



**STRATHMORE UNIVERSITY**  
**SCHOOL OF COMPUTING AND ENGINEERING SCIENCES**  
**Bachelor of Electrical Engineering**  
**Final Examination**  
**BEE 2111: FLUID MECHANICS**

**DATE: 27<sup>th</sup> July 2022**

**TIME: 3 HOURS**

**INSTRUCTION: ANSWER QUESTION ONE, AND ANY TWO OTHER QUESTIONS.**

**QUESTION ONE, (Properties of Fluids, Hydrostatic Forces, Buoyancy and Floatation) [40 Marks]**

**I. Viscosity**

The experimental set up, shown in Fig. 1. The tube is filled with the sample liquid under investigation. Plastic balls of different diameters are allowed to fall down this tube (one at a time) over a calibrated distance. The falling time and falling distances are recorded. Inner Diameter of tube  $R= 1.44$  cm. Density of fluid  $\rho_1=1.26\text{g/cm}^3$

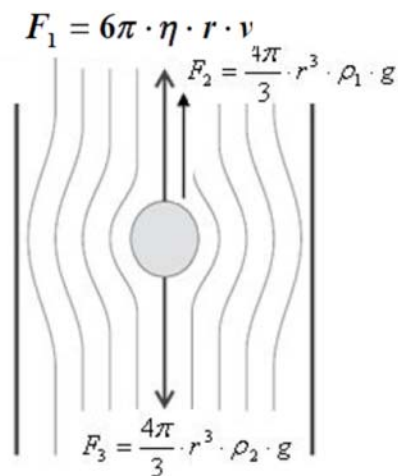


Figure 1

$$\eta = \frac{2}{9} \cdot r^2 \cdot \frac{(\rho_2 - \rho_1) \cdot g}{v}$$

a) Using the data provided plot the graph of terminal velocity. [9 marks]

sphere	diameter(cm)	mass(gm)	density( $\frac{gm}{cm^3}$ )
1	1.252	2.75	2.6767
2	1.336	3.05	2.4427
3	1.306	2.89	2.4779

Table 1

Sphere 1. Diameter 1.252 cm	
Falling Time	Falling Distance
0.3001	1.017
0.6002	4.07
0.9003	7.632
1.2004	10.68
1.5005	12.72
1.8006	16.28
2.1007	18.31
2.4007	21.36
2.7009	24.93
3.001	27.47
3.3011	29.51
3.6012	31.54
3.9013	34.17
4.2014	38.35

Sphere 2. Diameter 1.336	
Falling Time	Falling Distance
0.3001	1.5265
0.6002	4.0706
0.9003	7.6322
1.2004	11.7028
1.5005	14.2468
1.8006	17.2998
2.1007	20.3526
2.4007	22.3870
2.7009	24.93201
3.0010	30.020
3.3011	32.0553
3.6012	35.1085
3.9013	37.6526
4.2014	40.5490

Sphere 3. Diameter 1.306	
Falling Time	Falling Distance
0.30	1.5
0.60	3.6
0.90	6.6
1.20	10.2
1.50	14.3
1.80	18.9
2.10	22.5
2.40	25.6
2.70	28.1
3.00	31.2
3.30	33.7
3.60	36.8
3.90	39.9
4.20	43.4

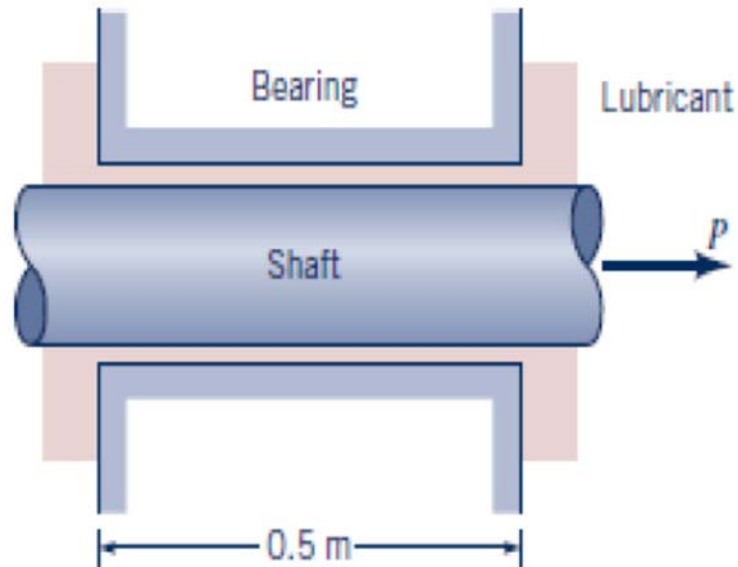
b) Determine the dynamic viscosities of the sample fluid.

[8 marks]

c) Sometimes the balls fall close to the wall. Comment on the effect that this will have on the measurements. [5 Marks]

d). A 25-mm-diameter shaft is pulled through a cylindrical bearing as shown in Fig. The lubricant that fills the 0.3-mm gap between the shaft and bearing is an oil having a kinematic viscosity of  $8.0 \times 10^{-4} \text{ m}^2/\text{s}$  and a

specific gravity of 0.91. Determine the force  $P$  required to pull the shaft at a velocity of 3 m/s. Assume the velocity distribution in the gap is linear. [ 6 Marks]



## II. Hydrostatic Forces

A structure is attached to the ocean floor as shown in Fig.2. 2-m-diameter hatch is located in an inclined wall and hinged on one edge. Determine the minimum air pressure,  $p_1$ , within the container that will open the hatch. Neglect the weight of the hatch and friction in the hinge. [6 marks]

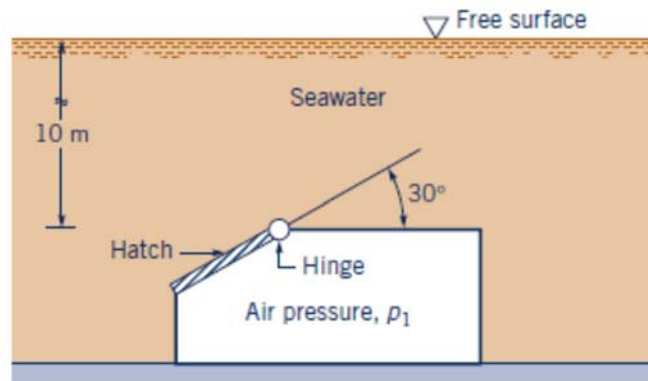


Figure 2

### III. Buoyancy and Floatation

A 1-m-diameter cylindrical mass,  $M$ , is connected to a 2-m wide rectangular gate as shown in Fig.3. The gate is to open when the water level,  $h$ , drops below 2.5 m.

Determine the required value for  $M$ . Neglect friction at the gate hinge and the pulley. **[6 Marks]**

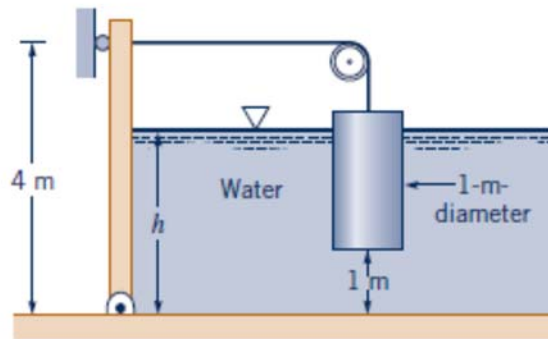


Figure 3

### QUESTION TWO (Fluid Dynamics) [ 30 Marks]

a) Show that.

**[4 marks]**

$$\frac{P_1}{\rho} + \frac{V_1}{2} + gz_1 = \frac{P_2}{\rho} + \frac{V_2}{2} + gz_2$$

b) Kerosene flows through the Venturi meter shown in Fig 4 with flowrates between 0.005 and 0.050  $\text{m}^3/\text{s}$  **[ 4 Marks]**

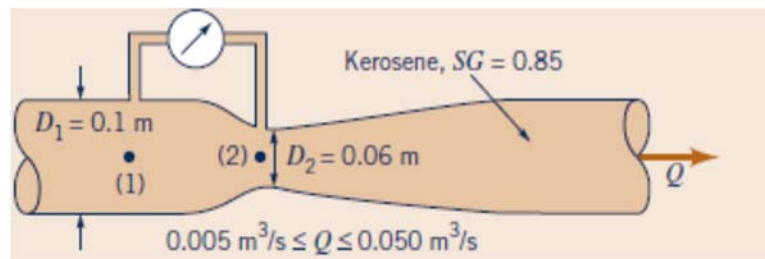


Figure 4

i) Determine the range in pressure difference ( $P_1 - P_2$ ), needed to measure these flowrates. **( 4 Marks)**

ii) Plot the graph of variation of pressure difference and volumetric flow rate. (4 Marks)

iii) What are your observations and conclusions from plot in (ii). [2 marks]

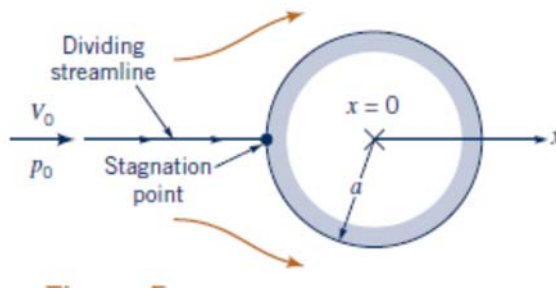
c). An incompressible fluid flows steadily past a circular cylinder as shown in Fig 5. The fluid velocity along the dividing streamline is found to be where  $a$  is the radius of the cylinder and  $V_0$  is the upstream velocity.

(i) Determine the pressure gradient along this streamline. [4 Marks]

(ii) If the upstream pressure is  $P_0$ , obtain the pressure  $P(x)$  for  $-\infty < x < -a$  [4 Marks]

(iii) Show from the result of part (ii) that the pressure at the stagnation point ( $x = -a$ ) is

$P_0 + \frac{\rho V_0^2}{2}$  as expected from the Bernoulli equation. [4 Marks]



### QUESTION THREE (Kinematics) [30 Marks]

a) Using sketches describe and give the differences of the following

i) Streamlines [1 Mark]

ii) Streamtubes [1 Mark]

iii) Pathlines [1 Mark]

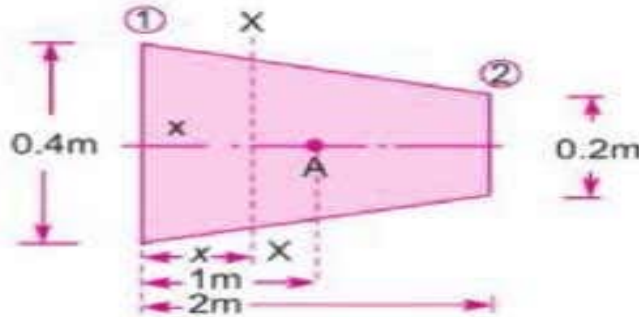
iv) Streaklines [1 Mark]

v) Timelines [1 Mark]

b) Show that the acceleration of a fluid particle is given by the equation. [5 Marks]

$$\vec{a}_{\text{particle}}(x, y, z, t) = \frac{d\vec{V}}{dt} = \frac{\partial \vec{V}}{\partial t} + u \frac{\partial \vec{V}}{\partial x} + v \frac{\partial \vec{V}}{\partial y} + w \frac{\partial \vec{V}}{\partial z}$$

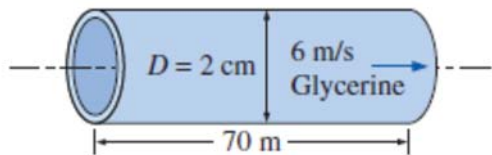
c) Find the convective acceleration at the **middle** of the pipe which converges uniformly from 0.4m diameter to 0.2m diameter over 2m length.



- i). When the rate of flow is 20 lit/s. [ 6 Marks]
- ii). When the rate of flow changes uniformly from 20lit/s to 40 lit/s in 30 seconds. [ 7 Marks]
- iii) Find the total acceleration at the **middle** of the pipe at 15<sup>th</sup> second. [ 7 Marks]

**QUESTION FOUR (Internal Flow-Laminar Flow and Turbulent Flow) [30 Marks]**

a) Consider the fully developed flow of glycerin at 40 C through a 70-m-long, 2-cm-diameter, horizontal, circular pipe, Density of glycerin is,  $\rho = 1252 \text{ kg/m}^3$  and dynamic viscosity,  $\mu = 0.3073 \text{ kg/m.s}$  Centerline velocity is 6m/s.



- i) Determine the velocity profile and the pressure difference across this 70-m-long section of the pipe. [4 Marks]
- ii) Determine the useful pumping power required to maintain this flow. [4 Marks]
- iii) For the same useful pumping power input, determine the percent increase of the flow rate if the pipe is inclined 15° downward. [3 Marks]
- iv) For the same useful pumping power input, determine the percent increase of the flow rate if the pipe is inclined 15° upward. [ 3 Marks]

**b)** Water at 15°C ( $\rho = 999.1 \text{ kg/m}^3$  and  $\mu = 1.138 \times 10^{-3} \text{ kg/m}\cdot\text{s}$ ) is flowing steadily in a 30-m-long and 4-cm-diameter horizontal pipe made of stainless steel at a rate of 8 L/s. roughness of pipe is  $2 \times 10^{-6} \text{ m}$ .

**(i)** Determine the pressure drop, [ 4 Marks]

**(ii)** Determine the head loss. [2 Marks]

**(iii)** Find the pumping power requirement to overcome this pressure drop. [2 Marks]

**c)** A geothermal heating system involves the transport of geothermal water at 110°C from a geothermal well to a city at about the same elevation for a distance of 12 km at a rate of  $1.5 \text{ m}^3/\text{s}$  in 60-cm-diameter stainless-steel pipes. The fluid pressures at the well head and the arrival point in the city are to be the same. The minor losses are negligible because of the large length-to-diameter ratio and the relatively small number of components that cause minor losses. Roughness of stainless steel pipe is  $2 \times 10^{-6} \text{ m}$

**i)** Assuming the pump–motor efficiency to be 80 percent, determine the electric power consumption of the system for pumping. [4 Marks]

**ii)** Would you recommend the use of a single large pump or several smaller pumps of the same total pumping power scattered along the pipeline? Explain. [4 Marks]

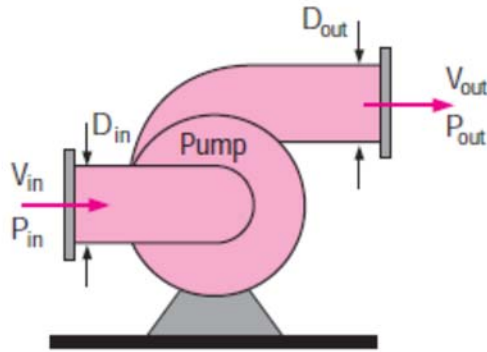
#### **QUESTION FIVE (Hydraulic Machines) [30 Marks]**

**a)** A water pump increases the pressure of the water passing through it. The water is assumed to be incompressible. For each of the three cases listed below, how does average water speed change across the pump? In particular, is  $V_{\text{out}}$  less than, equal to, or greater than  $V_{\text{in}}$ ? Show your equations, and explain.

**i)** Outlet diameter is less than inlet diameter ( $D_{\text{out}} < D_{\text{in}}$ ) [2 Marks]

**ii)** Outlet and inlet diameters are equal ( $D_{\text{out}} = D_{\text{in}}$ ) [2 Marks]

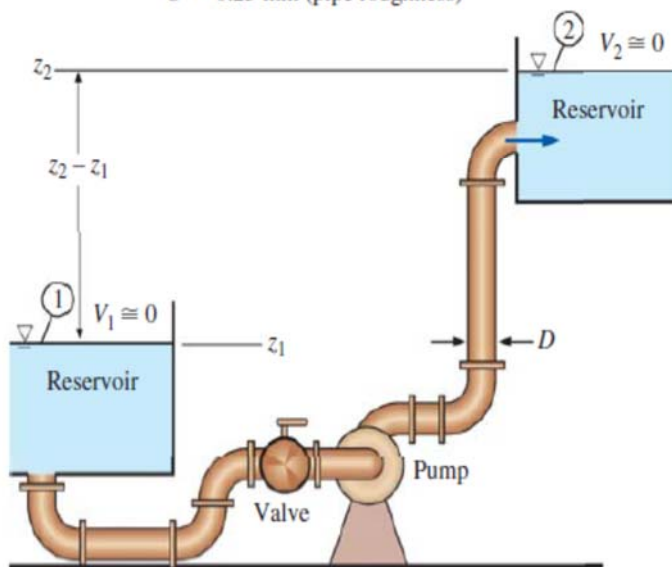
**iii)** Outlet diameter is greater than inlet diameter ( $D_{\text{out}} > D_{\text{in}}$ ) [2 Marks]



b) A water pump is used to pump water from one large reservoir to another large reservoir that is at a higher elevation. The free surfaces of both reservoirs are exposed to atmospheric pressure, as sketched in figure below. The dimensions and minor loss coefficients are provided in the figure below.

The pump's performance is approximated by the expression  $H_{\text{available}} = H_0 - aV^2$ , where shutoff head  $H_0 = 24.4$  m of water column, coefficient  $a = 0.0678$  m/Lpm<sup>2</sup>, available pump head  $H_{\text{available}}$  is in units of meters of water column, and capacity  $V$  is in units of liters per minute (Lpm). Estimate the capacity delivered by the pump. [10 Marks]

- $z_2 - z_1 = 7.85$  m (elevation difference)
- $D = 2.03$  cm (pipe diameter)
- $K_{L, \text{entrance}} = 0.50$  (pipe entrance)
- $K_{L, \text{valve}} = 17.5$  (valve)
- $K_{L, \text{elbow}} = 0.92$  (each elbow—there are 5)
- $K_{L, \text{exit}} = 1.05$  (pipe exit)
- $L = 176.5$  m (total pipe length)
- $\epsilon = 0.25$  mm (pipe roughness)

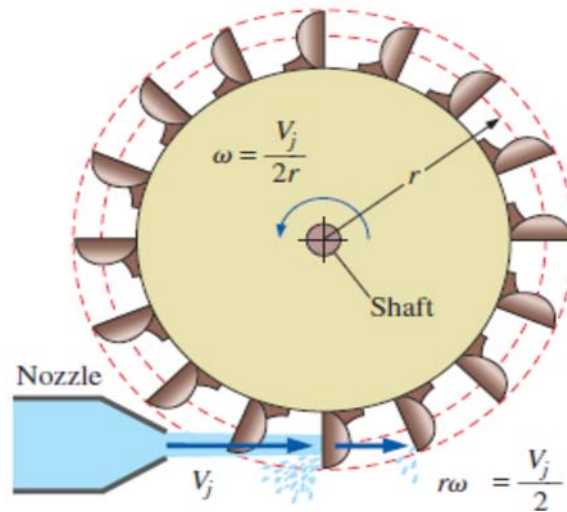


c) A Pelton wheel is used to produce hydroelectric power. The average radius of the wheel is 1.83 m, and the jet velocity is 102 m/s from a nozzle of exit diameter equal to 10.0 cm. The turning angle of the buckets is  $\beta=165^\circ$ .

(i) Calculate the volume flow rate through the turbine in  $\text{m}^3/\text{s}$ . [3 Marks]

(ii) What is the optimum rotation rate (in rpm) of the wheel (for maximum power)? [5 Marks]

(iii) Calculate the output shaft power in MW if the efficiency of the turbine is 82 percent. [6 Marks]



**Pelton wheel**

## Empirical Correlations

$$\Delta P_L = f \frac{L}{D} \frac{\rho V_{\text{avg}}^2}{2}$$

$$f = \frac{8\tau_w}{\rho V_{\text{avg}}^2}$$

$$f = \frac{64\mu}{\rho D V_{\text{avg}}} = \frac{64}{\text{Re}}$$

$$h_L = \frac{\Delta P_L}{\rho g} = f \frac{L}{D} \frac{V_{\text{avg}}^2}{2g}$$

$$\text{Re} = \frac{\text{Inertial forces}}{\text{Viscous forces}} = \frac{V_{\text{avg}} D}{\nu} = \frac{\rho V_{\text{avg}} D}{\mu}$$

Equivalent roughness values for new commercial pipes\*

Material	Roughness, $\epsilon$	
	ft	mm
Glass, plastic	0 (smooth)	
Concrete	0.003–0.03	0.9–9
Wood stave	0.0016	0.5
Rubber, smoothed	0.000033	0.01
Copper or brass tubing	0.000005	0.0015
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Stainless steel	0.000007	0.002
Commercial steel	0.00015	0.045

$$h_L = 1.07 \frac{\dot{V}^2 L}{gD^5} \left\{ \ln \left[ \frac{\varepsilon}{3.7D} + 4.62 \left( \frac{\nu D}{\dot{V}} \right)^{0.9} \right] \right\}^{-2} \quad \begin{matrix} 10^{-6} < \varepsilon/D < 10^{-2} \\ 3000 < Re < 3 \times 10^8 \end{matrix}$$

$$\dot{V} = -0.965 \left( \frac{gD^5 h_L}{L} \right)^{0.5} \ln \left[ \frac{\varepsilon}{3.7D} + \left( \frac{3.17 \nu^2 L}{gD^3 h_L} \right)^{0.5} \right] \quad Re > 2000$$

$$D = 0.66 \left[ \varepsilon^{1.25} \left( \frac{L \dot{V}^2}{g h_L} \right)^{4.75} + \nu \dot{V}^{9.4} \left( \frac{L}{g h_L} \right)^{5.2} \right]^{0.04} \quad \begin{matrix} 10^{-6} < \varepsilon/D < 10^{-2} \\ 5000 < Re < 3 \times 10^8 \end{matrix}$$

### Moody's Chart

