Experiment 2 - Pipe Flow

Manual

1 Objective

The goal of this laboratory is to study pressure losses due to viscous (frictional) effects in fluid flows through pipes. These pressure losses are a function of various geometric and flow parameters including pipe diameter, length, internal surface roughness, and types of fittings. In this experiment, the influence of some these parameters on pressure losses in pipe flows will be evaluated by measuring flow rates through different types of pipes and fittings.

2 Background

2.1 Head Loss in Pipe Flows

Pipe flows belong to a broader class of flows, called internal flows, where the fluid is completely bounded by solid surfaces. In contrast, in external flows, such as flow over a flat plate or an airplane wing, only part of the flow is bounded by a solid surface. The term pipe flow is generally used to describe flow through round pipes, ducts, nozzles, sudden expansions and contractions, valves and other fittings. In this experiment we will limit our study to flow through round pipes and pipe fittings, such as elbows and valves.

When a fluid (gas or liquid) flows through a pipe, there is a loss of pressure in the fluid. This is because energy is required to overcome the viscous or frictional forces exerted by the walls of the pipe on the moving fluid. In addition to the energy lost due to frictional forces, the flow also loses energy (or pressure) as it goes through fittings, such as valves, elbows, bends, contractions and expansions. This loss in pressure is mainly due to the fact that flow separates locally as it moves through such fittings. Pressure losses in pipe flows are commonly referred to as ***head loss***. The frictional losses are referred to as ***major losses*** (h_l) while losses due to fittings, valves, entrance & exit effects, and so on, are called ***minor losses*** (h_{lm}). Together they make up the ***total head loss*** (h_{lT}) for pipe flows. Hence:

$$h_{lT} = h_l + h_{lm} \tag{1}$$

Head losses in pipe flows can be calculated by using a special form of the energy equation discussed in the next section.

2.2 Energy Equation for Pipe Flows

Consider steady, incompressible flow through a piping system. The energy equation between any two points **1** and **2** for this flow can be written as follows.

$$\left(\frac{P_1}{\rho g} + \alpha_1 \frac{V_1^2}{2g} + z_1\right) - \left(\frac{P_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2\right) = h_{lT} \tag{2}$$

where,

- P is the pressure at a given cross section.
- z is the elevation of the cross section, taken to be positive upwards.
- α is called the kinetic energy factor. For laminar flow $\alpha = 2$, for turbulent flow $\alpha = 1$.

- Flow in a pipe is considered laminar if Reynolds number, $Re_D < 2000$, where $Re_D = VD/\nu$.
- V is the average velocity at a cross section.
- h_{lT}, as discussed earlier, is the total head loss between cross-sections 1 and 2.

Therefore, in Eqn. 2, the terms in the parentheses represent the mechanical energy per unit weight at a particular cross-section in the pipe. Hence, the difference between the mechanical energy at two locations, i.e. the total head loss, is a result of the conversion of mechanical energy to thermal energy due to frictional effects. Note: In the current form, the head loss (h_{lT}) has a unit of length [L].

Equation 2 further reveals that for a fixed amount of mechanical energy available at station **1**, a higher head loss will lead to lower mechanical energy at station **2**. The lower mechanical energy can be manifested as a lower pressure, lower velocity (i.e. lower volumetric flow rate), a lower elevation or any combination of all three. It should also be noted that for flow without losses, $h_{lT} = 0$, the energy equation (Eqn. 2) reduces to Bernoullis equation.

2.3 Calculation of Head Loss

2.3.1 Major losses

The major head loss in pipe flows is given by Eqn. 3.

$$h_l = f \frac{L}{D} \frac{V^2}{2g} \tag{3}$$

Here, L and D are the length and diameter of the pipe, respectively, V is the average fluid velocity through the pipe and f is the **friction factor** for the section of the pipe. In general, the friction factor is a function of the Reynolds number and the non-dimensional surface roughness, e/D. The friction factor is determined experimentally and is usually published in graphical form as a function of Reynolds number and surface roughness. The friction factor plot, shown in Fig. 1, is usually referred to as the **Moody Plot**, after *L. F. Moody* who first published this data in the given form.

When the Reynolds number is below 2000 and the flow can be assumed to be laminar, the friction factor is only a function of the Reynolds number and is represented by the form shown in Eqn. 4.

$$f = \frac{64}{Re_D} \tag{4}$$

This means that for laminar flow through pipes, pressure losses are mainly a function of Reynolds number and the effect of pipe surface roughness can be considered to be negligible.

2.3.2 Minor losses

Minor head losses due to valves, fitting, sudden expansion or contraction, entrance & exits effects, and so on can be calculated using Eqn. 5. In some cases, for instance, short pipe with multiple fittings, minor losses are actually a large percentage of the total head loss – hence, not really 'minor'.

$$h_{lm} = K \frac{V^2}{2g} \tag{5}$$

Here, K is the **Loss Coefficient** and must be determined experimentally for each situation. Another common way to express minor head loss is in terms of frictional (major) head loss through an equivalent length, L_e, of a straight pipe. The **equivalent length** of a pipe fitting can be defined as the length of a straight section of pipe that would result in the same pressure loss as the fitting. In this form, the minor head loss is written as:

$$h_{lm} = f \frac{L_e}{D} \frac{V^2}{2g} \tag{6}$$

Loss coefficients, K and equivalent lengths can be found in a variety of handbooks; representative data for limited fittings is available in most undergraduate Fluid Mechanics texts.

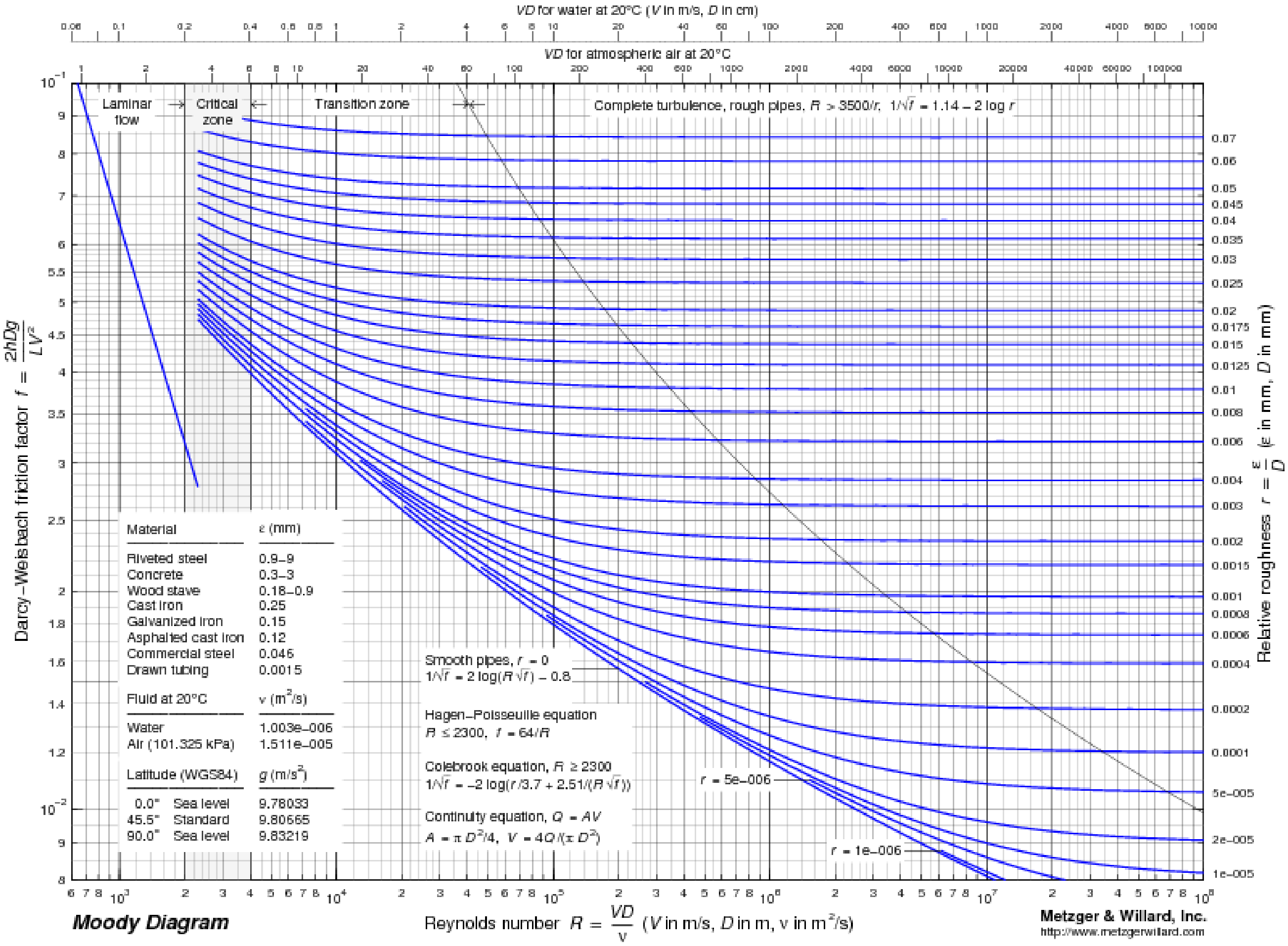

Figure 1: Moody diagram

The calculation of head loss for flow through a pipe with known conditions is generally carried out as follows. A reliable estimate of the pressure loss is critical for determining the hardware requirements, e.g. pump size, for a specific task.

1. If the fluid velocity and the pipe diameter are known, the Reynolds number can be calculated.
2. The Reynolds number and the pipe roughness are used to determine the friction factor, f, from the Moody plot using the appropriate curve.
3. Once the friction factor is known the major head loss can be calculated using Eqn. 3.
4. The frictional head loss can then be used to determine the pressure drop between two sections using Eqn. 2.
5. For minor losses, appropriate K values are used along with Eqn. 5.

Conversely, if the head loss (h_l), i.e. the pressure drop due to frictional losses, is measured, then the friction factor (f) can be calculated using the energy equation. This is the case in the present experiment. The pressure drop is measured for a range of flow rates corresponding to different Reynolds number, hence the friction factor can be calculated as a function of Reynolds number. These values can then be compared to the standard Moody chart.

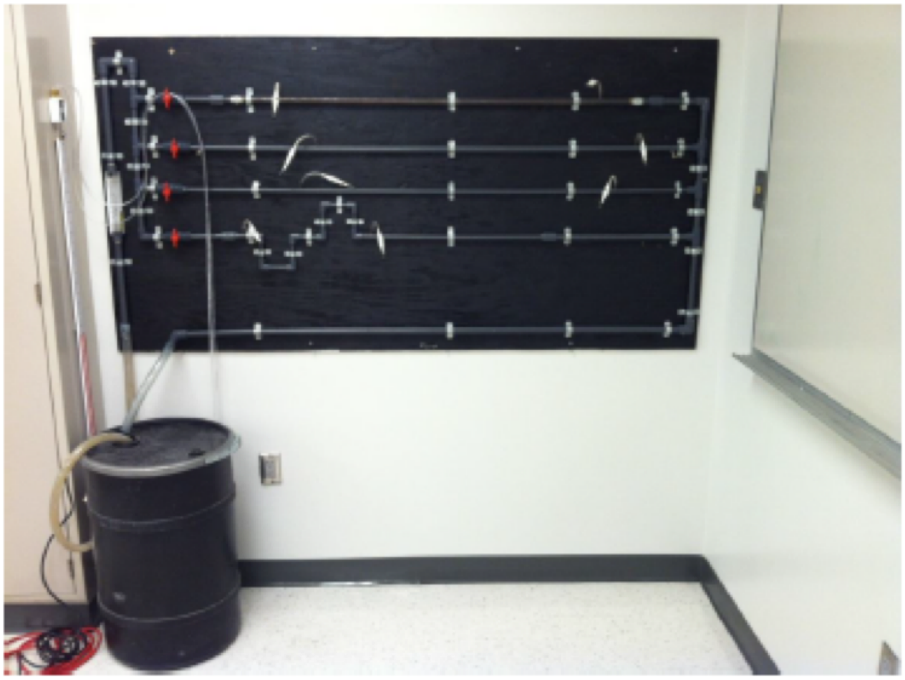

Figure 2: Pipe flow rig

3 Apparatus Used in Experiments

1. Pipe flow rig with various pipe arrangements.
2. A fluid manometer to measure the differential pressure between two sources (taps).
3. A rotameter-type flow meter.
4. A pump calibrated to provide a flow rate of 2 gpm through the straight steel pipe (top pipe).

Figure 2 shows a picture of the pipe flow rig.

4 Experimental Procedure

In performing this experiment, please proceed carefully to minimize any water spills, especially on the electronics and wire. ***Wipe any spills immediately***. Always keep paper towels handy.

4.1 Measurements of the Hardware

Measure and record the relevant dimensions and distances listed on the data sheet. Some of these include:

1. The height of each flow segment.
2. Distances between the pressure ports on the pipes
3. Also, record any other dimensions you think you may need even if they are not specified in the data sheet. These may include, but are not limited to:
   - The linear length of piping between the elbows, number and types of elbows
   - Pipe diameters (and wall thickness, if you think it is needed).

4.2 Setup

1. Ensure that the drain pipe (at the bottom of the rig) is draining into the bucket/tub and that the supply line from the pump is attached.

2. Ensure that all pressure ports have closed mates attached.

3. Ensure that there is adequate water in the reservoir to completely submerge the pump throughout the experiment.

4. Close all flow section control valves.

5. Plug in the pump, it will turn on.

6. Slowly open the control valve for the top flow section all the way, verify that the flow rate is 2.0 gpm.

7. Adjust the control valve on the pump outlet as needed (ask the TA for help before doing so).

4.3 Measuring the Pressure Drops

1. Connect the manometer tubes to the pressure taps on the flow section under study. **There should be no flow through the section when connecting or disconnecting pressure taps**.

2. Before opening the control valve hold the tubes attached to the pressure taps upright. This prevents water from entering the manometer and changing the density of the measuring fluid.

3. Slowly open the control valve for the given flow section to achieve the desired flow rate.

4. Read the resulting differential pressure displayed on the manometer.

5. Repeat procedure at flow rates of 1.0 gpm and 1.5 gpm for sections 1, 2 and 3. Use flow rates of 1.0 gpm and 0.5 gpm for section 4.

4.4 Shutdown

1. Close all valves

2. Shut off the supply pump

3. Clean up any spills.