KING FAHD
UNIVERSITY OF PETROLEUM & MINERALS

ME 316: Thermofluids Laboratory

Experiment # 2

FRICTION LOSSES IN PIPING SYSTEMS

1) OBJECTIVES

a) To investigate the effect of flow velocity on the friction head loss in a constant diameter pipe.
b) To determine the loss coefficient for a sudden pipe enlargement.

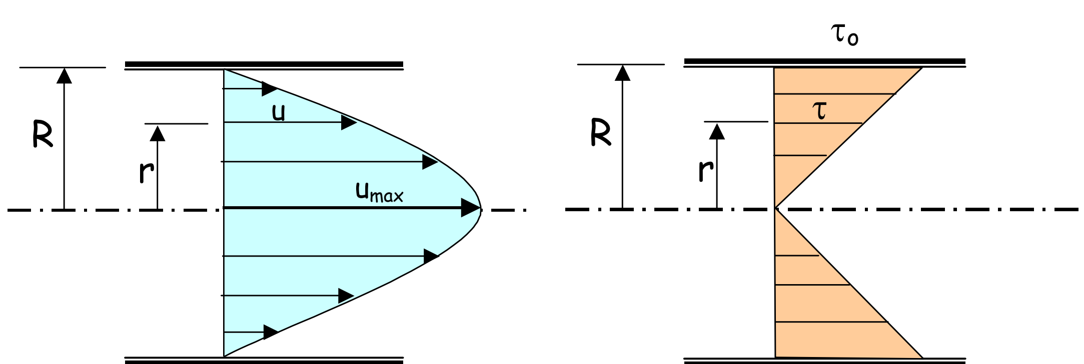
2) INTRODUCTION

Due to internal friction between adjacent fluid layers and also between the fluid and the pipe walls, there exists a continuous change of energy from a valuable form (such as kinetic or potential energies) to a less valuable form that is heat. This change of energy is usually referred to as the friction head loss that represents the amount of energy converted into heat per unit weight of fluid. The friction head loss in a piping system may be divided to the following two categories:

a) Major losses which represents the friction losses due to viscous resistance in straight constant diameter pipes, and
b) Minor losses, which represent losses due to localized effects, mainly arise from changes in the flow cross-sectional area (such as flow in nozzles, diffusers, valves and flow meters) or changes in the flow direction (such as flow in bends and elbows).

3) THEORETICAL BACKGROUND

At low Reynolds, the flow in various conduits is laminar and the analysis of laminar flow in pipes of circular cross-section was thoroughly covered in ME 311 course. The velocity distribution in laminar pipe flow is parabolic while the shear stress distribution is linear as shown below.



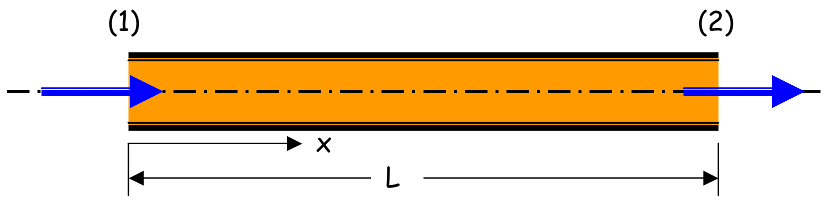
The friction head loss is given by

$$h_f = \frac{p_1 - p_2}{\gamma} = \frac{32\mu VL}{\gamma D^2} \quad (1)$$

where μ is the fluid viscosity, γ is the specific weight, L is the pipe length, D is the pipe diameter and V is the average velocity. It is clear from equation (1) that the friction head loss h_f is in linear proportion with the velocity in the case of laminar flow and equation (1) can be written in the form

$$h_f = K\,V \quad (2)$$

where K is a constant for a given pipe $\left(K = 32\mu L/\gamma D^2\right)$.



It is customary in engineering practice to write equation (1) in the form

$$h_L = f\,\frac{L\,V^2}{2gD} \quad (3)$$

where f is the friction coefficient and the above equation is called the Darcy-Weisbach equation. By comparing equations (1) and (3), one can easily prove that *f=64/Re*, where Re is the Reynolds number ($Re=\rho VD/\mu$ for pipe flow).

When the flow is turbulent, the analytical treatment of the problem to obtain an exact solution is extremely difficult and the experimental results represent the corner stone for understanding the phenomenon. It was found experimentally that the friction coefficient f depends on the Reynolds number Re as well as the pipe relative roughness, k_s/D and can be expressed in the form

$$f = \phi\left(Re, \frac{k_s}{D}\right) \quad (4)$$

The above equation can be easily obtained using dimensional analysis together with equation (3). The value of *f* can be obtained from the Moody Chart shown in Figure 1. Swamee and Jain (1976) developed the following explicit equation for the friction coefficient that was proven to be highly accurate.

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2} \quad (5)$$

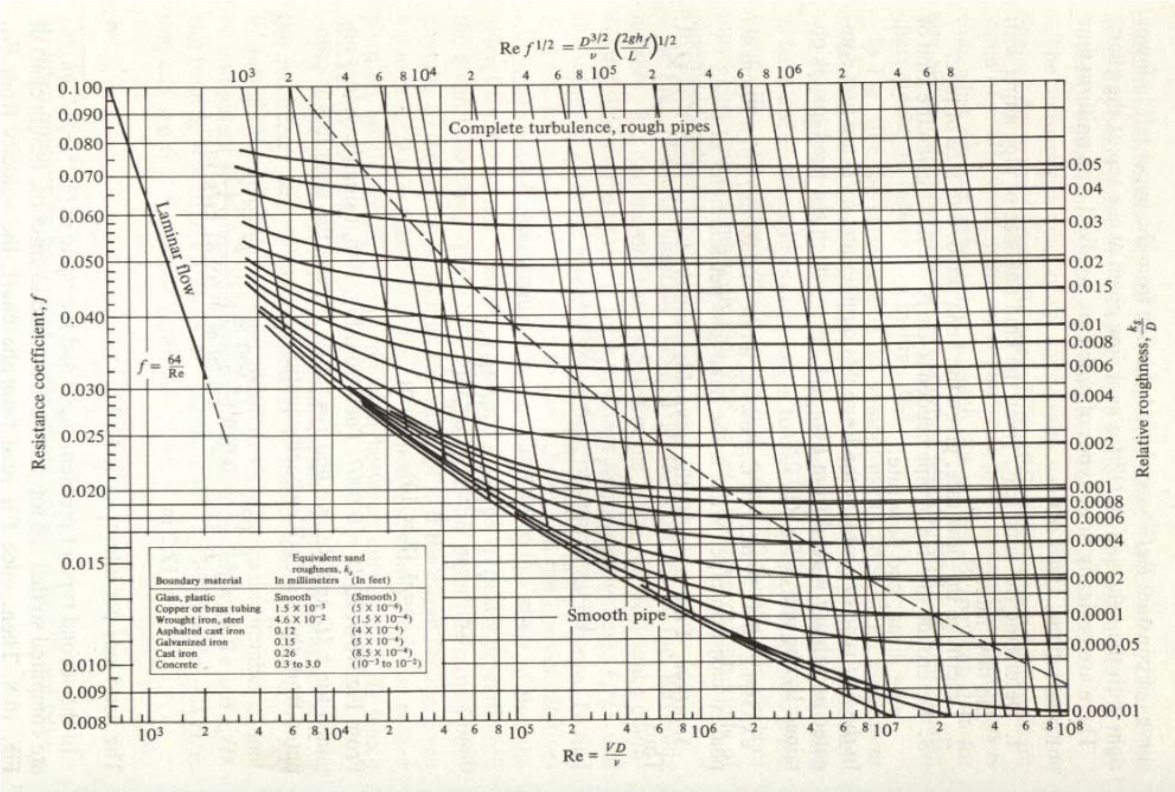


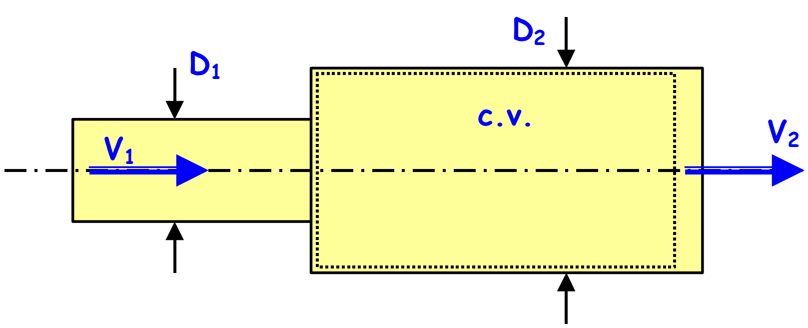
Figure 1. The Moody Chart

The relationship between h_f and V in the case of turbulent flow takes the form

$$h_f \approx K V^n \tag{6}$$

where K is a constant for a given pipe and the value of n ranges from 1.7 to 2 (depending on the range of Re and the value of k_s/D).

The head loss in a sudden pipe enlargement was discussed in detail in ME 311 and the following equation was obtained (based on theoretical grounds) for the head loss:



$$h_L = (V_1 - V_2)^2 / 2g \tag{7}$$

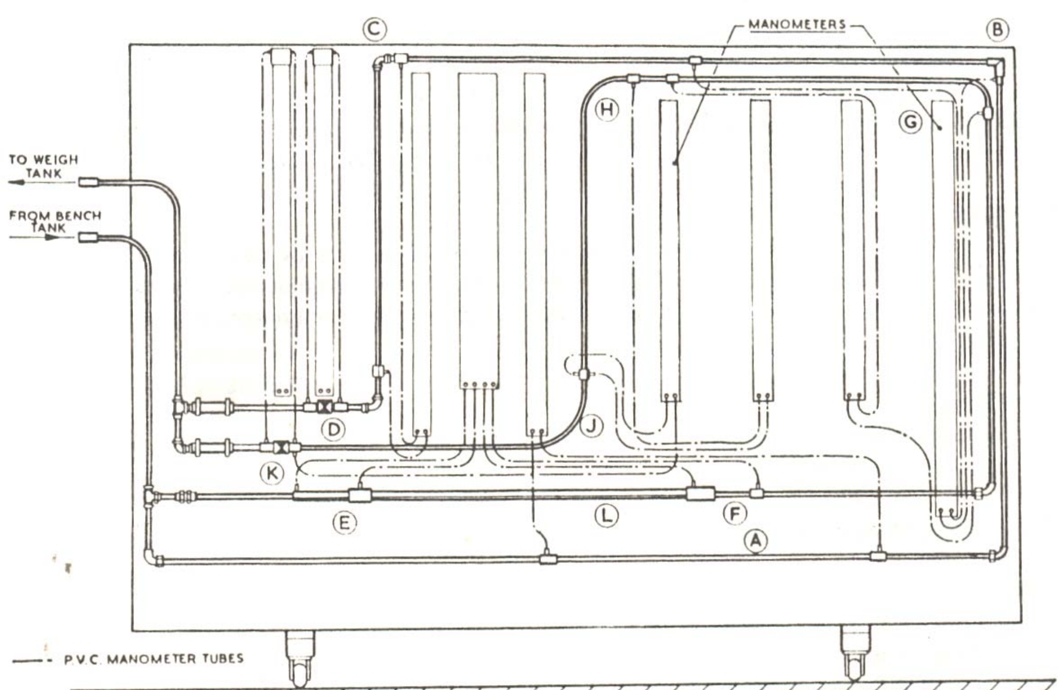
In general, minor losses in various pipe fittings are normally expressed in the form

$$h_L = K\,V^2/2g \tag{8}$$

where K is the loss coefficient and V is a characteristic flow velocity. The value of K for various fittings is determined experimentally.

4) APPARATUS

The apparatus shown in Figure 2 consists of two separate hydraulic circuits each one containing a number of pipe system components such as straight pipes, valves, elbows, bends, sudden contractions and sudden expansions. Both circuits are supplied with water from a hydraulic bench. The pressure difference across each of the components is measured by a pair of pressurized piezometer tubes.



A STRAIGHT PIPE 13·7mm (0·54 in) BORE
B 90° SHARP BEND (MITRE)
C PROPRIETORY 90° ELBOW
D GATE VALVE
E SUDDEN ENLARGEMENT - 13·7mm(0·54in)/26·4mm(1·04in)
F SUDDEN CONTRACTION - 26·4mm(1·04in)/13·7mm(0·54in)
G SMOOTH 90° BEND 52mm (2in) RADIUS
H SMOOTH 90° BEND 102mm (4in) RADIUS
J SMOOTH 90° BEND 152mm (6in) RADIUS
K GLOBE VALVE
L STRAIGHT PIPE 26·4mm (1·04in) BORE

Figure 2. Schematic diagram of the pipe flow apparatus

In this experiment the pressure heads before and after each fitting (h_1 and h_2) are measured by using piezometer tubes. Considering the arrangement shown in Figure 3, the head loss between points 1 and 2 can be determined experimentally by applying the energy equation as follows:

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1 = \frac{p_2}{\gamma}+\frac{V_2^2}{2g}+ z_2 + h_L \tag{9}$$

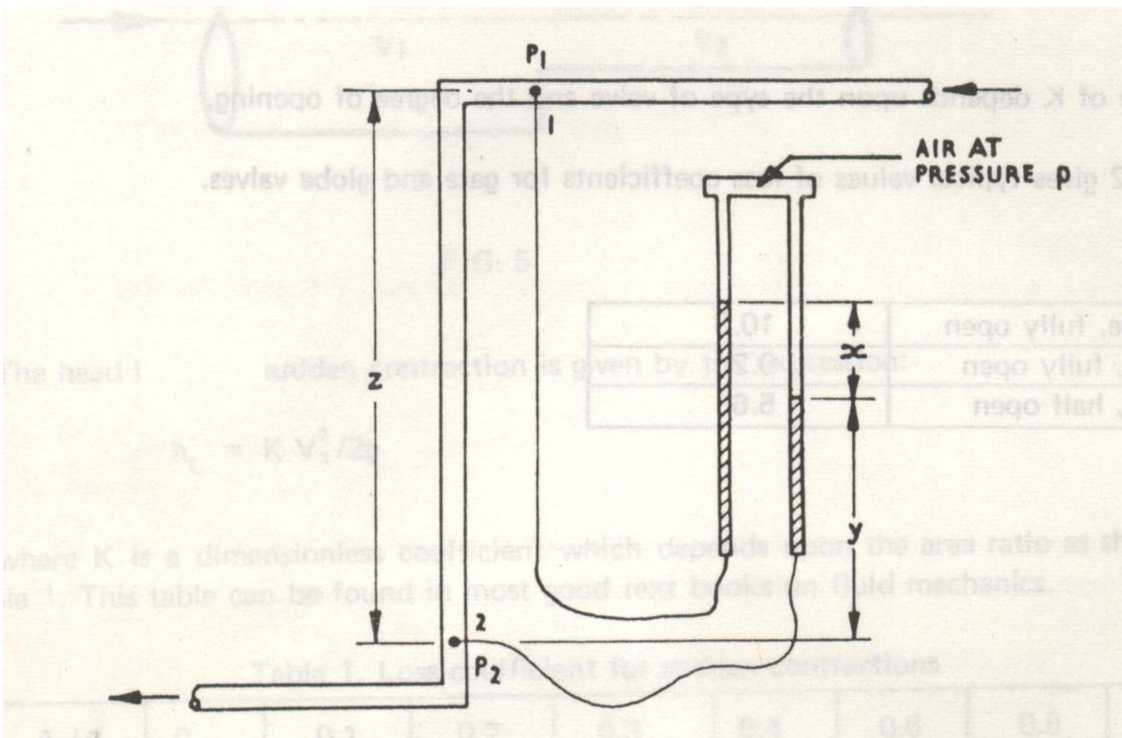


Figure 3. Pressurized piezometer tubes used for measuring the pressure difference between two points at different elevations

But since $V_1=V_2$, one can write the above equation in the form $h_L = \frac{p_1 - p_2}{\gamma} + (z_1 - z_2)$

and by using the basics of fluid statics, one can easily show that $h_L = x$.

5) TEST PROCEDURE

1. Measure the water temperature in order to determine the viscosity.
2. Level the apparatus so that the piezometer tubes are all vertical.
3. Connect common inlet to supply from the hydraulic bench and common outlet to the measuring tank.

4. Open supply valve and remove any trapped air in the piezometer tubes.
5. Open fully the gate valve in the dark blue circuit to obtain the maximum flow rate.
6. Measure the flow rate Q through the circuit using the measuring tank and take the readings h_1 and h_2 of the two piezometer tubes connected to the 13.7 mm diameter straight pipe (the pipe is 0.914 m long). The friction head loss, h_f , can be obtained from $h_f = h_1 - h_2$.
7. Repeat the above procedure for seven more flow rates, obtained by closing the gate valve, equally spaced over the full range.
8. Repeat the above procedure for the sudden pipe expansion (light blue circuit) and note that the head loss in this case is to be calculated from the energy equation.

6) <u>PRESENTATION OF RESULTS</u>

1. It is required to plot a graph between $\log h_f$ and $\log V$ to obtain the values of K and n in equation (6) for turbulent flow in a pipe. Make sure that $Re>2000$ for all points to ensure that the flow is turbulent.
2. Calculate f and Re for every flow rate and use Figure (1) to estimate the relative roughness, k_5/D, of the pipe.
3. For the head loss in a sudden pipe enlargement, you are required to determine the head loss experimentally by using equation (9) and compare the results with the theoretical prediction given in equation (7).
4. Show the above comparison graphically on h_L vs Q plot.

7) <u>Possible Additional Work (20% extra credit)</u>

It is required to carry out an experiment using the pipe flow apparatus to determine the loss coefficient for the miter bend in the dark blue circuit. You are expected to take measurements at three different flow rates and the loss coefficient should be based on the average value. Note that the pressure tapes available in the apparatus are not exactly at the inlet and exit sections of the miter bend.