SJSU ME115 - THERMAL ENGINEERING LAB
EXPERIMENT NO: F5

Losses in Piping Systems

Objective
One of the most common problems in fluid mechanics is the estimation of pressure loss. It is the objective of this experiment to enable pressure loss measurements to be made on several small bore pipe circuit components such as pipe bends valves and sudden changes in area of flow.

Description of Apparatus

The apparatus is shown diagrammatically in Figure 1. There are essentially two separate hydraulic circuits one painted dark blue, and the other painted light blue, but having common inlet and outlets. A hydraulic bench is used to circulate and measure water. Each one of the two pipe circuits contain a number of pipe system components. The components in each of the circuits are as follows:

Dark blue circuit

1. Gate Valve
2. Standard Elbow Bend
3. 90° Mitre Bend
4. Straight Pipe

Light blue circuit

5. Globe Valve
6. Sudden Expansion
7. Sudden Contraction
8. 150 mm 90° Radius Bend
9. 100 mm 90° Radius Bend
10. 60 mm 90° Radius Bend

In all cases (except the gate and globe valves) the pressure change across each of the component is measured by a pair of pressurized piezometer tubes. In the case of the valves, pressure measurement is made by U-tubes containing mercury.

Theoretical Background

For an incompressible fluid flowing through a pipe (Fig. 2) the following equations apply:

$$Q = V_1 A_1 = V_2 A_2 \qquad (continuity) \tag{1}$$

$$Z_1 + P_1 / \rho g + V_1^2 / 2g = Z_2 + P_2 / \rho g + V_2^2 / 2g + h_{L1-2} \tag{2}$$

(Bernoulli's equation)

Head Loss

The head loss in a pipe circuit falls into two categories:

a) that due to viscous resistance extending throughout the total length of the circuit

b) that due to localized affects such as valves, sudden changes in area of flow and bends.

The overall head loss is a combination of both these categories. Because of the mutual interference that exists between neighboring components in a complex circuit, the total head loss may differ from that estimated from the losses due to the individual components considered in isolation.

Head loss in straight pipes

The head loss along a length L of straight pipe of constant diameter d is given by the expression:

$$h_L = 2f\ L V^2 / gd \ \Rightarrow \ f \ = \frac{h_L g d}{2LV^2} \tag{3}$$

where f is a dimensionless constant (i.e. friction factor) which is a function of the Reynold's number of the flow and the roughness of the internal surface of the pipe.

Head loss Due to Sudden Changes in Area of Flow

i) Sudden Expansion - The head loss at a sudden expansion is given by

(Figure 3) and its expression is:

$$h_L = (V_1 - V_2)^2 / 2\,g \tag{4}$$

ii) Sudden contraction - The head loss at a sudden contraction is given by

(Figure 4) and its expression is:

$$h_L = K V_2^2 / 2g \tag{5}$$

where K is a dimensionless coefficient which depends upon the area ratio as shown in Table I.

Table 1: Loss Coefficient for Sudden Contractions

A_2/A_1	0	0.1	0.2	0.3	0.4	0.6	0.8	1.10
K	0.50	0.46	0.41	0.36	0.30	0.18	0.06	0

<u>Head loss Due to Bends</u>

The headloss due to a bend is given by the expression:

$$h_B = K_B V^2/2g \tag{6}$$

where K_B is a dimensionless coefficient which depends on the bend radius/pipe radius ratio and the angle of the bend. It should also be noted that the loss given by this expression is not the total loss caused by the bend but the excess loss above that which would be caused by a straight pipe equal in length to the length of the pipe axis.

<u>Head loss Due to Valves</u>

The head loss due to a valve is given by the expression:

$$h_L = KV^2/2g \tag{7}$$

where the value of K depends upon the type of valve and degrees of opening. Table 2 gives typical valves of loss coefficients for gate and globe valves.

Table 2: Loss Coefficient

Valve type	K
Globe valve, fully open	10.0
Gate valve, fully open	0.2
Gate valve, half open	5.6

Principles of Pressure Loss Measurements

a) **Pressure Loss Between Two Points at Different Elevations**

Considering Fig. 5, applying Bernoulli's equation between 1 & 2, gives:

$$Z + P_1/\rho g + V_1^2/2g = P_2/\rho g + V_2^2/2g + h_L \quad (8)$$

but $V_1 = V_2, \Rightarrow h_L = Z + P_1 - P_2/\rho g$ (9)

Consider piezometer tubes:

$$P = P_1 + \rho g[Z - (x + y)] \quad (10)$$

also $P = P_2 - \rho gy$ (11)

giving: $x = Z + (P_1 - P_2) / (\rho g)$ (12)

Comparing equations 9 and 12 gives:

$$h_L = x \quad (13)$$

b) **Pressure Loss Across Valves**

Considering Fig. 6, since 1 & 2 have the same elevation and pipe diameter; Bernoulli's equation when applied between 1 & 2 becomes:

$$P_1/\rho g = P_2/\rho g + h_L \quad (14)$$

$$h_L = (P_1 - P_2) / (\rho_{H_2O}\, g)$$

Consider U-tube. Pressure in both limbs of U-tube are equal at level 00. Therefore equating pressures at 00:

$$P_2 - \rho_{H_2O} (x + y) + \rho_{Hg}\, gx = P_1 - \rho_{H_2O}\, gy \quad (15)$$

giving, $P_1 - P_2 = xg (\rho_{Hg} - \rho_{H_2O})$ (16)

hence, $P_1 - P_2 = xg\, \rho_{H_2O} (\rho_{Hg}/\rho_{H_2O} - 1)$

$$P_1 - P_2 / g\, \rho_{H_2O}\, x (\rho_{Hg}/\rho_{H_2O} - 1)$$

Taking $\rho_{Hg} / \rho_{H_2O} = S$ (specific gravity of mercury, 13.6)

$$P_1 - P_2 / g\, \rho_{H_2O} = x(S - 1) = 12.6x \quad (17)$$

Comparing equations 14 & 17:

$$h_L = 12.6\ x \qquad (18)$$

Experimental Procedure

1. Open fully the water control on the hydraulic bench.

2. With the globe valve closed, open the gate valve fully to obtain maximum flow through the dark blue circuit. Record the readings on the piezometer tubes and the U-tube. Measure the flowrate by timing the level rise in the volumetric tank.

3. Repeat the above procedure for a total of ten different flow rates obtained by closing the gate valve, equally spaced over the full flow range.

4. With a simple mercury in glass thermometer record the water temperature in the sump tank.

5. Close the gate valve, open the globe valve and repeat the experimental procedure for the light blue circuit.

NOTE: BEFORE SWITCHING OFF THE PUMP, CLOSE BOTH THE GLOBE VALVE AND THE GATE VALVE. THIS PREVENTS AIR GAINING ACCESS TO THE SYSTEM AND SO SAVES TIME IN SUBSEQUENT SETTING UP.

Report (Data Analysis)

In addition to tables showing all experimental results, the report must include the followings:

i) **Dark blue circuit experiment**

a) Obtain the relationship between the straight pipe head loss and the volume flow rate (h_L & Q^n) by plotting log h_L against log Q (log h_L vs. log Q).

b) Plot friction factor data versus Reynold's number for the straight pipe (L = 0.914 m, D = 13.7 mm). Also, obtain relationship between f & Re^n, by plotting log f against log Re. Comment on your result by comparing with the literature given equations (i.e $f = 0.04\ Re^{-0.16}$ for $4000 < Re < 10^7$ & $f = 0.079\ Re^{-1/4}$ for $4000 < Re < 10^5$).

c) Obtain the value of K for the gate valve when it is fully opened and compare with literature (Table 2).

d) Discuss head losses in 90° Mitre and Standard Elbow bend.

i) **Light blue circuit experiment**

a) If head rise across a sudden expansion(13.7 mm / 26.4 mm) is given by expression $h_L = \dfrac{0.396V_1^2}{2g}$ .Compare this head rise with the measured head rise. Plot the measured and the calculated head rise.

b) If head loss due to sudden contraction (26.4 mm / 13.7 mm) is given by the expression $h_L = \dfrac{1.303V_2^2}{2g}$. Compare this fall in the head with the measured head loss. Plot the measured and calculated fall in head due to sudden contraction.

c) Obtain the value of K for the globe valve when it is fully opened and compare with literature (Table 2).

d) What is the effect of bend radius on head losses?

Reference:

Beek, W.J. & K.M. Muttzall, **Transport Phenomena**, John Wiley (1975).

Denn, M.M. **Process Fluid Mechanics**, Prentice-Hall (1980).

de Nevers, Noel, **Fluid Mechanics for Chemical Engineers**, McGraw-Hill, Singapore (1991)

Notation:

Q volumetric flowrate, (m^3/s)

V mean velocity, (m/s)

A cross-sectional area, (m^2)

Z height above datum, (m)

P static pressure, (N/m^2)

h_L head loss, (m)

ρ density, (kg/m^3)

g acceleration due to gravity, (9.81 m/s^2)

f	Friction factor
d	Diameter of pipe, (m)
L	Length of pipe, (m)
K	Loss Coefficient
K_B	Loss coefficient due to bends
Re	Reynolds Number

Prepared by: Mr. N. M. Tukur

Identification of Manometer Tubes & Components

Manometer	Unit
1	Standard elbow bend
2	
3	Straight Pipe
4	
5	90^{o} Mitre Bend
6	
7	Expansion
8	
9	Contraction
10	
11	100 mm bend
12	
13	150 mm bend
14	
15	50 mm bend
16	

Date:_______________

EXPERIMENTAL RESULTS FOR DARK BLUE CIRCUIT(Expt#F5)

Test #	Flowrate		Piezometer tube Readings (mm) water			U-Tube (mm) Hg
	Vol. (Liter)	Time (s)	1 2	3 4	5 6	Gate Valve
*1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

*Valve fully open Water Temperature =

Date:_____________

EXPERIMENTAL RESULTS FOR LIGHT BLUE CIRCUIT(Expt#F5)

Test #	Flowrate		Piezometer tube Readings (mm) water					U-Tube (mm) Hg
	Vol. (Liter)	Time (s)	7 8	9 10	11 12	13 14	15 16	Globe Valve
*11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

*Valve fully open Water Temperature =

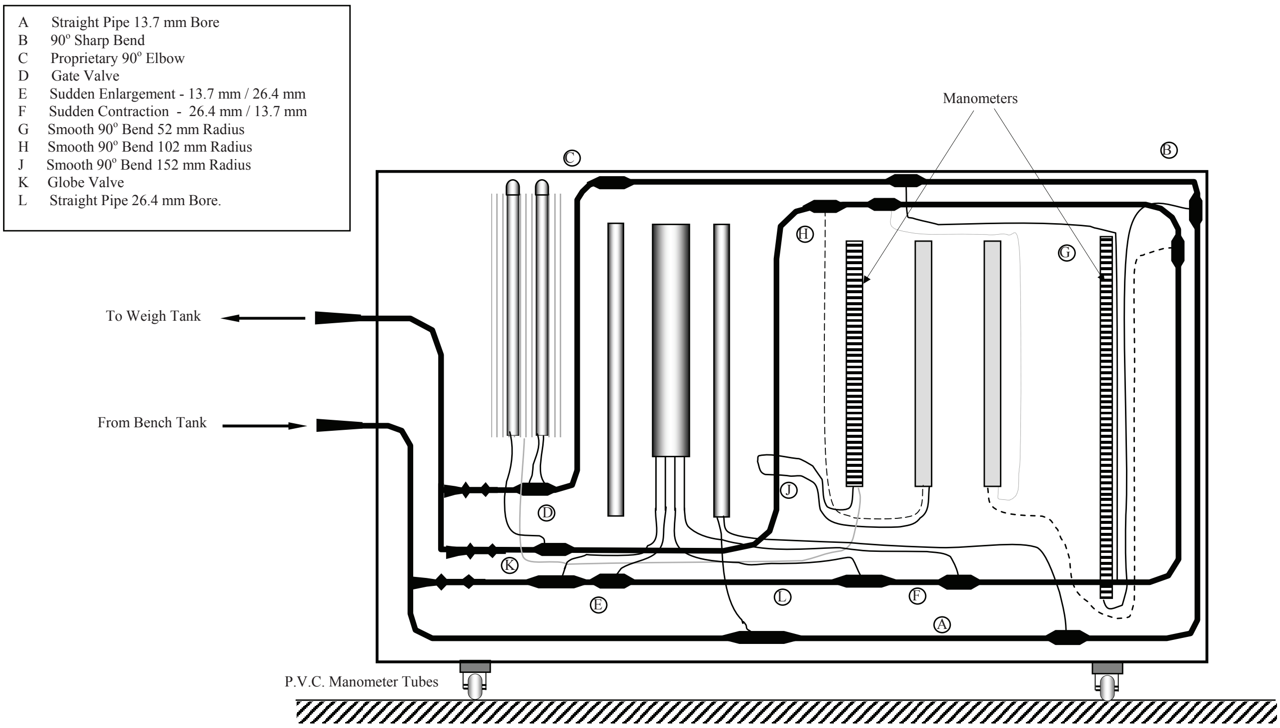

Fig. 1: Diagrammatic Arrangement of Apparatus AApparatus.

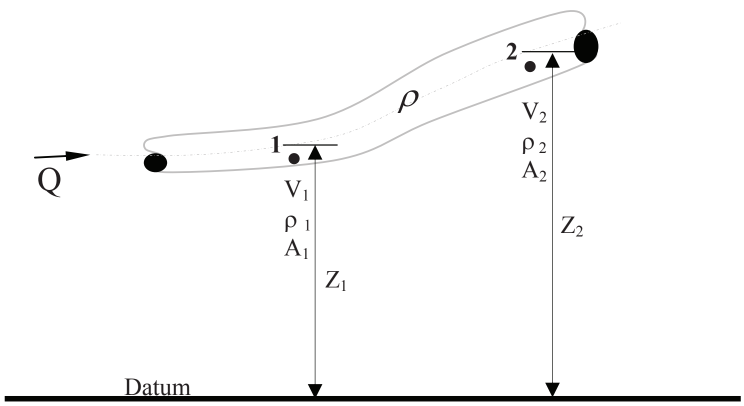

Fig. 2: An Incompressible Fluid Flowing Through a Pipe.

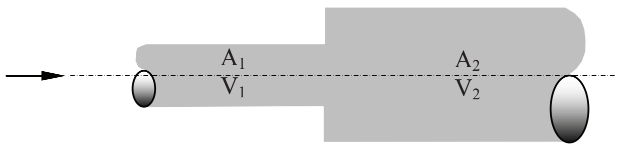

Fig. 3: A Sudden Expansion.

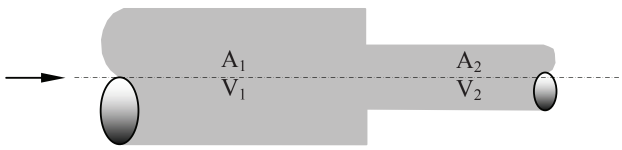

Fig. 4: A Sudden Contraction.

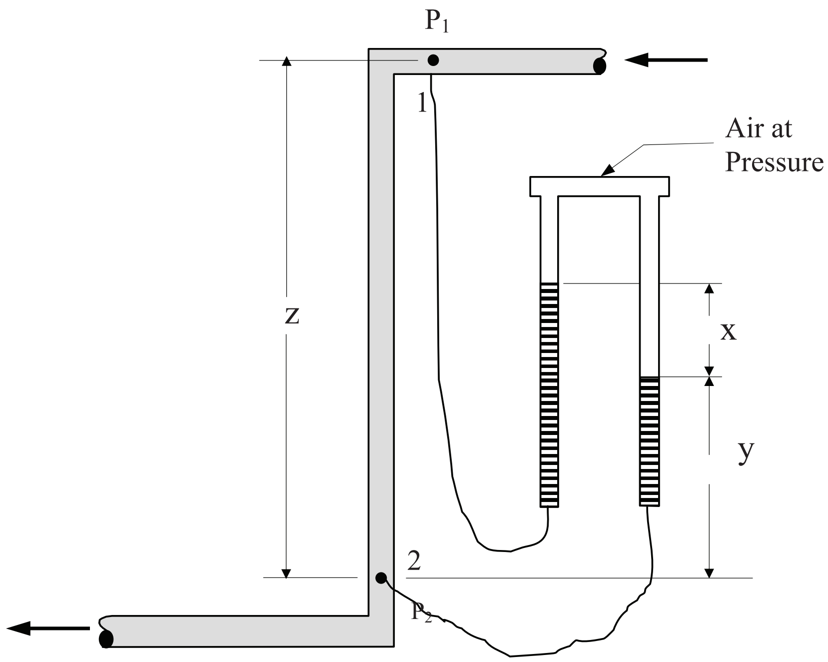

Fig. 5: Pressurized Piezzometer Tubes to measure Pressure Loss between two points at different elevations.

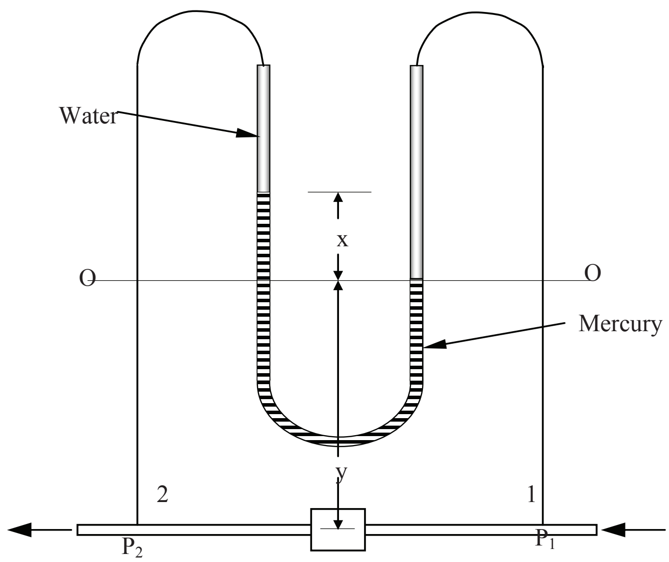

Fig. 6: U-Tube containing mercury used to measure Pressure Loss across valves.