NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2019-2020

MA3006 – FLUID MECHANICS

November/December 2019 Time Allowed: $2^1/_2$ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED BOOK** examination.

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1 (a) Figure 1 shows a water jet discharging from a nozzle at 12 m/s. The nozzle is inclined at an angle of 30 degrees to the horizontal and has a diameter of 0.008 m. The water jet strikes a plate inclined at an angle of 60 degrees to the horizontal.
The height difference between the nozzle and the plate is negligible. The height difference between the plate ends is also negligible and the flow is assumed frictionless. The weight of the plate can be neglected.

(i) Determine the force F required to hold the inclined plate stationary

(ii) If the plate is vertical, determine the force F required to hold the plate stationary and calculate the mass flow rates of water, m_2 and m_3.

(iii) What is the power required to move the vertical plate horizontally towards the water jet at a steady speed of 3 m/s?

(20 marks)

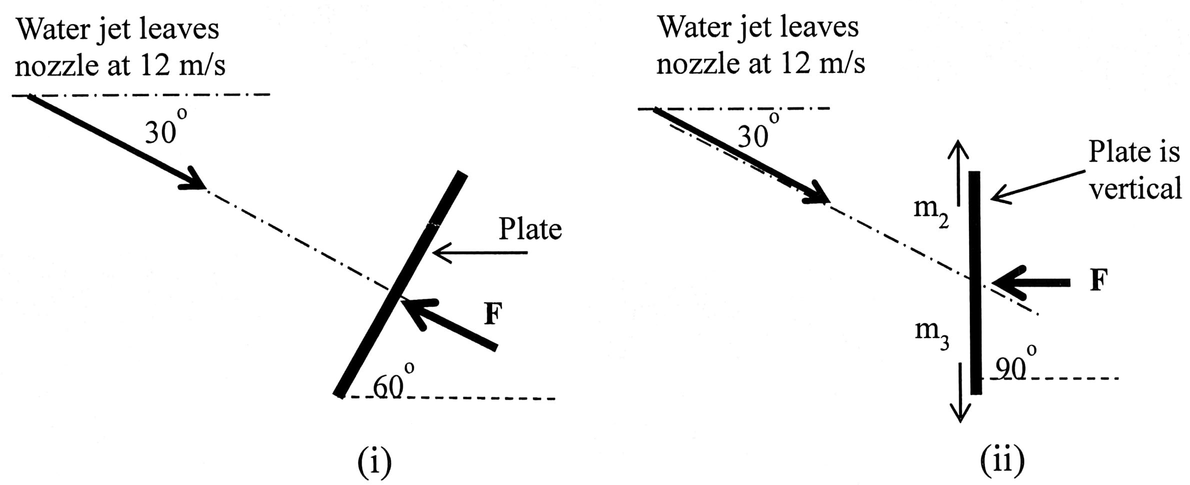

Figure 1

Note: Question 1 continues on page 2.

(b) Water flows from a smaller to a larger diameter pipe as shown in Figure 2. The volume flow rate is 0.002 m^3/s and head loss between point 1 to point 2 is 0.22 m. Determine the pressure head difference, h.

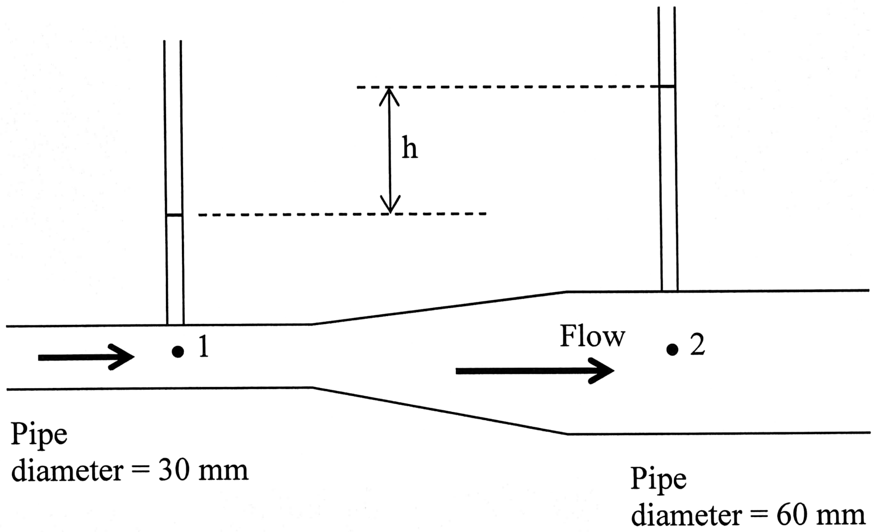

Figure 2

(5 marks)

2 (a) An orifice plate of diameter d is installed in a pipe of diameter D to monitor the volume flow rate.
Assuming ideal flow, derive an expression for the pressure difference between upstream pressure (P_1) in the pipe and the pressure (P_2) at the orifice in terms of the following:

Q_{ideal} = ideal flow rate,
A_2 = area at orifice,
ρ = density of fluid, and

$$\beta = \frac{d}{D}.$$

An orifice plate is assembled in a piping system to monitor the water flow rate. The diameter of the pipe is 80 mm and the orifice plate diameter is 56 mm. If the velocity of water in the pipe is 1.8 m/s, what is the pressure difference between the upstream pressure (P_1) and the pressure at orifice (P_2)?
Dynamic viscosity of water, $\mu = 1.002 \times 10^{-3}$ Ns/m^2
Density of water, $\rho = 1000$ kg/m^3
Figure 3 shows the coefficient of discharge for an orifice plate.

(12 marks)

Note: Question 2 continues on page 3
Figure 3 appears on page 3.

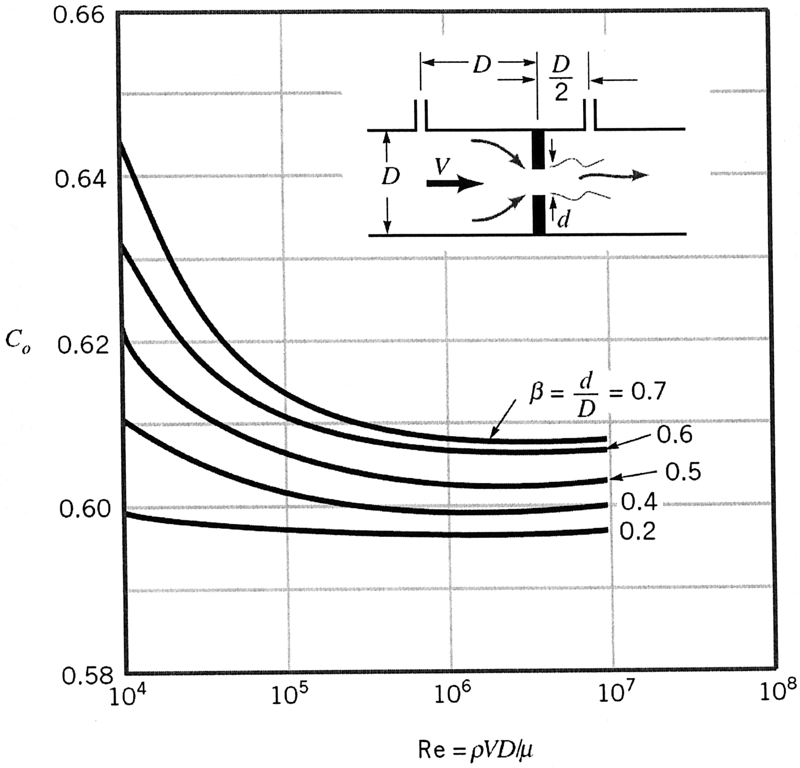

Figure 3

(b) The pressure rise Δp across a fan blade depends on the rotor rotational speed ω, the external diameter of fan D, the volume flow rate Q, the density ρ and dynamic viscosity μ of the fluid. Using dimensional analysis, determine suitable dimensionless groups.
From the established dimensionless group, derive the power coefficient.
You may use ρ, ω and D as repeating variables.

(10 marks)

(c) The external diameter of a prototype blower fan operating at 500 rpm is 0.8m. The power of the blower fan is 200 W and delivers a volume flow rate of 1.5 m^3/s. A geometrical similar model fan which is 80% smaller than the prototype is used for model testing.
What should be the speed of the model fan to achieve dynamic similarity?

(3 marks)

3 (a) A student conducted an experiment whereby fluids A and B having the same volume flow rate, flowed through two identical horizontal pipes 1 and 2 respectively as shown in Figure 4. If the diameter of each pipe is 0.1 m and the flow rate through each pipe is 0.01 m^3/s, determine the ratio of the centerline velocities, V_c, in pipe 2 to that in pipe 1. Comment on the results obtained with the aid of sketches, if necessary.

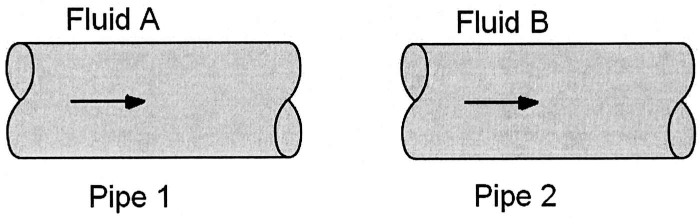

Figure 4

The properties of the fluids are given below:

Fluid	Density (kg/m^3)	Dynamic viscosity (kg/m.s)
A	800	0.1
B	7	0.00001

The expressions for volume flow rate are:

Laminar flow: $Q = \pi R^2 V_c / 2$, and

Turbulent flow: $$Q = 2\pi R^2 V_c \frac{n^2}{(n+1)(2n+1)}$$

where n is a constant to be determined from Figure 5.

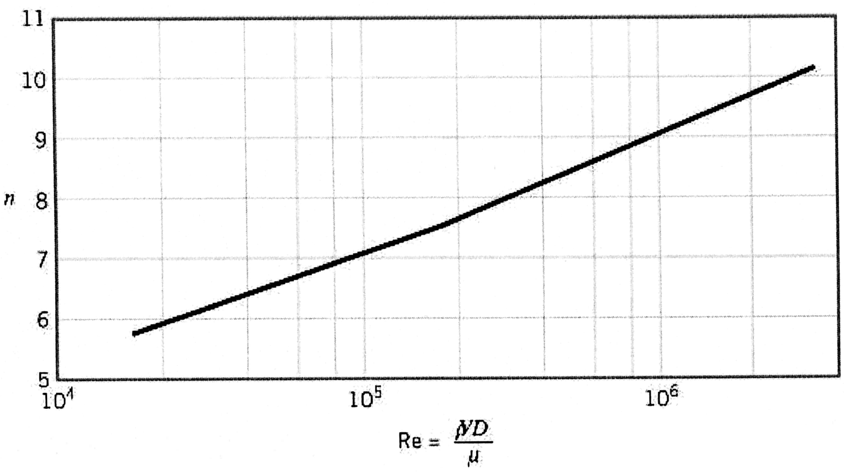

Figure 5

(10 marks)

(b) Water flows from reservoirs A and B into reservoir C as shown in Figure 6. The elevations of the free surface of reservoirs A, B and C are 40 m, 45 m and 0 m respectively. If the volume flow rates from reservoirs A and B are each equal to 0.2 m^3/s, determine the diameter D_3 and the length L_2. All minor losses are neglected. Which pipe has the largest frictional head loss per unit length? Information on the pipes are given below.

Note: Question 3 continues on page 5.
Figure 6 appears on page 5.

Description	Diameter (m)	Length (m)	Friction factor	ΣK_L
Pipe 1	0.5	1000	0.02	0
Pipe 2	0.4	L_2	0.02	0
Pipe 3	D_3	500	0.02	0

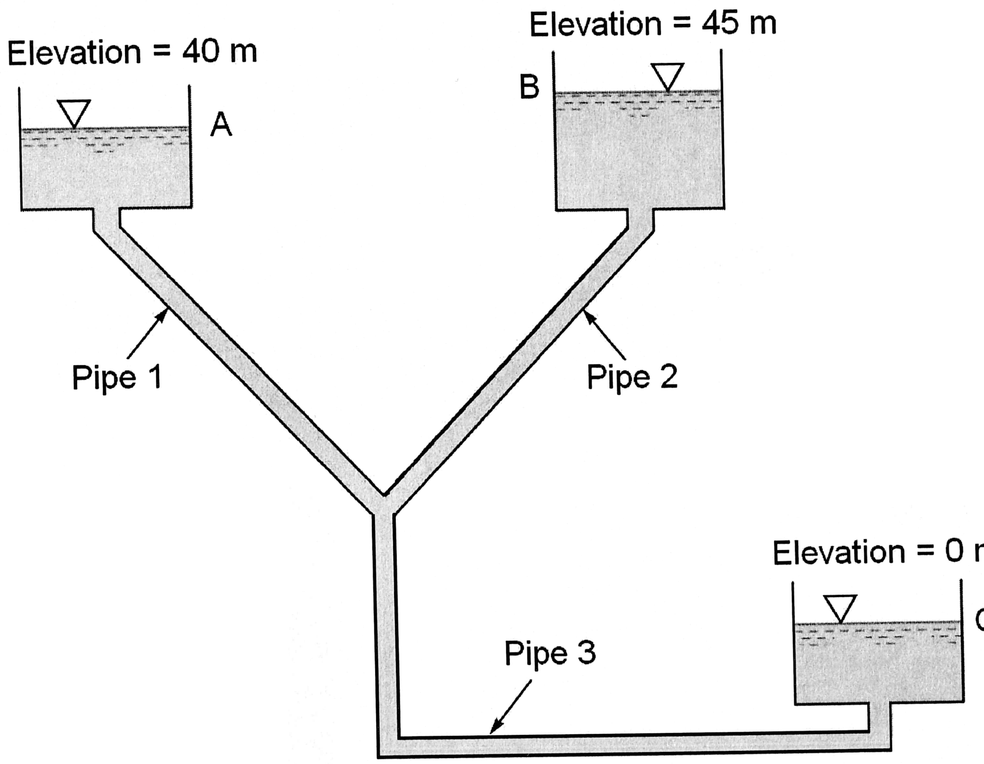

Figure 6

(15 marks)

4 Water is pumped from a closed tank A to reservoir C as shown in Figure 7. The elevations of the free surface of A and C are 0 m and 50 m respectively. The air pressure in the closed tank is 200 kPa (gauge) and the pump characteristics is given as:

$$H_p = 100 - 400Q^2$$

where H_p is the pump head and Q is the volume flow rate.

The $NPSH$ required is given by: $NPSH_R = 3 + 100Q^2$

(i) Determine the volume flow rate through the system.

(ii) If the rotational speed of the pump impeller is 2000 rpm, what type of pump would you recommend?

(iii) Given that the elevation of point B is 70 m, do you think cavitation will occur at point B when the volume rate is that obtained in part (i)? Explain your answer.

Note: Question 4 continues on page 6.
Figure 7 appears on page 6.

(iv) On a certain day, the air pressure in the closed tank drops to -80 kPa (gauge) and the corresponding flow rate in the system is 0.18 m^3/s. Given that the pump is located 2 m below the free surface of closed tank A, determine the *NPSH* available. Do you think cavitation will occur at the pump inlet? Explain your answer.

(v) Are there any differences between the cavitations that may occur in part (iii) and (iv)? Explain your answer.

Information on the pipes are given below.

Description	Diameter (m)	Length (m)	Friction factor	ΣK_L
Pipe 1	0.25	10	0.02	0
Pipe 2	0.25	240	0.02	4
Pipe 3	0.25	200	0.02	2

The density of water is 1000 kg/m^3. The atmospheric pressure is 100 kPa and the vapour pressure (p_v) of water is 2340 Pa and *NPSH* available is defined as

$$NPSH_A = \frac{P_s - p_v}{\rho g} + \frac{V_s^2}{2g}$$

where P_s is the pump suction pressure and V_s is the flow velocity in the pipe.

The pump specific speed N_s is given as $$N_s = \frac{\omega\sqrt{Q}}{(gH_p)^{3/4}}$$

where ω is the pump rotational speed.

For $N_s \le 1$, Centrifugal pump
For $1 < N_s < 4$, Mixed flow pump
For $N_s \ge 4$, Axial flow pump

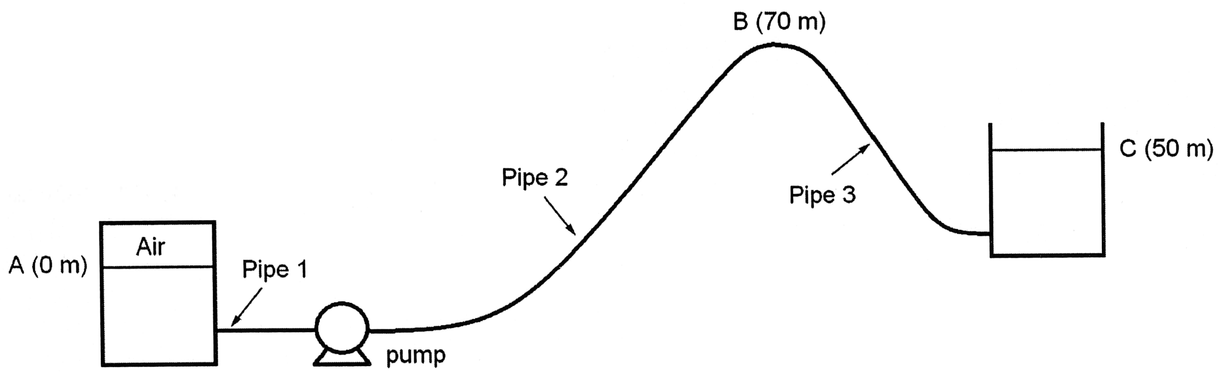

Figure 7

(25 marks)

END OF PAPER

MA3006 FLUID MECHANICS

Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.