THE UNIVERSITY OF MELBOURNE
ENGR30002 FLUID MECHANICS

EXPERIMENT 1: FLUID FLOW IN A SMOOTH PIPE

AIMS

1. To investigate the variation of pressure drop with volumetric flowrate of water in a circular pipe
2. To construct a plot of friction factor versus Reynolds number
3. To observe the transition from laminar flow to turbulent flow by injecting a dye into water flowing in a pipe

SITUATION

You are now working as a graduate engineer in a company which manufactures pipeline. The first task given by your boss is to study the correlation between Fanning friction factor and Reynolds number of water flowing in a pipe and, therefore, construct a Moody diagram.

To complete the task, you have been given access to the company's laboratory, where you will conduct scientific experiments to achieve your goal. In particular, you will have access to pressure gauges, flow meters and a glass straight pipe. A description of each of the apparatus is provided below.

Pressure Gauges

A pressure gauge is to measure pressure by analysing an applied force by a fluid on a surface. Various types of pressure gauges are used to measure different pressure range. In the laboratory, you will have access to a capsuhelic different pressure gauge (up to 250 Pa), inverted water-air manometer (up to 10 kPa) and a wet-wet digital pressure gauge (up to 100 kPa). You will need to choose a pressure gauge accordingly to maintain accuracy. To measure the pressure, you simply read the pressure reading when using the capsuhelic different pressure gauge or the wet-wet digital pressure gauge. Alternatively, you need to use hydrostatic pressure to calculate pressure differential using the inverted water-air manometer.

Flow Meter

A flow meter is used to control the flowrate of fluid. In the laboratory, you will have access to three rotameters which can control water flowrate up to 70, 250 and 1600 L/hr. A rotameter is an example of a variable area flow meter, where a weighted float rises in a tapered tube as the flow rate increases. The float stops rising when area between float and tube is large enough that the weight of the float is balanced by the drag of fluid flow. Rotameters are available for a wide range of liquids but are most commonly used with water or air. They can be made to reliably measure flow down to 1% accuracy

Tube

In the laboratory, you will also have access to a glass pipe which is 12.6 mm in diameter and 1.5 m in length.

(a) (b) (c)

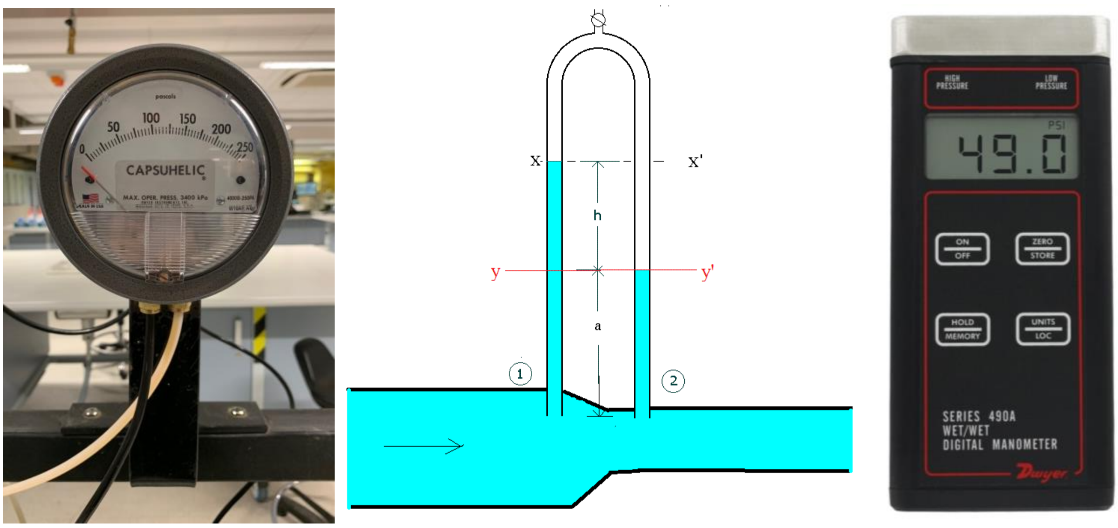

Figure 1. The 3 types of pressure gauges to be used in the experiment, including (a) capsuhelic differential pressure gauge (up to 250 Pa), (b) inverted water-air manometer (up to 10 kPa) and (c) wet-wet digital pressure gauge (up to 100 kPa).

(a) (b)

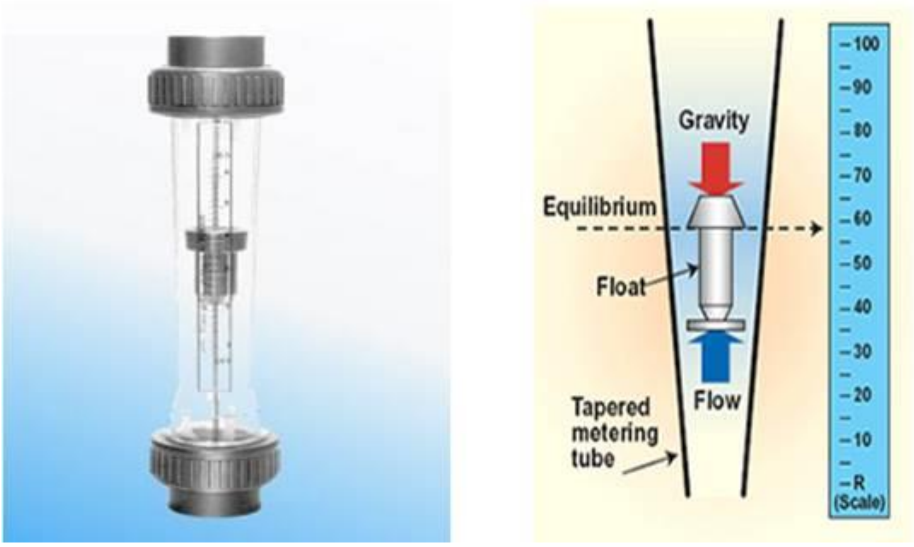

Figure 2. (a) A rotameter to be used in the experiment. (b) A schematic diagram of a rotameter. The flow of liquid creates an upward force to balance the weight of the float and create an equilibrium situation so the float will remain stationary to indicate the flowrate.

TASK

Your group needs to design an experiment using the above apparatus to measure pressure drop of water flowing in a straight glass pipe by altering the volumetric flowrate in the pipe between 0 to 1600 L/hr.

You will meet the lab demonstrator before you attend the lab session. During the meeting, each group needs to prepare a presentation no more than 10-minutes to talk about your **proposed experimental procedures and schematic diagram of the experiment**. You should consider the following when you design your experimental protocol and construct your schematic diagram:

- Give specific step-by-step procedures in dot points
- Are there any safety checks or calibrations required before switching on the pressure gauges and flow meters?
- What are the parameters to be measured in the experiment?
- What calculation steps are required to obtain Fanning friction factor and Reynolds number?
- How many flowrates should you run for each of the 3 flow meters?
- Should you start the pipe flow with high or low flowrate? Why?
- How do you know which of the 3 pressure gauges should you use to measure pressure drop so to maintain accuracy?
- Show all the pipelines and how the experimental apparatus are connected in the schematic diagram
- There are 3 pressure gauges to be used in the experiment. Think about how you should connect the pressure gauges to the pipe.
- There are 3 flow meters to be used in the experiment. Again, think about how you should connect the flow meters to the pipe. Should the flow meters be put towards the front or the end of the pipe? Why?

After presenting your experimental protocols and schematic diagram to the lab demonstrator, you will then attend your scheduled lab session to conduct the experiment you have designed.

THEORY

For fluid to flow in a pipe, a driving force in the form of pressure drop (ΔP) is required. The pressure drop required depends on the average velocity (V), fluid density (ρ), fluid viscosity (μ), pipe diameter (D) and pipe length (L).

The pressure change in a fluid under steady-state flow condition is described by the Bernoulli equation which is given by:

$$\frac{P_1}{\rho g} + \frac{1}{2g}V_1^2 + z_1 = \frac{P_2}{\rho g} + \frac{1}{2g}V_2^2 + z_2 + h_L$$

where
P = Pressure in the fluid
ρ = Density of the fluid
g = Acceleration due to gravity
V = Velocity of fluid
z = Elevation of fluid
h_L = Head loss due to friction

For flow in a horizontal pipe at a constant velocity, $z_1 = z_2$ and $V_1 = V_2$. It therefore follows that:

$$h_L = \frac{P_1 - P_2}{\rho g}$$

That is, the drop in pressure is due to fluid friction alone and is not due to changes in kinetic or potential energy.

The head loss (h_L) may also be expressed in terms of a Fanning friction factor (f):

$$h_L = \frac{2fLV^2}{dg}$$

Experimentation has shown the following to be true for fluid flow in a smooth horizontal pipe:

1. the head loss varies directly with the length of the pipe
2. the head loss varies almost with the square of the velocity
3. the head loss varies almost inversely with the diameter of the pipe
4. the head loss depends upon the fluid properties of density and viscosity
5. the head loss is independent of the pressure

The Fanning friction factor (f) is a function of fluid velocity (V), pipe diameter (D), fluid density (ρ) and fluid viscosity (μ) and the only way to make them dimensionless is as follow:

$$f = fn\left(\frac{\rho V D}{\mu}\right)$$

The group $\rho VD/\mu$ is known as the Reynolds number. Hence, Fanning friction factor is only a function of the Reynolds number.

When the flowrate through the pipe is low, the flow pattern is smooth and steady. A dye solution carefully injected into the pipe will trace out a straight line. This orderly flow is referred to as laminar flow. As the flowrate is increased the stream of dye loses its steadiness and begins to vacillate. This vacillation increases as the velocity of the fluid increases. At sufficiently high velocity the dye solution no longer retains its identity and is dispersed across the pipe. It becomes completely mixed with the surrounding liquid indicating that the flow pattern is no longer steady and smooth. It has become chaotic. The flow is now said to be turbulent.

The transition from the laminar flow to turbulent flow occurs at different velocities for different fluids and different pipe sizes. However, when expressed in terms of Reynolds number, the transition occurs at a fairly well defined value for Reynolds number. This is known as the critical Reynolds number for pipe flow. In this experiment the critical value may be determined by observing the gradual change to disordered state of a line of dye injected into the centre of a flowing water stream.

Your demonstrator will show you the flow pattern of laminar, transition and turbulent flow in the laboratory by injecting a dye into the water flow channel at various flowrates.

SAFETY AND STUDENT DRESS

It is a University requirement that student dress and behaviour in the lab must conform to the following safety standards:

1. Safety glasses, long-sleeve and long-leg clothing are compulsory (otherwise lab coats must be worn)
2. Do not take your safety glasses off while in the lab.
3. Footwear must completely cover feet.
4. No smoking, drinking, or eating in lab.
5. No sitting on table or floor.
6. Let the demonstrator know if you need to leave the lab.
7. Keep table/work area tidy, notes and other items away from chemicals.
8. Handle chemicals and equipment with care.
9. Follow the lab supervisor's instruction in case of emergency evacuation.
10. Ask question if you are unsure of anything during the practical session.

The laboratory demonstrator will determine whether students meet these requirements. Students not meeting these requirements will be asked to leave the laboratory and will receive zero for this part of the subject assessment.

QUESTIONS TO ANSWER IN THE LAB REPORT

1. Draw a schematic diagram of the apparatus used in this experiment. Show and label all components, material flow and direction of flow.

2. From the results obtained from the experiment, construct a log-log plot of f versus Re, showing clearly the three flow regimes. Draw a straight line of best fit through the data points in the laminar flow region and determine the slope of this line.

3. What is the theoretical relationship between f and Re in the laminar flow regime for pipe flow? State the expected value of the slope of the log(f) versus log(Re) plot in this regime. Does the plot you obtained in question 2 agree with that found in the literature? If not, explain why this is so.

4. For the data point at the maximum fluid flowrate, present a sample calculation to show how V, Re, f and h_L are calculated. (Show all steps, parameter values, units and equations used.) Do these values agree with theoretical values? How much are they different?

5. A viscous liquid (ρ = 1460 kg/m^3, μ = 5.2 × 10^{-1} Ns/m^2) is to be pumped through a smooth pipe 0.1 m in diameter at a rate of 5 × 10^{-2} m^3/s. Use your friction factor versus Reynolds number plot to estimate the driving force needed to maintain the flow rate specified. Express the driving force in terms of pressure drop per unit length of the pipe.