutes.

1. Attempt all six (6) questions. Marks are noted in the left page margin. Total marks = 100.
2. Only Schulich sanctioned calculators are permitted. Notes and textbooks are not allowed.
3. A separate handout listing formulas, charts and data is provided.
4. You must show all of your work and specify units in order to obtain full marks.
5. Print your name and lecture section clearly in the space provided on the cover page. Write your ID No. on all other pages in the provided space.

Surname: LAW **Given Name(s):** CURTIS SWAYNE **Section*** L02

***L01** (Dr. Sen); **L02** (Dr. Moore)

STUDENT IDENTIFICATION: Each candidate must sign the Seating List confirming presence at the examination. All candidates for final examinations are required to place their University of Calgary student I.D. cards on their desks for the duration of the examination. Students writing mid-term tests can also be asked to provide identity proof. Students without an I.D. card who can produce an acceptable alternative I.D. e.g. one with a printed name and photograph, are allowed to write the examination. A student without acceptable I.D. will be required to complete an Identification Form. The form indicates that there is no guarantee that the examination paper will be graded if any discrepancies in identification are discovered after verification with the student's file. A **Student who refuses to produce identification or who refuses to complete and sign the Identification Form is not permitted to write the examination.**

EXAMINATION RULES

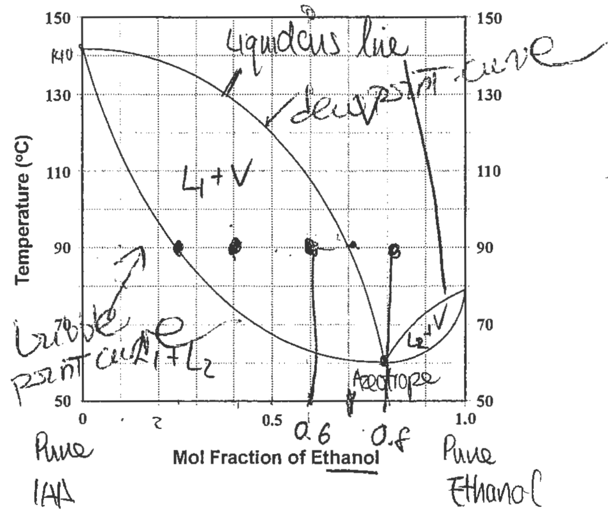
(1) Students late in arriving will not normally be admitted after one-half hour of the examination time has passed.
(2) No candidate will be permitted to leave the examination room until one-half hour has elapsed after the opening of the examination, nor during the last 15 minutes of the examination. All candidates remaining during the last 15 minutes of the examination period must remain at their desks until their papers have been collected by an invigilator.
(3) All inquiries and requests must be addressed to supervisors only.
(4) **Candidates are strictly cautioned against:**
(a) speaking to other candidates or communicating with them under any circumstances whatsoever;
(b) bringing into the examination room any textbook, notebook or memoranda not authorized by the examiner;
(c) making use of calculators and/or portable computing machines not authorized by the instructor;
(d) leaving answer papers exposed to view;
(e) attempting to read other student's examination papers.
The penalty for violation of these rules is suspension or expulsion or such other penalty as may be determined.
(5) Candidates are requested to write on both sides of the page, unless the examiner has asked that the left hand page be reserved for rough drafts or calculations.
(6) Discarded matter is to be struck out and not removed by mutilation of the examination answer book.
(7) Candidates are cautioned against writing in their answer book any matter extraneous to the actual answering of the question set.
(8) The candidate is to write his/her name on each answer book as directed and is to number each book.
(9) A candidate must report to a supervisor before leaving the examination room.
(10) Answer books must be handed to the supervisor-in-charge promptly when the signal is given. Failure to comply with this regulation will be cause for rejection of an answer paper.
(11) If during the course of an examination a student becomes ill or receives word of domestic affliction, the student should report at once to the supervisor, hand in the unfinished paper and request that it be cancelled. If physical and/or emotional ill health is the cause, the student must report at once to a physician/Counsellor so that subsequent application for a deferred examination is supported by a completed Physician/Counsellor Statement form. Students can consult professionals at University Health Services or University Counselling Services during normal working hours or consult their physician/Counsellor in the community.
Should a student write an examination, hand in the paper for marking, and later report extenuating circumstances to support a request for cancellation of the paper and for another examination, such a request will be denied.

RO 93-02

Question No.	Maximum Mark	Mark Obtained
I	18	17.5
II	15	14
III	18	18
IV	18	18
V	14	13.5
VI	17	16.5
Total (out of 100)		97.5

QUESTION I ***(18 marks)***

Isoamyl acetate (IAA) is a chemical that is used in the food industry to provide the scent of bananas, and is called banana oil. IAA has M=130.19 kg/kmol and T_c = 586.1 K. When IAA is mixed with ethanol, the resulting mixture smells like pears, and is called pear oil. Ethanol has M=46.07 kg/kmol and T_c = 514 K. You carry out some experiments on a mixture of IAA and ethanol, and obtain the liquid-vapour phase diagram to the right at a constant pressure of 1 atm.



1.5 **(a)** On the diagram, label all the regions and curves

0.5 **(b)** What is the normal boiling point (in °C) of pure IAA?

141°C

(c) You are in a region of the graph that contains 40 mol% ethanol at 90°C. Calculate the degrees of freedom remaining in this region.

1 F = C−P+2 = 2−2+2 = 2 → BUT constant pressure 2−1 = 1 ✓

(d) You mix together 52.08 kg of IAA with 27.64 kg of ethanol in a sealed container at a temperature of 45°C. The vessel is then heated to a final equilibrium temperature of 90°C and pressure of 101.325 kPa.

(i) Determine the amount (in mol) of each phase present under these conditions.

4 $52.08\text{ kg} \times \frac{\text{kmol}}{130.19\text{ kg}} = .400\text{ kmol IAA}$

$27.64\text{ kg} \times \frac{\text{kmol}}{46.07\text{ kg}} = 0.600\text{ kmol ethanol}$

Total # mole: 1.00 kmol

L ——+——+—— V
0.25 0.6 0.7

$L = \frac{0.7-0.6}{(0.7-0.25)} = (0.2222\ldots)(1\text{ kmol})$

0.222 kmol of liquid ✓

Use the other side of this page if you run out of space.

1 − 0.222 kmol = 0.7777

0.778 kmol of vapor ✓

QUESTION I ***(Contd.)***

3 **(ii)** Determine the mass (in kg) of IAA in each phase present under these conditions.

Liquid = 0.222 kmol

~~(0.25 mol fraction ethanol)(0.222 kmol) = 0.0555 kmol ethanol~~

(0.75 mol fraction IAA)(0.222 kmol) = 0.1665 kmol

0.1665 kmol × $\frac{130.19 \text{ kg}}{\text{kmol}}$ = 21.6766... kg of liquid is IAA

Vapour: (0.778 kmol × 0.3 mol fraction IAA) = 0.2334 kmol

0.2334 kmol × $\frac{130.19 \text{ kg}}{\text{kmol}}$ = 30.386 kg of vapour is IAA

(e) How many moles of ethanol need to be added to the mixture in part (d) to reach the azeotrope composition?

2

$$0.2 = \frac{0.400 \text{ kmol}}{1.0 \text{ kmol} + x}$$

$$0.2 + 0.2x = 0.4 \text{ kmol}$$

$x = 1$

∴ 1 kmol of ethanol needs to be added

(f) The mixture in (d) is isobarically heated in a variable volume container to a temperature of 609.3 K 336.15°C

(i) Determine the partial pressure (in kPa) of IAA under these conditions

1

(101.325 kPa)(0.4 mole fraction IAA)

= 40.53 kPa

QUESTION I ***(Contd.)***

(ii) Determine the volume (in m^3) of the mixture under these conditions.

1 $\frac{PV}{P} = \frac{nRT}{P} = \frac{(1\,kmol)\left(8.314\,\frac{kPa\cdot m^3}{K\cdot kmol}\right)(609.3K)}{101.325\,kPa}$

$= 49.995\,m^3$

(iii) Determine the rate of collisions per unit area *(Note: use M_{avg} if the molar mass is required)*.

4 $= \rho_N \frac{\bar{c}}{4}$ $M_{avg} = \left(0.4 \times 130.19\,\frac{kg}{kmol}\right) + \left(0.6 \times 46.07\,\frac{kg}{kmol}\right)$

$= 79.718\,kg/kmol$

$\bar{c} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{(8)\left(8.314\,\frac{kPa\cdot m^3}{kmol\,K}\right)(609.3K)}{\pi(0.079718)}} = 402.265\,m/s$

$\rho_N = \frac{P}{kT} = \frac{101325\,Pa}{(1.3805\times10^{-23}\,J/K)(609.3K)}$

$\rho_N = 1.2046\times10^{25}$ molecules

$= \left(1.2046\times10^{25}\text{ molesules}\right)\left(\frac{402.265\,m/s}{4}\right)$

$= 1.21143\times10^{27}$ collisions/m

14/15

QUESTION II ***(15 marks)***

PART A: At 20°C, calcium (M = 40.08 kg/kmol) is known to exist in an FCC structure for which the closest interatomic distance is 3.94 Å.

$\sigma = 3.94$ Å

(a) Calculate the density (in kg/m^3) of a crystal of calcium.

2

$$\frac{40.08\,g}{mol} \times \frac{1\,mol}{6.02 \times 10^{23}\,molecules} \times \frac{1\,kg}{1000\,g} = 6.657807... \times 10^{-26}\,kg$$

$$\frac{(\sqrt{2})(6.657807 \times 10^{-26}\,kg)}{(3.94 \times 10^{-10}\,m)^3} = 1538.9\,\frac{kg}{m^3}$$

✓

(b) If a crystal of calcium occupies a volume of 1.0 cm^3, estimate the number of calcium atoms in that crystal.

3

$$1.0\,cm^3 \times \frac{1\,m}{100\,cm} \quad \frac{1539.4\,kg}{m^3} \times \frac{1 \times 10^{-6}\,m^3}{} = 1.5394 \times 10^{-3}\,kg$$

$$1\,molecule = 6.657807 \times 10^{-26}\,\frac{kg}{molecule}$$

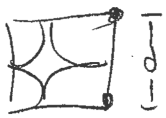
$$\frac{1.5394 \times 10^{-3}\,kg}{6.657807 \times 10^{-26}\,\frac{kg}{mole}} = 2.31217 \times 10^{22}\ atoms$$

✓

QUESTION II ***(Contd.)***

PART B: Core samples taken from an oil reservoir are porous in nature and contain void spaces. To simulate a porous core in the laboratory, spherical glass beads with a diameter of 0.5 mm are packed into a container that has the dimensions 45 cm by 45 cm by 10 cm. The beads pack in a simple cubic structure.

3 **(c)** Determine the number of beads that can fit in the container. d = 0.5 mm ⇒ 5×10^{-4} m



1 unit cell

Volume of unit cell = $(5\times10^{-4}\text{ m})^3 = 1.25\times10^{-10}\text{ m}^3$

a = d

↳ 1 unit cell holds 1 atom/molecule.

(0.45 m) × (0.45 m) × (0.10 m)

$= \frac{0.02025\text{ m}^3}{1.25\times10^{-10}\text{ m}^3}$ ⇒ 162 000 000 beads

3 **(d)** Calculate the ~~total mass~~ (in kg) of the glass bead pack in the container if the density of each glass bead is 2650 kg/m^3.

$\frac{m}{d^3}$ = density

$\frac{m}{(5\times10^{-4})^3} = 2650\text{ kg/m}^3$

beads not unit cell (-1)

$m = \left(3.3125\times10^{-7}\frac{\text{kg}}{\text{molecule}}\right)$(162 000 000 beads)

= 53.6625 kg

QUESTION II *(Contd.)*

2 **(e)** Determine the void fraction of the glass bead pack.

$$V = \frac{1.25\times10^{-10}\,m^3 - \left(\frac{4}{3}\pi(2.5\times10^{-4}\,m)^3\right)}{1.25\times10^{-10}\,m^3}$$

$= 0.4764$

(f) Oil with a density of 800 kg/m³ is injected into the container until the void space between the packed beads is totally filled. Calculate the mass of oil (in kg) that can fit in the container.

2 $(0.4764)(1.25\times10^{-10}\,m^3)(800\,\frac{kg}{m^3}) = 4.76401\times10^{-8}$ kg per unit cell

There 162 000 000 "unit cells"

$(162\,000\,000)(4.76401\times10^{-8}\,kg)$

$= 7.71769$ kg of oil can fit

QUESTION III *(18 marks)*

Molecules of octane (C_8H_{18}) and nonane (C_9H_{20}) are similar in size and shape. These two substances are completely miscible.

Parameter	Octane	Nonane
Molar Mass	114.23 kg/kmol	128.26 kg/kmol
C_{P_L}	262.2 J/mol·K	322.2 J/mol·K
Normal Boiling Point	398.82 K	
Vapour Pressure at 415 K	155.79 kPa	76.235 kPa
ΔH_V	39,400 J/mol	46,500 J/mol

3 **(a)** Develop a correlation for nonane in the form $\ln(P_V) = - A/T + B$ where A and B are constants.

$$\Delta H_v = \frac{46500\ J}{mol} \times \frac{1000\ mol}{1\ kmol} \times \frac{1\ kJ}{1000\ J} = 46500\ kJ/kmol$$

$$-A = -\frac{\Delta H_v}{R} = \frac{46500\ kJ/kmol}{\left(8.314\ \frac{kPa \cdot m^3}{kmol\ K}\right)} = 5592.9$$

$$\ln(P_v) = -\frac{5592.9}{T} + C$$

$$\ln(76.235\ kPa) = -\frac{5592.9}{415\ K} + C$$

$$C = 17.8106\ldots$$

$$\ln(P_v) = \frac{-5592.9}{T} + 17.81$$

Where P_v is in KPa and T is in kelvin.

QUESTION III ***(Contd.)***

(b) Determine the normal boiling point (in K) of nonane.

2 $\ln(101.325\text{ kPa}) = \frac{-5592.9}{T} + 17.61$

$T = 423.9\ K$

(c) 20 mol of nonane is mixed with 80 mol of octane in a rigid, sealed vessel, and the mixture is allowed to come to equilibrium at a final temperature of 415 K and pressure of 135.9 kPa. Under these equilibrium conditions, a vapour and liquid co-exist within the vessel.

(i) Determine the composition (mol fraction) of the liquid phase at equilibrium.

2.5 Total pressure = 135.9 kPa

$135.9\text{ kPa} = (x \times 155.79\text{ kPa}) + (1-x)(76.235\text{ kPa})$

$135.9\text{ kPa} = 155.79x + 76.235\text{ kPa} - 76.235x$

$59.665 = 79.555x$

$x = .75$

0.75 mol fraction octane

0.25 mol fraction nonane

(ii) Determine the composition (in mol fraction) of the vapour phase at equilibrium

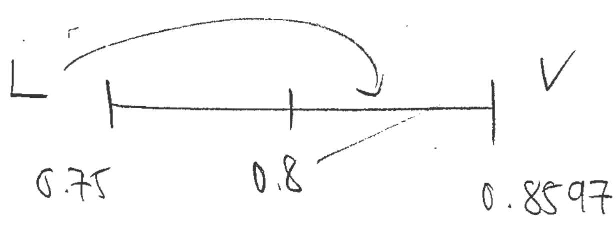
1.5 $y_i = \frac{P_{v_i} x_i}{P}$

$\frac{(155.79\text{ kPa})(0.75)}{135.9\text{ kPa}} = 0.8597$ mol fraction octane

0.1402 mole fraction nonane

(iii) Determine the amount (in mol) of liquid in the vessel at equilibrium.

3



$\frac{0.8597 - 0.8}{(0.8597 - 0.75)} = (0.544211\ldots)(100\text{ mol})$

$= 54.42$ mol of liquid

QUESTION III *(Contd.)*

$\Delta E_{gained} = -\Delta E_{lost}$

(d) If 10 mol of liquid octane at 20°C is mixed with 10 mol of liquid nonane at 40°C, determine the final equilibrium temperature of the mixture (in °C).

3

$-[(10 mol)(262.2 J/mol)(T_2 - 20°C)] = (10 mol)(322.2 J/mol K)(T_2 - 40°C)$

$-(2622 T_2 - 52440) = 3222 T_2 - 128880$

$52440 - 2622 T_2 = 3222 T_2 - 128880$

$T_2 = 31.019 °C$

∴ the final equilibrium temperature is $31.019°C$

(e) You have a new vessel that can be heated at a constant rate of 20 kW. You place 2 kmol of pure liquid octane into this vessel at a starting temperature of 20°C. What is the minimum time required (in min) to completely vaporize the octane?

3

Assume normal boiling point

$20000 \frac{J}{s}$ 2 kmol C_8H_{16} 293.15 K

$(2000 mol)(262.2 J/mol K)(398.82 K - 293.15 K) + (2000 mol)(39400 J/mol)$

$= 55413348 + 78800000 J$

$= 134213348 J / 20000 J/s$

$= 6710.6674 s$

111.8 minutes

$V_m = \frac{kmol}{m^3}$

$PV = nRT$

$V_m = \frac{V}{n}$

QUESTION IV *(18 marks)*

18/20

Three pure gases are combined in a laboratory to test the effectiveness of this mixture as a miscible solvent for an enhanced oil recovery project. Because of the hazardous properties of one of the components (H_2S), the gas mixture is prepared in a fixed volume cell, and then transferred to a variable volume cell from which it is injected into an apparatus that contains a reservoir core. Properties of the three gases are provided in the following table.

Compound	M (kg/kmol)	T_c (K)	P_c (kPa)	a (kPa(m³/kmol)²)	b (m³/kmol)
Methane	16	190.6	4600	228.0	0.0428
Carbon Dioxide	44	304.2	7376	364.8	0.0428
Hydrogen Sulfide	34	373.2	8940	454.	

(a) The gas mixture is prepared by weighing the fixed volume cell (volume of 5 litres) as the individual components are injected. The masses of the components are 26 grams of CH_4, 23 grams of CO_2 and 16 grams of H_2S. The cell is then maintained at an equilibrium temperature of 20°C.

(i) Determine the composition of the gas mixture in mole percent.

3

$26g\ CH_4 \times \frac{mol}{16.0g} = 1.625 mol \rightarrow 62.0$ mole percent CH_4

$23g\ CO_2 \times \frac{mol}{44g} = 0.5227 mol \rightarrow 20.0$ mole percent CO_2

$V = \frac{V}{n}$

$16g \times \frac{mol}{34g} = 0.4705 mol \rightarrow 18.0$ mole percent H_2S

$2.6182 mol$

(ii) Calculate the average molecular mass (in kg/kmol) of the gas mixture.

1

$(0.62 \times 16 g/mol) + (0.20 \times 44 g/mol) + (0.18 \times 34 g/mol)$

$= 24.84 kg/kmol$

QUESTION IV *(Contd.)*

4 **(iii)** Determine the van der Waals constants $\bar{a}$ $\left(\text{in kPa}\cdot\left(\frac{m^3}{kmol}\right)^2\right)$ and $\bar{b}$ $\left(\text{in } \frac{m^3}{kmol}\right)$ for the mixture.

a for H_2S = $\bar{a} = \frac{27}{64}\frac{R^2 T_c^2}{P_c} = \frac{\left(8.314 \frac{kPa\ m^3}{kmol\ K}\right)^2 (373.2\ K)^2}{8940\ kPa}\left(\frac{27}{64}\right) = 454.307$ kPa(m³/kmol)²

b for H_2S = 0.0433 m³/kmol

$\bar{a} = \left[(0.62 \times \sqrt{228.01 \text{ kPa m}^3\text{kmol}}) + (0.2 \times \sqrt{364.8 \text{ kPa}(m^3/kmol)^2}) + (0.18 \times \sqrt{454.307 \text{ kPa}(m^3/kmol)^2})\right]^2$

$\bar{a} = 289.624 \text{ kPa} \left(\frac{m^3}{kmol}\right)^2$

$\bar{b} = (0.62 \times 0.0428) + (0.20 \times 0.0428) + (0.18 \times 0.0433)$

$\bar{b} = 0.04289$ m³/kmol

4 **(iv)** The fixed volume cell containing the gas mixture is placed in a constant temperature oven and heated until the pressure within the cell reaches 2000 kPa. Estimate the temperature (in °C) in the cell at this high pressure.

$V = 5\,L \times \frac{1\,m^3}{1000\,L} = 5\times10^{-3}\ m^3$

2.6182×10^{-3} kmol

$V_m = 1.909 \frac{m^3}{kmol}$

~~T = 482.9609 K~~

~~T = 756.11°C~~

Use $\frac{\left(P + \frac{a}{V_m^2}\right)(V_m - b)}{R} = \frac{RT}{R}$

$T = \left(2000\ kPa + \frac{289.624\ kPa\left(\frac{m^3}{kmol}\right)^2}{1.909\ m^3/kmol}\right)\left(1.909\ m^3/kmol - 0.04289 \frac{m^3}{kmol}\right)$

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÷ 2111 kPa·m³

QUESTION IV ***(Contd.)***

(b) 30 grams of gas mixture from the fixed volume cell is transferred to a variable volume cell. The temperature of this cell is set at 105°C and the volume of the gas mixture is reduced until the pressure reaches 10,500 kPa. Using the pseudocritical method (Kay's rule) with the generalized compressibility chart, estimate the volume (in litres) occupied by the gas mixture.

6

$30g \times \frac{mol}{24.84 g} = 1.208$ mol

$T_{PC} = (0.62 \times 190.6 K) + (0.20 \times 304.2 K) + (0.18 \times 373.2 K)$

$= 246.188 K$

$P_{PC} = (0.62 \times 4600 kPa) + (0.20 \times 7376 kPa) + (0.18 \times 8940 kPa)$

$= 5936.4 kPa$

$T_{RC} = \frac{378.15 K}{246.188 K} = 1.536$

$P_{RC} = \frac{10500 kPa}{5936.4 kPa} = 1.768$

$z = 0.88$

$PV = znRT$

$\frac{PV}{P} = \frac{znRT}{P}$

$V = \frac{(0.88)(0.001208 kmol)(8.314)(378.15 K)}{10500 kPa}$

$V = 3.18 \times 10^{-4} m^3$

$1 m^3$

$= 0.3183 L$

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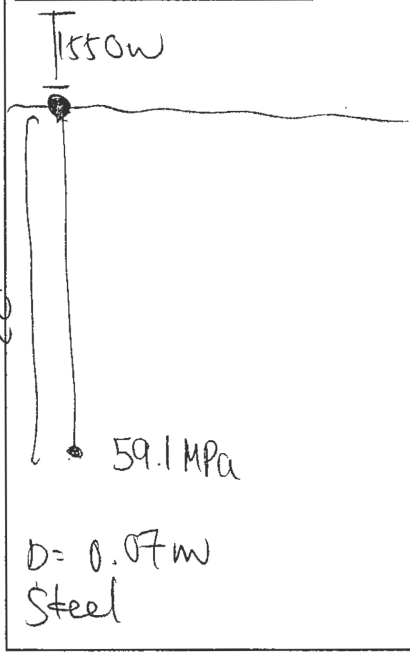
QUESTION V *(14 marks)*

A company discovers an oil reservoir located below the floor of a sea, and drills a pipe from the sea floor (which is located at a water depth of 1550 m) down to the reservoir, which is 4050 m below the sea floor. The absolute pressure in the producing reservoir is 59.1 MPa. The drill pipe, which allows oil to flow from the reservoir up to the level of the sea floor, has an inside diameter of 70 mm, and a roughness corresponding to commercial steel pipe. After drilling, a blowout occurs, and all of the flowing oil accidently escapes from the drill pipe into the sea water.

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



13.5 / 14

You are given the following data:

Density of sea water: 1020 kg/m^3
Atmospheric pressure: 101.325 kPa
Density of oil: 850 kg/m^3
Acceleration due to gravity: 9.81 m/s^2
Viscosity of the oil: 0.16 mPa·s

Use the information provided to answer the questions below (*Note: if you ever need to iterate, start with $f = 0.0047$, and perform a maximum of 2 iterations*).

(a) Determine the pressure (in MPa) of the water at the sea floor.

2

$101325 Pa + (9.81\ m/s^2)(1550 m)(1020\ kg/m^3)$

$= 15.5096 MPa$

(b) The oil pressure at the exit of the drill pipe is 0.49 MPa greater than the water pressure at the sea floor. Calculate the pressure drop (in MPa) in the drill pipe between the reservoir and the exit.

1

$0.49 MPa + 15.50961 MPa = 16. MPa$

$\Delta P =$ Outlet − Inlet

$= 16 MPa - 59.1 MPa$

$= -43 MPa$

QUESTION V *(Contd.)*

(c) Estimate the average velocity (in m/s) of the oil flowing in the drill pipe.

6

$Re = \frac{D\bar{u}\rho}{\mu} \Rightarrow \frac{(0.07m)(u)(850\,kg/m^3)}{(0.16\times10^{-3}\,Pa\cdot s)}$

$Re = 371875\,u$

Assume Turbulent flow!

$-\left[\frac{\Delta P}{L} + \rho g h \frac{\Delta h}{L}\right] = \frac{2f\rho(\bar{u})^2}{D}$ → Assume $\Delta h = \ell$

$-\left[\frac{-43100\,000\,Pa}{4050m} + \frac{(850kg/m^3)(9.81m)(4050m)}{(4050m)}\right] = \frac{2f\bar{u}^2(850\,kg/m^3)}{0.07m}$

$+2303.475 = 24285.71\,fu^2$

$u = \sqrt{\frac{0.09484}{f}}$

f_{guess} 1 = 0.0047

u = 4.49 m/s (See next page)

→ Re = 1670568.943

$f_{guess} \neq f_{result}$!

f_{result} = 0.0040

→ Average velocity = 4.869 m/s

(d) Estimate the daily volumetric flow rate (in m^3/day) of the oil escaping into the sea.

2

$Q = uA$

$A = \pi\left(\frac{0.07}{2}\right)^2 = (1.225\times10^{-3}\,m^2)(4.869\,m/s)$ 0.5

$Q = (5.9845\times10^{-3}\,m^3/s)\left(\frac{3600\,s}{1\,hr}\right)\left(\frac{24\,hr}{day}\right)$

Q = 515.33 m^3/day

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f_{guess} 2 = 0.0040

u = 4.869 m/s

Re = 1810 767

f_{result} = 0.0040

∴ Average velocity is 4.869 m/s ✓

QUESTION V ***(Contd.)***

(e) An experiment was performed using a Fann viscometer in order to determine the viscosity of the oil. The data shown in the table to the right were obtained at 50°C.

Trial	shear rate (s^{-1})	shear stress (Pa)
1	25	50
2	60	100

(i) In 20 words or less, explain why this oil is not a Newtonian fluid.

1

Ratio between shear rate & shear stress are not constant between trials.

(ii) If this oil is a power law fluid, calculate the value of the fluid behavior index (n).

2

$$\ln \tau = \ln K + n \ln\left(\frac{du}{dy}\right)$$

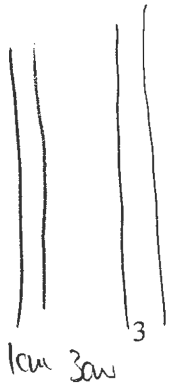
$$\ln(100) = \ln K + n \ln(60)$$

$$-\ \ln(50) = \ln K + n \ln(25)$$

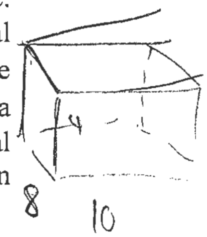
$$0.69314 = 0.87546\, n$$

$$n = 0.7917$$

QUESTION VI *(17 marks)*



A detached garage located in the town of Watson Lake, Yukon, has the dimensions 10 m long, 8 m wide and 4 m tall. The four walls and the flat roof are made of a three layer composite structure. The inner layer is 1 cm thick drywall ($\kappa = 0.18$ W/m·K), the middle layer is 3 cm thick mineral wool (0.03 W/m·K) and the outer layer is 1 cm thick pine plywood ($\kappa = 0.15$ W/m·K). One of the 8 m x 4 m walls contains a maple wood ($\kappa = 0.13$ W/m·K) garage door that is 7 m x 3.5 m with a thickness of 2 cm. The garage must maintain a constant temperature of 20°C using an electrical heater. On a particularly cold day, the air temperature outside is -45°C. Using the information provided, answer the following questions:



(a) Calculate the area (in m^2) of:

(i) The roof

$8m \times 10m = 80 m^2$

(ii) The garage door

$7m \times 3.5m = 24.5 m^2$

(iii) The composite walls

$2(4\times10) + 1(4\times8) + 1((4\times8) - 24.5m^2) = 119.5m^2$

(b) Calculate the rate of heat loss (in kW) through the roof of the garage.

2

$$\frac{-(80m^2)(-45°C - 20°C)}{\frac{0.01m}{0.18 \frac{W}{mK}} + \frac{0.03m}{0.03 \frac{W}{m\cdot K}} + \frac{0.01m}{0.15 \frac{W}{mK}}} = \frac{5200 \, m^2K}{1.1222 \frac{W}{m^2 K}} = 4633.66 \, W$$

$= 4.633$ kW

QUESTION VI *(Contd.)*

(c) Calculate the total rate of heat loss (in kW) through the walls and the garage door.

3

$$\frac{-(24.5 m^2)(-45 C - 20°C)}{\frac{0.02 m}{0.13 \frac{W}{mK}}} + \frac{-(119.5 m^2)(-45 C - 20°C)}{\frac{0.01 m}{8.18 \frac{W}{mK}} + \frac{0.03 m}{0.03 \frac{W}{mK}} + \frac{0.01 m}{0.15 \frac{W}{mK}}}$$

$$\frac{1592.5 m^2 K}{0.153846 \frac{m^2 K}{W}} + \frac{7767.5}{1.12222 \frac{m^2 K}{W}}$$

$$= 10348 W + 6921.534 W$$

$$\boxed{= 17.272 kW}$$

(d) If energy costs $0.04 per kWh, determine how much it will cost to heat the garage on a day where the average outside temperature is -45°C.

2

$$4.633 kW + 17.272 kW$$

$$= 21.905 kW$$

$$(21.905 kW)\left(\frac{0.04}{kWh}\right)\left(\frac{24 hr}{1 day}\right)$$

$$\boxed{= \$21.03}$$

QUESTION VI *(Contd.)*

(e) Snow (κ = 0.3 W/m·K) that settles on the roof of the garage acts as an additional layer of insulation. Determine the depth of snow (in cm) required on the roof to reduce the cost of heating the garage by 5%.

4

($21.03) − (0.05 × 21.03)
= $19.98

Total energy lost = 20.8125 kW
− 17.272 kW
3.5405

$$\frac{-(80m^2)(-45°C - 20°C)}{1.222 \frac{W}{m^2K} + \frac{\Delta X}{0.3}} = 3.5405 kW$$

$$1.222 \frac{W}{m^2K} + \frac{\Delta X}{0.3} = 1.4687$$

ΔX = 0.0740 m

∴ 7cm of snow is needed

(f) In 20 words or less, describe one thing that you could do to significantly reduce the heat loss from the garage.

1

Add pink insulation inbetween the drywood and the wood walls.

$V_m = \frac{m^3}{kmol}$

V_n $\frac{V}{N}$

(g) The air in the garage has a density of 1.205 kg/m³. Assuming that air acts as ideal gas, determine the density of the air outside.

2

$$\rho = \frac{1.205 kg}{m^3} \times \frac{1 kmol}{28.97 kg} =$$

$V_m = 24.041 \frac{km^3}{kmol}$

$PV_m = RT$

P

Set a ratio.

$$\frac{V_m = \frac{RT}{P}}{V_m = \frac{RT}{P}} \Rightarrow \frac{24.041 \frac{m^3}{kmol}}{V_m} = \frac{293.15 K}{228.15 K}$$

$V_m = 18.7104 \, m^3/kmol \times \frac{1 kmol}{28.97 kg} \rightarrow \rho = 1.548 kg/m^3$