F2017

RYERSON UNIVERSITY

Department of Mechanical and Industrial Engineering

FLUID MECHANICS – BME516 / MEC516

MIDTERM EXAM

TIME: 12:10-2:00pm, October 12, 2017

EXAMINER: Dr. D. Naylor

Duration: 1 hour & 50 minutes

INSTRUCTIONS:

1. This is a CLOSED BOOK TEST – only permitted aids allowed. Permitted aids are: one 8.5 inch × 14 inch (legal size) 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.
3. A basic formula sheet is also included with this exam paper.
4. Prohibited items include: textbooks, class notes, cell-phones (text and/or video display), pagers and other wireless devices, laptop computers, etc. **Possession of a communication device will trigger charges of academic misconduct.**
5. A valid student identification card must be presented when attendance is taken.
6. Answer all questions. Marks are indicated beside each question.
7. To get full marks you must clearly show the formulas, methods and numbers used to solve the problem.
8. **For maximum part marks use the symbols given in the problem statement.** Also, be sure to give the proper units on all intermediate results.
9. Marks will be deducted for incorrect or missing units.

Student Name (Please Print): SOLUTIONS

Student Number: ______________________ Section Number: __________

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

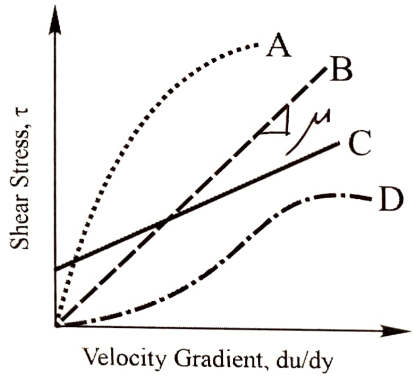
PART A - MULTIPLE CHOICE QUESTIONS

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. The graph below shows the variation of the shear stress (τ) with the fluid velocity gradient (du/dy) for four fluids. Which curve(s) corresponds to a ***Newtonian fluid***?

(a) Curve A
(b) Curve B
(c) Curve C
(d) Curve D
(e) All four fluids are *Newtonian*

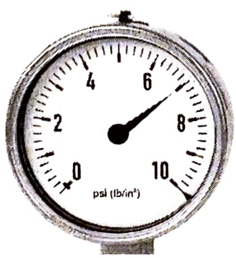


$$\tau = \mu \frac{du}{dy}$$

CONSTANT FOR A NEWTONIAN FLUID

A2. A Bourdon gauge attached to a tank reads 7.0 psi when the local atmospheric pressure is 14.7 psi. If the absolute pressure in the tank remains constant, what will the Bourdon gauge read if the local atmospheric pressure ***decreases*** to 14.4 psi?

(a) 6.3 psi
(b) 6.7 psi
(c) 7.0 psi
(d) 7.3 psi
(e) 21.7 psi



$P_g + P_{atm} = P_{abs.}$

SITUATION 1: $7.0\,psi + 14.7\,psi = 21.7\,psi$

SITUATION 2: $P_g + 14.4\,psi = 21.7\,psi \quad P_g = 7.3\,psi$

A3. Using the nomenclature of Chapter 1, what are the **dimensions** of the term created by dividing pressure (p) by fluid density (ρ)?

$$\left\{\frac{p}{\rho}\right\}$$

(a) ML^2T^{-1}
(b) L^2T^{-2}
(c) ML^2T^{-3}
(d) ML^2T^{-2}
(e) MLT^{-2}

$$\left\{\frac{F}{L^2}\cdot\frac{L^3}{M}\right\} = \left\{\frac{\cancel{M}L}{T^2}\,\frac{L}{\cancel{M}}\right\} = \left\{\frac{L^2}{T^2}\right\}$$

A4. A tank contains carbon dioxide gas (CO_2) at temperature of 50°C. The gauge pressure in the tank is 90 kPa. The absolute pressure in the tank is 190 kPa. The gas constant for carbon dioxide is R_{CO2}=189 J/(kgK). What is density (ρ) of the carbon dioxide gas in the tank?

(a) 0.795 kg/m³
(b) 1.47 kg/m³
(c) 3.11 kg/m³
(d) 9.52 kg/m³
(e) 20.1 kg/m³

$$\rho = \frac{P_{abs}}{RT} = \frac{190\times10^3\ \text{Pa}}{189\,\frac{\text{J}}{\text{kgK}}\,(323\text{K})} = 3.11\ \text{kg/m}^3$$

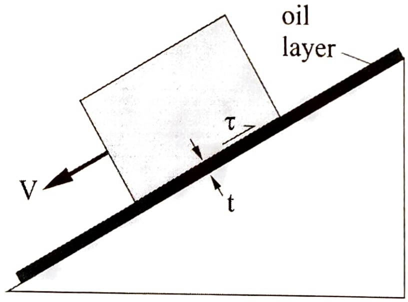
A5. Consider a solid cube of material (with no internal cavities or voids) placed into a container with liquid. Which **one** of the following statements related to buoyancy is ***true***?

(a) The cube will float if the fluid has a lower specific gravity than the cube material.
(b) If the cube sinks, the fully submerged cube displaces its weight in fluid.
(c) If the cube sinks, the fully submerged cube ***does not*** experience an upward buoyancy force.
(d) If the cube floats, the cube displaces its volume in fluid.
(e) If the cube floats, the cube displaces its weight in fluid. (Archimedes' Principle).

BONUS QUESTION (2 marks)

A6. A block slides down an inclined plane on an oil layer at a steady speed of V=0.11 m/s. The dynamic viscosity of the oil is 0.75 kg/(ms) and the oil layer thickness is t=0.25 mm. The fluid shear stress (τ) at the surface of the block is:

(a) 33 Pa
(b) 330 Pa
(c) 0.33 Pa
(d) 33 N
(e) 330 N



$$\tau = \mu \frac{du}{dy} = \mu \frac{U}{t}$$

$$= 0.75 \frac{kg}{\cancel{m} s} \cdot \frac{0.11 \frac{\cancel{m}}{s}}{0.00025 m}$$

$$= 330 \frac{kg}{m s^2} = 330 \text{ Pa}$$

$$\frac{kg}{m s^2} \equiv \frac{N s^2}{m\, m s^2} \equiv \frac{N}{m^2} \equiv Pa$$

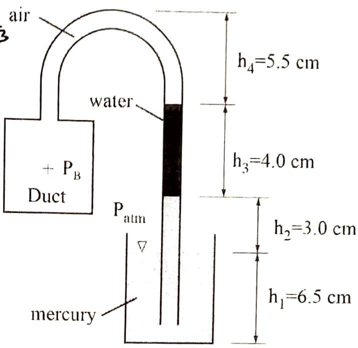
PART B – LONG ANSWER QUESTIONS

B1. Analyze the two simple manometer configurations shown below. **Use the symbols shown in the sketches in your analysis.**

(a) A manometer that contains water and mercury is connected to a duct. The density of mercury is ρ_m=13,550 kg/m^3 and the density of water is ρ_w=998 kg/m^3. Gravitational acceleration is g=9.81 m/s^2. Calculate the **gauge pressure** in the duct, P_B. ***(5 marks)***

$$\gamma_w = \rho_w g = 998 \frac{kg}{m^3}\left(9.81 \frac{m}{s^2}\right) = 9790 \frac{N}{m^3}$$

$$\gamma_m = \rho_m g = 1.329 \times 10^5 \, N/m^3$$



$$P_B + h_3\gamma_w + h_2\gamma_m = P_{atm}$$

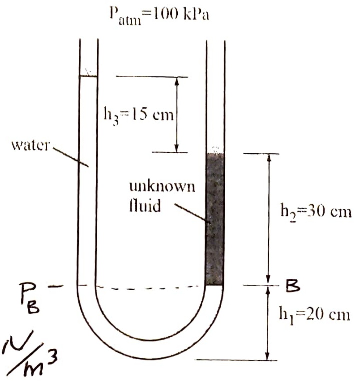
$$\underbrace{P_B - P_{ATM}}_{\text{THIS IS THE GAUGE PRESS. AT B.}} = -h_3\gamma_w - h_2\gamma_m$$

$$P_B - P_{ATM} = -0.040m\left(9790\frac{N}{m^3}\right) - 0.030m\left(1.329\times10^5 \, N/m^3\right)$$

$$= -392 \, Pa - 3988 \, Pa = -4380 \, Pa = -4.38 \, kPa$$

THE NEGATIVE VALUE INDICATES A PARTIAL VACUUM AT POINT B.

(b) A U-tube manometer is open to the atmosphere at both ends. It contains water (γ_w=9790 N/m^3) and an unknown fluid. Calculate the specific weight (γ_f) of the unknown fluid on the right side. ***(5 marks)***



$$P_B = \gamma_w(h_2 + h_3) = \gamma_f h_2$$

$$\gamma_f = \gamma_w \frac{(h_2 + h_3)}{h_2}$$

$$\gamma_f = 9790 \frac{N}{m^3}\left(\frac{0.15 + 0.30}{0.30}\right)$$

$$\gamma_f = 9790 \frac{N}{m^3}(1.5) = 14685 \, N/m^3$$

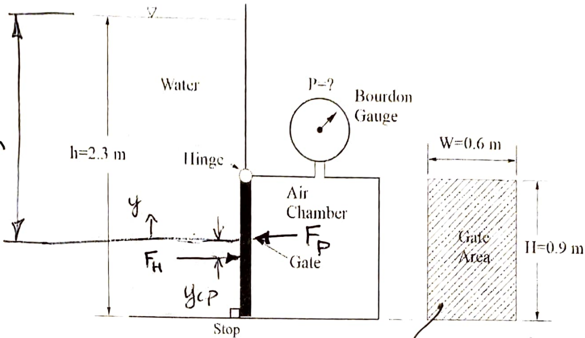
P_B –

B2. As shown in the figure, the height of the water (γ_w = 9790 N/m^3) on the left side of a hinged gate is 2.3m. There is an air chamber on the right side of the gate. The gate is 0.9m high and 0.6m wide (into the page). Determine the minimum air pressure (P) in the chamber required to keep the gate closed. Express your answer in kPa. Draw a fully labelled free body diagram of the gate. ***(10 marks)***

$h_{CG} = h - H/2$

$= 2.3 - 0.45\,m$

$= 1.85\,m$



$A = 0.6(0.9) = 0.54\,m^2$

HYDROSTATIC FORCE

$$F_H = \gamma_w h_{CG} A = 9790\,\frac{N}{m^3}(1.85\,m)(0.54\,m^2)$$

$$= 9780\,N \rightarrow$$

2

LINE OF ACTION OF F_H.

$$I_{xx} = \frac{WH^3}{12} = \frac{(0.6\,m)(0.9\,m)^3}{12} = 0.03645\,m^4$$

1

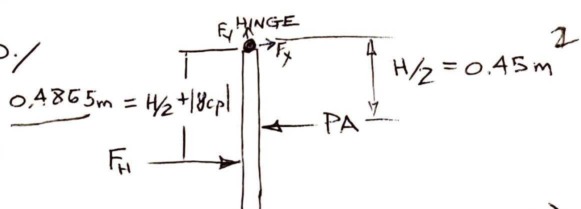
BELOW CENTROID

$$y_{cp} = \frac{-I_{xx}\sin\theta}{h_{CG}A} = \frac{-0.03645\,(1)\,m^4}{1.85\,m\,(0.54\,m^2)} = -0.03649\,m$$

1

PRESSURE FORCE PA ACTS AT GATE CENTROID.
(UNIFORM PRESS. DISTRIBUTION ON AIR SIDE)

1 F.B.D./



$\Sigma M_{HINGE} = 0$ 1

$$F_H(0.4865) = PA(0.45)$$

$$P = \frac{9780\,N(0.4865\,m)}{0.54\,m^2(0.45\,m)} = 19580\,N/m^2$$

$$= 19.6\,kPa$$ 1

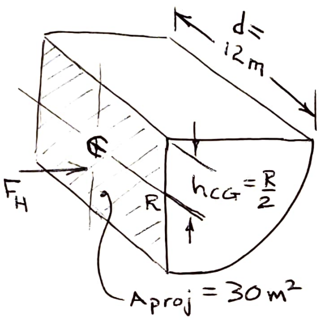
9.8 wrong. -2

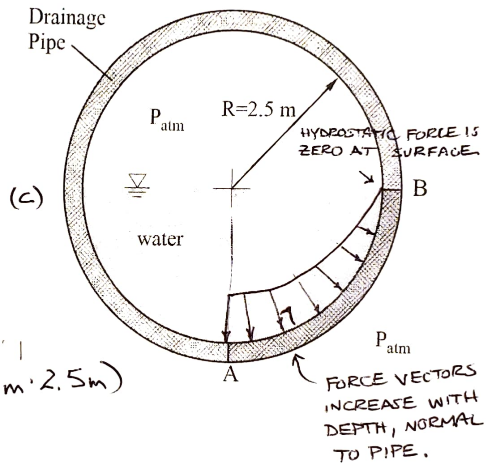
B3. A cylindrical drainage pipe with a radius of 2.5 m is half filled with water ($\gamma_w = 9790$ N/m³). The pipe is 12 meters long (into the page). The pressure inside and outside of the pipe is atmospheric pressure.

(a) Calculate the magnitude *and* line of action of the horizontal hydrostatic force F_H (in kN) on the **quarter section of the pipe A-B**. Clearly indicate the location and direction of F_H in a sketch. ***(5 marks)***

(b) Calculate the magnitude *and* line of action of the vertical hydrostatic force F_V (in kN) on the **quarter section of the pipe A-B**. Clearly indicate the location and direction of F_V in a sketch. ***(3 marks)***

(c) Carefully sketch the **hydrostatic pressure distribution** on curved surface A-B. Use an array of arrows to show both the magnitude and direction of the local hydrostatic pressure on surface A-B. You can draw directly on the diagram or make a separate sketch. ***(2 marks)***





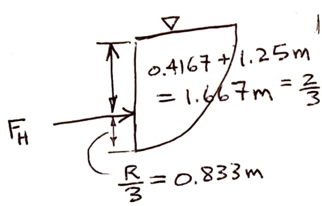
(a) $F_H = \gamma_w h_{CG} A_{proj}$

$$F_H = 9790 \frac{N}{m^3} \left(\frac{2.5m}{2}\right)(12m \cdot 2.5m)$$

$F_H = 367$ kN →

LINE OF ACTION OF F_H $\qquad I_{xx} = \frac{dR^3}{12} = \frac{(12)(2.5)^3}{12} = 15.625\,m^4$

$$y_{cp} = -\frac{I_{xx} \sin\theta}{h_{CG} A} = \frac{-15.625\,m^4 (1)}{(1.25m)\,30\,m^2} = -0.4167\,m$$

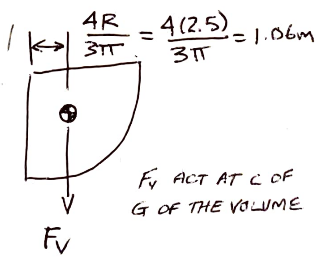


(b) F_V IS THE WEIGHT OF THE LIQUID ABOVE THE PIPE

$$F_V = \gamma V = \left(9790 \frac{N}{m^3}\right)\left(\frac{\pi\, 2.5^2}{4}\right) 12\ m^3$$

$V = 58.90\,m^3 \qquad F_V = 577$ kN ↓

F_V ACTS AT C. OF G. OF THE FLUID VOLUME



FORMULA SHEET

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

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

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

Hydrostatic forces on plane surfaces:

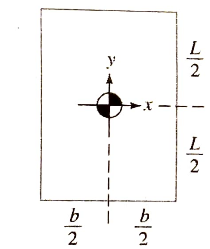
$$F = \gamma\, h_{CG} A \qquad y_{CP} = -\frac{I_{xx}\sin\theta}{h_{CG}\,A} \qquad x_{CP} = -\frac{I_{xy}\sin\theta}{h_{CG}\,A}$$

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

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

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

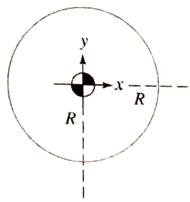
Areas, centroids and second moments of area of common shapes



$A = bL$

$I_{xx} = \frac{bL^3}{12}$

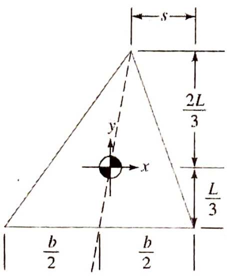
$I_{xy} = 0$



$A = \pi R^2$

$I_{xx} = \frac{\pi R^4}{4}$

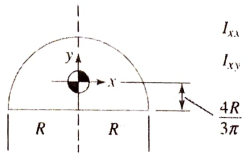
$I_{xy} = 0$



$A = \frac{bL}{2}$

$I_{xx} = \frac{bL^3}{36}$

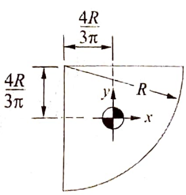
$I_{xy} = \frac{b(b-2s)L^2}{72}$



$A = \frac{\pi R^2}{2}$

$I_{xx} = 0.10976 R^4$

$I_{xy} = 0$



$A = \frac{\pi R^2}{4}$

$I_{xx} = 0.05488\, R^4$