ME 302 FLUID MECHANICS II

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EXPERIMENT II - FRICTION LOSS ALONG PIPE AND LOSSES AT PIPE FITTINGS

A. Objective:

The objective of this experiment is to meausere the pressure drop along a pipe and across sudden enlargement, and sudden contraction, and to calculate the pipe friction factor and loss coefficient for the sudden enlargement and contraction, and compare them with data, from literature.

B. Theory:

1) Loss Due to Friction

In hydraulic engineering practice, it is frequently necessary to estimate the total pressure loss (head loss) incurred by a fluid as it flows along a pipeline. Along a straight pipe pressure drops due to the friction (shear) force at the pipe surface. At the pipe fittings, pressure drops due to the fluid mixing occurs at the fittings. Pressure loss due to friction at the pipe surface is known as major loss, and pressure loss at pipe fittings is called minor (local) losses.

Consider flow of a fluid through a pipe as shown below.

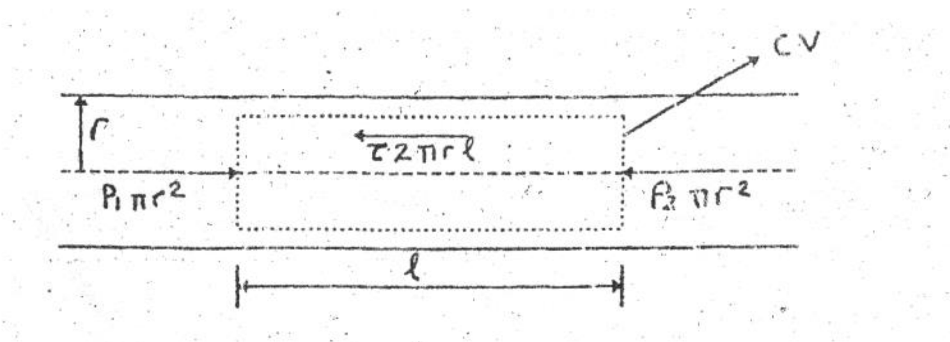

Figure 1. How of a fluid through a pipe.

A cylindrical control volume (CV) of length l is defined in the pipe. The diameter of the CV is D(=2r). For steady flow through the pipe, conservation of mass (continuity) requires that mass flow rate into the CV equals the mass flow rate out of the CV. Therefore,

$$\dot{m}_i = \dot{m}_o \tag{1}$$

where $m=\rho AV$. Forces act on all of the boundaries of the CV and are indicated above. The forces on the ends of the CV are caused by a pressure acting over an area. The forces on the circumferences is due to the friction between the fluid and the wall. Since the CV is defined to be stationary, the sum of the forces acting .on the CV must equal zero (conservation of momentum). This force balance can be written as.

$$P_1\pi r^2 - P_2\pi r^2 - \tau_w 2\pi r l = 0$$

or (2)

$$\Delta P = P_2 - P_1 = -\tau_w 4l / D$$

From Eq. 2, we see that all wall shear stress, τ_W, which is a measure of the friction between the fluid and the wall, causes a decrease in pressure of the fluid as it flows through a pipe. Eq. 2. can be applied to a pipe or channel having an arbitrary cross-section if D_h, the equivalent hydraulic diameter, is substituted for D. D_h is defined as

D_h=4(Cross-sectional area of flow)/(Perimeter wetted by fluid) (3)

It is easy to show that for a circular pipe, Dh=D and for a square duct, Dh=s, the length of one side. Therefore, in general, we can write,

$$\Delta P = P_2 - P_1 = -\tau_w 4l / D_h \quad (4)$$

The wall shear stress is a complex function of the velocity, viscosity, density, wall surface roughness, etc. Analytical expressions for τ_W can be developed for both laminar and turbulent flows, but in practical situations, accounting for the wall surface roughness is difficult. Because of the complexity of determining τ_W, it is customary to express the pressure drop, ΔP, as a product of a non-dimensional friction factor, f, and the dynamic pressure ($\rho V^2/2$). So

$$\Delta P = f(1/D_h)(\rho V^2/2) \quad (5)$$

Eq.4 and Eq.5, we obtain

$$f = 8\tau_w/(\rho V^2) \quad (6)$$

Therefore, the friction factor, f, is a measure of the shear stress at the wall. A more detailed treatment of the wall shear stress and the friction factor both laminar and turbulent flows is found in Ref. l Sec 8.7.

A dimensional analysis of the pressure drop through a pipe shows that the friction factor,f, is a function of the flow Reynolds number and the non-dimensional surface roughness, ε/D_h, where ε is the surface roughness height and D_h is defined by Eq.3 (See Ref 1. sections 7.1 - through 7.4). The Reynolds number is given as

$$\mathrm{Re} = \rho V D_h / \mu$$

where ρ and μ are the density and absolute viscosity of the fluid, respectively, and V is the mean velocity, in this experiment, the friction factor will be determined for a number of pipe flow configurations and analyzed as a function of the Reynolds number.

2) Pressure Drop at Pipe Components

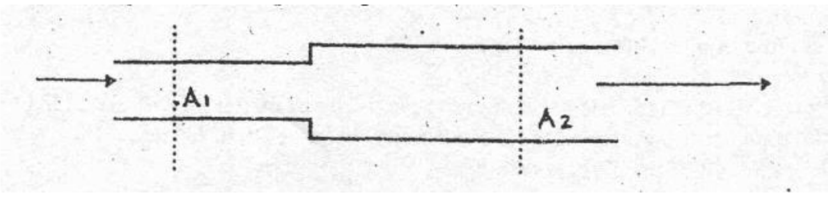

Figure 2. Sudden enlargement.

Pipe components, such as bends, elbows, tees, valves etc., can also contribute significantly to the total pressure drop of the system. Fig. 2 shows the flow pattern through a sudden expanding duct. This flow is very complex and its description would not only include frictional effects associated with wall roughness but also a non-uniform velocity profile across the pipe. Even with these complexities, the pressure drop across these components can be represented as,

$$\Delta P = k(\rho V^2 / 2) \quad (7)$$

where k is the loss coefficient. The value k depends on the geometry of the component being considered and, because of the complex flow patterns through most of these devices, must be determined by experiment. Values of the loss coefficient for various pipe components are shown in Table 1. Notice that the values can range from very near to zero for a rafter smooth pipe connection to practically infinity for a partially closed valve. A table of the loss coefficient for sudden expansion and sudden contraction is given in the Table 2,3. In this experiment you will measure the loss coefficient for a suddenly expanding and for a suddenly contracting duct shown below. Your measured loss coefficient for several flow conditions will be compared to those obtained from Table 2.

C. Equipment:

The experiments will be performed using the equipment shown in Fig. 3. This test facility consist of a fan, removable pipes and pipe fittings and inclined manometers. In Fig. 3, points P_0, P_1, P_2, P_3 are the points where manometers will be connected.

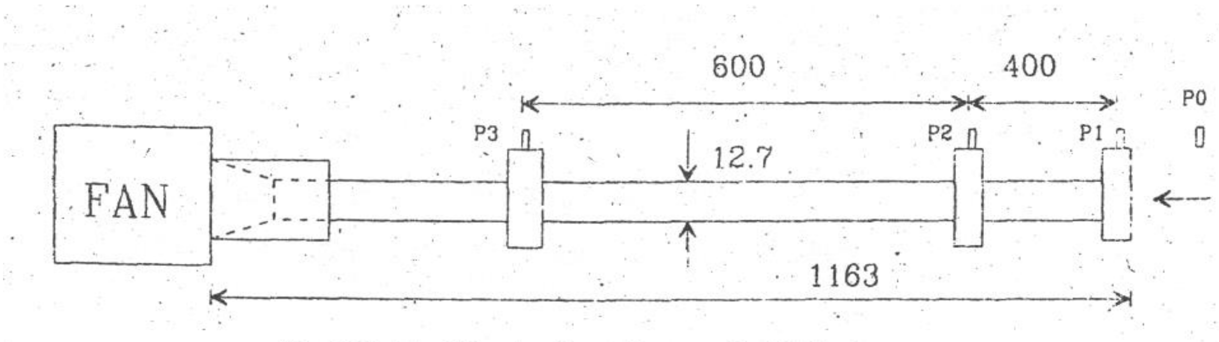

Fig. 3. Sketch of the experimental system for friction loss measurement

Sudden enlargement and sudden contraction loss measurement will be also performed using the same equipment. As seen in the Fig. 4, two pipes with different diameters are connected to form a sudden enlargement and a sudden contraction flow. In Fig. 4, points P_0,P_1,P_2,P_3 are the point where the manometers will be connected.

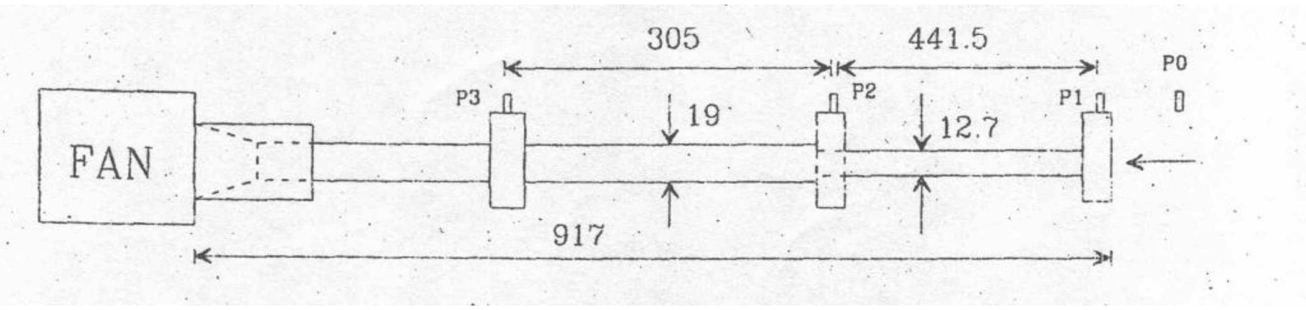

Fig. 4 Sketch of the experimental system for measurement of the loss coefficient at a sudden enlargement

D. Procedure:

Throughout this laboratory, a manometer will be used to measure pressure differences. A manometer operates on the principle that the height of a fluid can be related to a pressure difference. Accurate pressure measurement can be made only if one is familiar with the operating principal. A description of manometer operation and related terminology can be found in Ref. 2.

After connecting manometers, set motor to different speed and measure the pressure difference P0-P1 for different flow rates.

E. Pre-Lab:

After reviewing the experimental produces, prepare a data sheet on which you record your experimental measurements and observations. Bring this sheet to the lab with you.

F. Data Analysis and Reporting Requirements

1. Using the measured pressure value and employing the Bernoulli equation between a point outside the pipe and the point where pressure is measured calculate the flows velocity and flow rate.
2. Calculate The Reynolds number.
3. Using Eq. 5 calculate friction factor f for each test condition.
4. Using Eq. 7, calculate the loss coefficient k at sudden enlargement and sudden contraction for different flow conditions.
5. Plot the friction factor f as a function of Reynolds number.
6. Compare your measured data to the published data and comment on how they differ.

G. References:

1. Fox, Robert W. and McDonald, Alan T., Introduction to Fluid Mechanics, John Wiley and Sons, 1985.
2. Holman. J. P., Experimental Methods for Engineers, 3rd Edition, McGraw Hill, 1978.

Table 1. Loss Coefficients for Pipe Components $(\Delta p = K_L \frac{\rho V^2}{2})$

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
e. Valves	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, ¼ closed	0.26
Gate, ½ closed	2.1
Gate, ¾ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, ⅓ closed	5.5
Ball valve, ⅔ closed	210

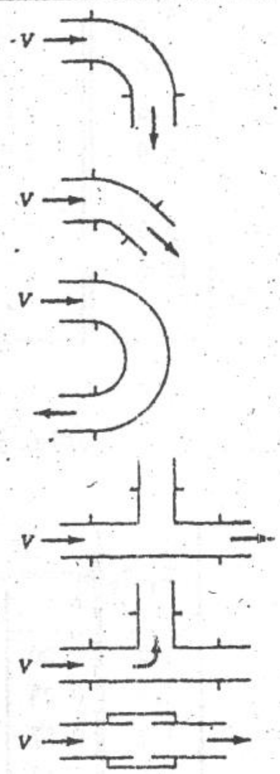

Table 2. Head loss coefficients for the sudden enlargement

d_2/d_1	Theoretical k	Experimental k, Velocity, V_1 (m/s) 0.60	1.20	3.00	4.50	6.00	9.00	12.00
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2	0.10	0.11	0.10	0.09	0.09	0.09	0.09	0.09
1.4	0.24	0.26	0.25	0.23	0.22	0.22	0.21	0.20
1.6	0.37	0.40	0.38	0.35	0.34	0.34	0.33	0.32
1.8	0.48	0.51	0.48	0.45	0.43	0.42	0.41	0.40
2.0	0.56	0.60	0.56	0.52	0.51	0.50	0.48	0.47
2.5	0.71	0.74	0.70	0.65	0.63	0.62	0.60	0.58
3.0	0.79	0.83	0.78	0.73	0.70	0.69	0.67	0.65
4.0	0.88	0.92	0.87	0.80	0.78	0.76	0.74	0.72
5.0	0.92	0.96	0.91	0.84	0.82	0.80	0.77	0.75
10.0	0.98	1.00	0.96	0.89	0.86	0.84	0.82	0.80
∞	1.00	1.00	0.98	0.91	0.88	0.86	0.83	0.81

Table 3. Head loss coefficients for the sudden contraction

d_1/d_2	Velocity, V_2 (m/s) 0.6	1.2	1.8	2.4	3.0	3.6	4.5	6.0	9.0	12.0
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.1	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.06
1.2	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.10	0.11
1.4	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.20
1.6	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.24
1.8	0.34	0.34	0.34	0.33	0.33	0.32	0.32	0.31	0.29	0.27
2.0	0.38	0.37	0.37	0.36	0.36	0.34	0.34	0.33	0.31	0.29
2.2	0.40	0.40	0.39	0.36	0.38	0.37	0.37	0.35	0.33	0.30
2.5	0.42	0.42	0.41	0.40	0.40	0.39	0.38	0.37	0.34	0.31
3.0	0.44	0.44	0.43	0.42	0.42	0.41	0.40	0.39	0.36	0.33
4.0	0.47	0.46	0.45	0.45	0.44	0.43	0.42	0.41	0.37	0.34
5.0	0.48	0.47	0.47	0.46	0.45	0.45	0.44	0.42	0.39	0.35
10.0	0.49	0.48	0.48	0.47	0.46	0.46	0.45	0.43	0.40	0.36
∞	0.49	0.48	0.48	0.47	0.47	0.46	0.45	0.44	0.41	0.38