RYERSON UNIVERSITY

Department of Mechanical and Industrial Engineering

FLUID MECHANICS I – BME516/MEC516

MIDTERM EXAM

DATE: Thursday, October 17, 2019 EXAMINER: Dr. D. Naylor

TIME: 12:10 - 1:55pm DURATION: 105 minutes

INSTRUCTIONS:

1. This is a CLOSED BOOK EXAM. Permitted aids are: one 8.5 inch × 11 inch personal equation (aid) sheet, both sides; non-communicating electronic calculator; and drawing and writing instruments (i.e., ruler, pens and pencils).
2. A table of centroids and second moments of area is included with this exam paper. A basic formula sheet is also included with this exam paper.
3. Prohibited items include: textbooks, class notes, cell-phones and other wireless devices, laptop computers, etc. **Possession of a communication device will trigger charges of academic misconduct.**
4. A valid student identification card must be presented when attendance is taken.
5. Answer all questions. Marks are indicated beside each question and in the table below.
6. To get full marks you must clearly show the formulas, methods and numbers used to solve the problem.
7. **You must use the symbols given in the problem statement.** Also, be sure to give the proper units on all intermediate results.
8. Marks will be deducted for incorrect or missing units.

Student Name (Please Print): ____________________

Student Number: ________________________ Section Number: ____________

Please Check One: ☐ Online Course

☐ Face-to-Face Lecture Course

Question	Mark
A1-A5	/10
B1	/10
B2	/10
B3	/10
Total	/40

PART A - MULTIPLE CHOICE QUESTIONS

Each of the questions below is followed by several suggested answers. ***On the exam paper, circle the ONE that is best.*** There is no penalty for incorrect answers.

Questions *A1* to *A5* are worth 2 ***marks*** each.

A1. Using the nomenclature of Chapter 1, what are the ***dimensions*** of viscous shear stress (τ)?

(a) $\{M^{-1}L^{-1}T^{-2}\}$
(b) $\{ML^{-1}T^{2}\}$
(c) $\{MLT^{-2}\}$
(d) $\{ML^{-1}T^{-2}\}$

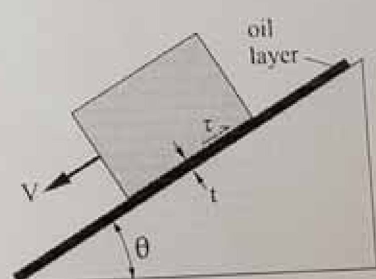
$$\tau \equiv \frac{N}{m^2} = \frac{kg\,\cancel{m}}{s^2\,m^{\cancel{2}}} = \frac{kg}{s^2\,m} \quad \{ML^{-1}T^{-2}\}$$

A2. The **absolute** pressure in a tank is 50.0 kPa. Standard atmospheric pressure at sea level is 101.3 kPa. The local atmospheric pressure where the tank is located is 98.5 kPa. What would a Bourdon gauge read that is attached to this tank?

(a) -48.5 kPa
(b) -51.3 kPa
(c) 50.0 kPa
(d) 148.5 kPa

$$P_{gauge} = P_{abs} - P_{local\ atm} = 50 - 98.5 = -48.5\ kPa$$

A3. A block slides down an inclined plane on a layer of oil with thickness t=0.20 mm. The block has a speed of V=0.35 m/s. The oil has a kinematic viscosity of $\nu=3.4\times10^{-4}$ m^2/s and a specific gravity of SG=0.85. Calculate the fluid shear stress (τ) on the block.



(a) 0.60 N/m^2
(b) 51 N/m^2
(c) 506 N/m^2
(d) 594 N/m^2

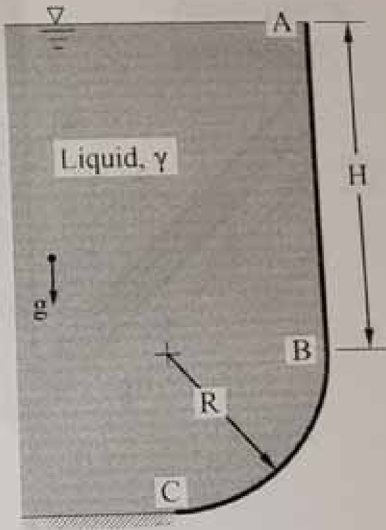
$$\mu = \nu\rho = 3.4\times10^{-4}\frac{m^2}{s}\left(850\frac{kg}{m^3}\right) = 0.289\frac{kg}{m\,s}$$

$$\tau = \mu\frac{V}{t} = 0.289\frac{kg}{m\,s}\ \frac{0.35\,m/s}{0.0002\,m} = 506\frac{kg}{m\,s^2} = 506\ N/m^2$$

A4. Referring to the diagram, a liquid with specific weight (γ) is contained by a wall that consists of a straight vertical section (A-B) of height H and a curved section (B-C) with radius R. What is the total **horizontal** force of the liquid on the wall A-B-C per unit depth (into the page)?

(a) $F_H = \gamma[HR + \pi R^2/4]$
(b) $F_H = \gamma[\pi R^2/4]$
(c) $F_H = \gamma[H + R]^2/2$
(d) $F_H = \gamma R[H + R/2]$

$$F_H = \gamma h_{CG} A$$
$$= \gamma\left(\frac{H+R}{2}\right)(H+R)$$
$$= \gamma(H+R)^2/2$$



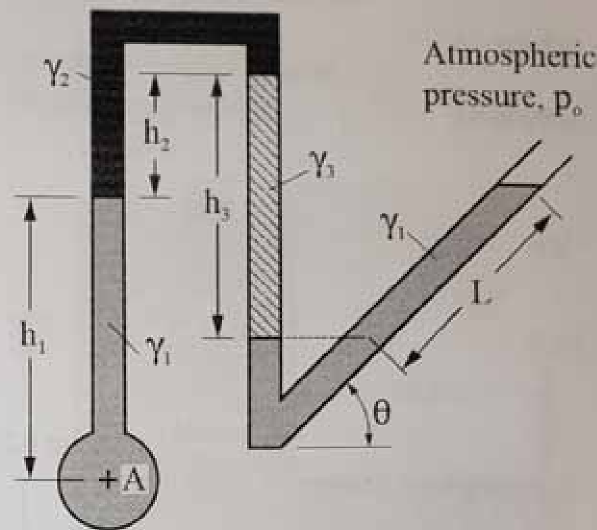
A5. Referring to the diagram, a liquid with specific weight (γ) is contained by a wall that consists of a straight vertical section (A-B) of height H and a curved section (B-C) with radius R. What is the total **vertical** force of the liquid on the wall ABC per unit depth (into the page)?

(a) $F_v = \gamma[HR + \pi R^2/4]$
(b) $F_v = \gamma[\pi R^2/4]$
(c) $F_v = \gamma[H + R]^2/2$
(d) $F_v = \gamma[HR + \pi R^2/2]$

$$F_v = W = \gamma \forall = \gamma\left[HR + \frac{\pi R^2}{4}\right]$$

B1. (a) An open-ended manometer is shown in the sketch. The open end is exposed to local atmospheric pressure, p_o. Obtain an expression for the ***absolute*** pressure at point A (p_A) in terms of the manometer heights (h_1, h_2, h_3), the length and angle of the inclined section (L, θ), and the specific weights of the three fluids ($\gamma_1, \gamma_2, \gamma_3$).

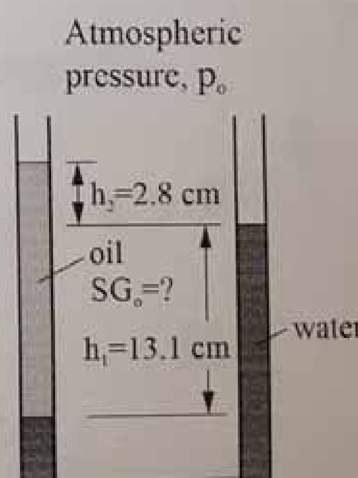
(7 marks)



$$p_A = p_0 + \gamma_1 L \sin\theta - \gamma_3 h_3 + \gamma_2 h_2 + \gamma_1 h_1 \; /$$

(b) A U-tube manometer contains water and oil, as shown below. Both ends are open to the atmosphere. Estimate the specific gravity of the oil (SG_o).

(3 marks)



$$\gamma_\omega h_1 = \gamma_o (h_1 + h_2)$$

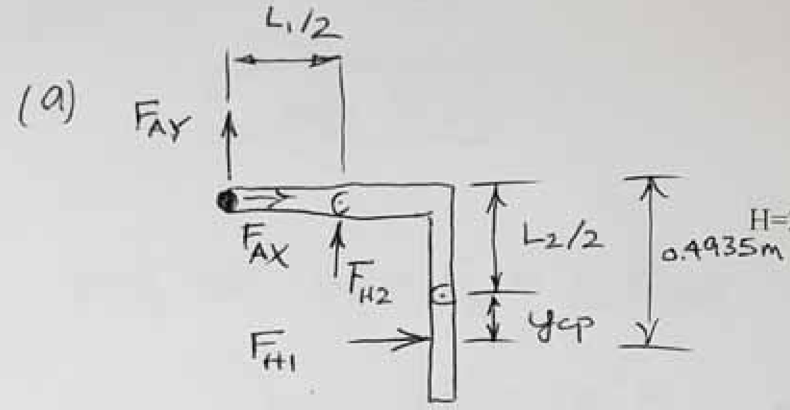
$$SG_o = \frac{\gamma_o}{\gamma_w} = \frac{h_1}{h_1 + h_2} = \frac{13.1}{15.9} = 0.824 \; /$$

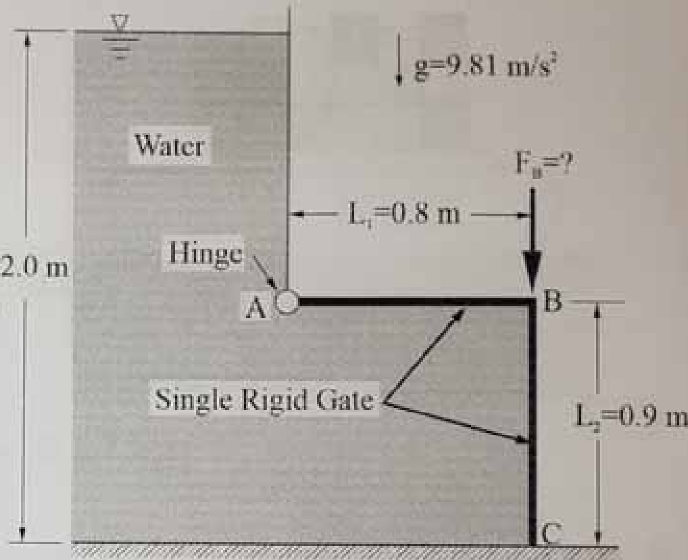
B2. Water (ρ=998 kg/m^3) is contained behind a rigid L-shaped gate (A-B-C) as shown in the sketch. The gate has a depth of 0.5 m (into the page). Note that the entire gate (A-B-C) is rigid and rotates about a hinge at point A. The weight of the gate can be neglected.

(a) Draw a separate and fully labelled free body diagram of the gate. Show the locations and directions of all the forces. *(2 marks)*

(b) For the dimensions shown on the sketch, calculate the minimum vertical force (F_B) applied at point B required to keep the gate from opening. *(8 marks)*

(a)





(b) $F_{H1} = \gamma_W h_{CG} A = 9790 \, \frac{N}{m^3} (2.0-0.45)m \, (0.9 \cdot 0.5)m^2 = 6828 \, N \rightarrow$

$$y_{cp} = -\frac{I_{xx} \sin\theta}{h_{CG} A} = \frac{0.5m\,(0.9)^3 m^3}{12\,(1.55m)\,0.45m^2} = -0.04355 \, m$$

$F_{H2} = \gamma_W h A = (9790 \, \frac{N}{m^3}) \, 1.1m \, (0.8 \cdot 0.5)m^2 = 4308 N \uparrow$

$$\Sigma M_A = 0 \qquad F_B L_1 = F_{H1}\left(\frac{L_2}{2} - y_{cp}\right) + F_{H2} \frac{L_1}{2}$$

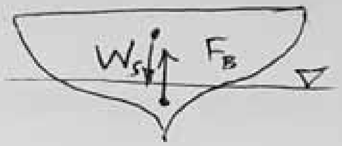
$$F_B = \frac{6828 \, N \, (0.4935m) + 4308 N \, (0.4m)}{0.8m} = 6366 \, N \downarrow$$ Ans.

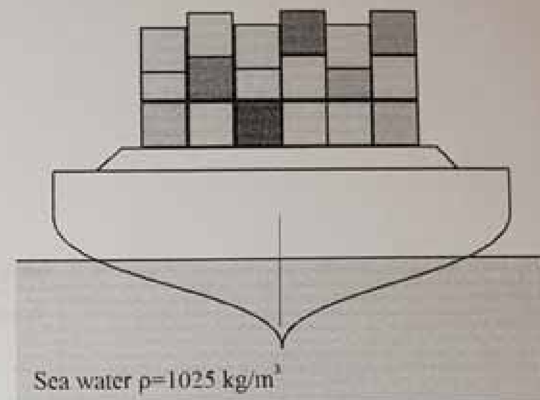
B3. The hull of a ship has a total internal volume of 24,300 m^3. Without cargo, the ship weighs 26,500 kN. The ship floats in sea water with a density of ρ=1025 kg/m^3.

(a) Draw a separate free body diagram for the ship without cargo. What faction of the hull's volume will be **above** the waterline when the ship has no cargo? ***(4 marks)***

(b) When loaded, one half of the ship's hull volume is below the waterline. Draw a separate free body diagram for the ship with cargo. Calculate the mass of cargo in metric tonnes. Note: 1 tonne=1000 kg ***(6 marks)***

(a)





$$\Sigma F_z = 0 \quad W_s = F_B = \gamma_w \forall_{DISP}$$

$$\forall_{DISP} = \frac{W}{\gamma_w} = \frac{26500 \times 10^3 \, N}{1025 \, kg/m^3 \, (9.81 \, m/s^2)} = 2635 \, m^3$$

$$\text{\% HULL VOL. ABOVE WATERLINE} = \frac{24,300 - 2635}{24,300} = 0.891 \times 100\%$$

(89.1%)

ANS/

(b)

$$W_c + W_s = F_B$$

$$W_c = F_B - W_s = \gamma_w \forall_{DISP} - W_s$$

$$= 10,055 \, N/m^3 \left(\frac{24300}{2} m^3\right) - 26500 \times 10^3 \, N$$

$$= 9.567 \times 10^7 \, N$$

$$m_c = \frac{W}{g} = \frac{9.567 \times 10^7 \, N}{9.81 \, m/s^2} \frac{1 \, tonne}{1000 \, kg} = 9750 \text{ tonnes}$$

ANS/

FORMULA SHEET

Ideal gas equation of state: $p = \rho R T$

Relationship between kinematic (ν) and dynamic viscosity (μ): $\nu = \frac{\mu}{\rho}$

Hydrostatic Pressure: $\frac{dp}{dz} = -\gamma = -\rho g$

Fluid (viscous) shear stress: $\tau = \frac{F}{A} = \mu \frac{du}{dy}$

Hydrostatic forces on plane surfaces:

$$F = \gamma\, h_{CG} A \qquad y_{CP} = -\frac{I_{xx} \sin\theta}{h_{CG}\, A}$$

Buoyancy force: $F_B = \gamma \forall_{displaced}$

Reynolds number: $Re = \frac{\rho\, V\, D}{\mu}$

Volume of a Sphere: $\forall_{sphere} = \frac{4}{3}\pi r^3$ Area of a Sphere: $A_{sphere} = 4\pi r^2$

Standard Atmospheric Pressure: p_{atm}=101.3 kPa

Gravitational acceleration: g=9.81 m/s^2