Experiment 3: Closed Conduit Flow

Key Concepts: Friction Factor, Reynolds Number,

Minor Losses, Grade Lines

Refer to: Roberson & Crowe, 7th ed., Chapter 7, pp. 270-293

See also: Chapter 10, pp. 403-432

I. Introduction

The losses of energy in conduits flowing full of a liquid usually result from the resistance of the conduit walls to the flow (pipe friction), or from pipe appurtenances (e.g. elbows, contractions, valves) which cause the flow velocity to be changed in magnitude and/or direction. These losses must be calculated so that, for example:

- the proper size and number of pumps can be specified in the design of a municipal water distribution system;
- the conduit size for a gravity-flow urban drainage project may be determined;
- the optimum size of valves and the radius of curvature of elbows can be stipulated in the specifications of a pipeline design.

When the ratio of the length of the pipeline, L, to the diameter, D, exceeds 2000:1, pipe system energy losses are predominantly the result of pipe friction. The energy losses resulting from pipe appurtenances are termed *"minor"* losses and are usually neglected in the calculation of pipe system energy losses. In short lengths of pipe, however, these minor losses can become *major* sources of energy loss.

The **Darcy-Weisbach** equation is used to express energy loss caused by pipe friction, h_f:

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \qquad (1)$$

where f is the dimensionless Darcy-Weisbach friction factor, V is the average fluid velocity, and g is the acceleration of gravity.

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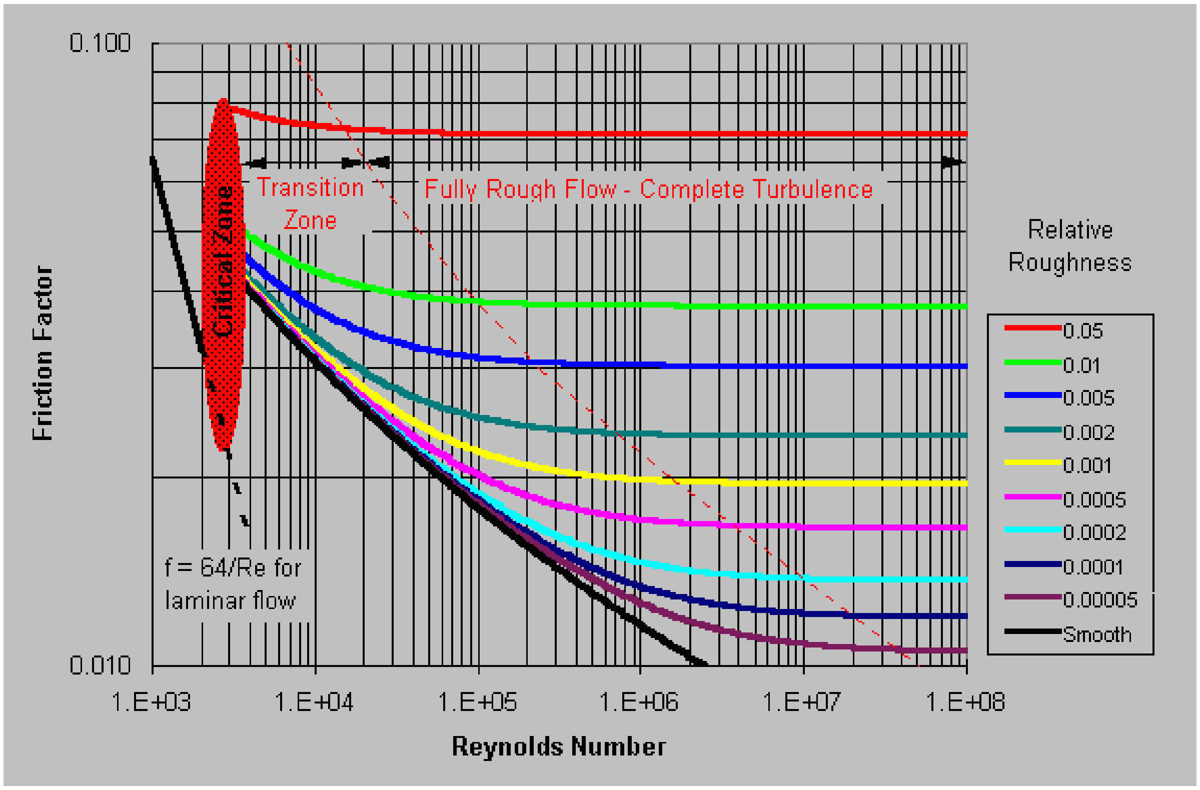

Figure 10. Moody Diagram [Note: this Moody Diagram is for illustration purposes only. Refer to the Moody Diagram in your text for all calculations.]

For pipe flow, the **Moody diagram** (see Figure 10) was developed to show the relationship between the friction factor, the relative roughness of the pipe, ε, and **Reynolds number** (see “Dimensionless Fluid Parameters” on page 8). On the Moody diagram there are three zones of flow: laminar, transitional, and turbulent. In lieu of the Moody diagram, the following equations (Table 1) may be used to determine f for *smooth* pipes ($\varepsilon \rightarrow 0$), where f is a function of the Reynolds number only:

	R_e	f
Laminar	$R_e < 2000$	$f = 64/R_e$
Transitional	$2000 < R_e < 10^5$	$f = 0.316/R_e^{0.25}$
Turbulent	$R_e > 10^5$	$1/\sqrt{f} = 2.0 \log[(R_e\sqrt{f}) - 0.8]$

Table 1. Friction Factor equation for three flow regimes

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The energy loss may also be expressed as:

$$h_f = ZLV^n \tag{2}$$

Refer to "Analysis of Log-Log Plots" on page 9 for the procedure to determine n and Z. The values of n and Z are functions of the type of flow, i.e., laminar, transitional, or turbulent.

The losses due to appurtenances (minor losses) in pipe flow are usually expressed as:

$$h_L = K\frac{V^2}{2g} \tag{3}$$

where K is the dimensionless head loss coefficient related to the type of appurtenance. Typical K values can be found in most hydraulics textbooks.

Consider the energy equation for steady, incompressible, viscid, turbulent flow:

$$\frac{p_1}{\gamma} + h_1 + \frac{V_1^{\,2}}{2g} = \frac{p_2}{\gamma} + h_2 + \frac{V_2^{\,2}}{2g} + h_{L(1-2)} \tag{4}$$

where p_i/γ is pressure head at point i, h_i is elevation head at point i, $V_i^2/2g$ is velocity head at point i, and $h_{L(1-2)}$ is the head loss between points 1 and 2. Each of these terms has units of length.

The sum of pressure head, elevation head and velocity head at a particular point is the total head at that point. A plot of total head vs. distance from the pipe entrance is an **energy grade line (EGL).** In fact, an EGL is simply a spatial representation of the total energy. For a real fluid, $h_{L(1-2)} > 0$, so the EGL must slope downward in the direction of flow.

The sum of the pressure head and elevation head at a particular point is the piezometric or static head at that point. A plot of piezometric head vs. distance from the pipe entrance is a **hydraulic grade line (HGL).** The vertical distance between the EGL and the HGL at a particular point is, by definition, the velocity head at that point.

Figure 11 shows the EGL and HGL for a horizontal constant diameter pipe with flow from left to right. Note the EGL slopes downward in the direction of flow and $h_L = h_1 - h_2$ equals the head loss over the length of the pipe. Furthermore, the difference in total head between <u>any</u> two points represents the head loss between those two points.

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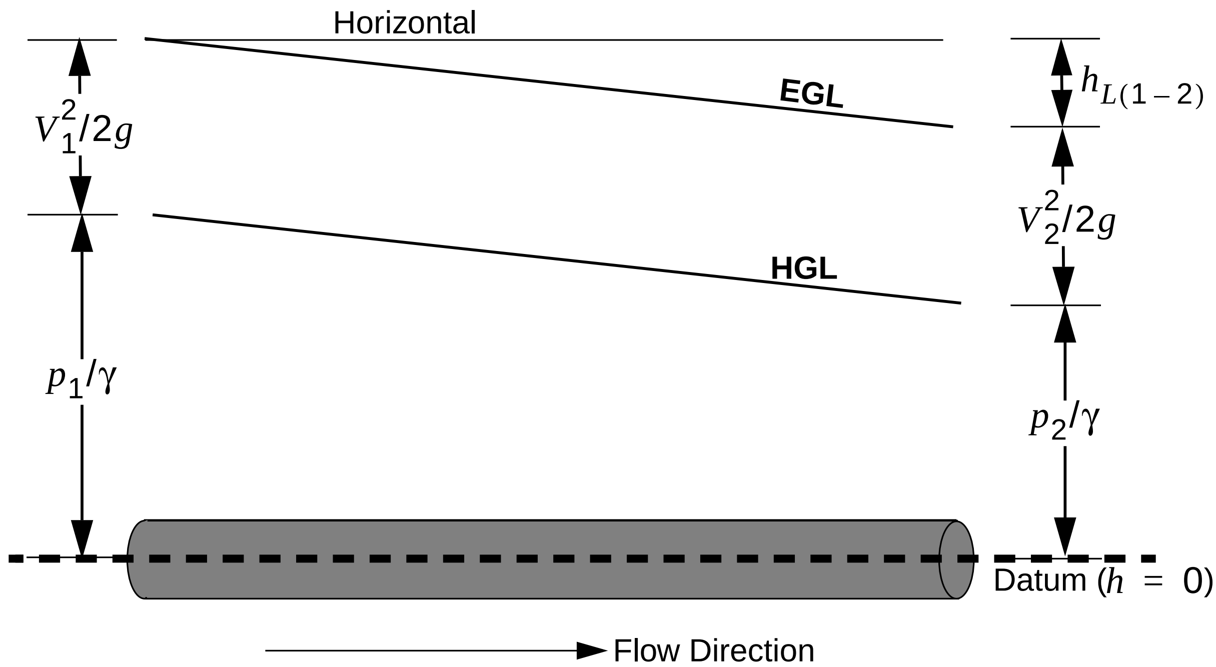

Figure 11. Energy and hydraulic grade lines

Note also that the EGL and HGL are parallel, this implies that the velocity head ($V^2/2g$) is constant over the length of the pipe. Since ‘2’ and g are constants, clearly the velocity is also constant.

Finally, the distance between the HGL and the centerline of the pipe represents the pressure head. In this case, the loss in total energy is reflected in the loss of pressure head only, as elevation and velocity heads are constant over the length of the pipe.

II. Objective

Determine the energy loss for pipelines in which a steady-state flow exists. Also determine the head loss coefficients for an orifice meter, a venturi meter, and a gate valve one-half open and full open. Compare measured K values to authoritative sources. Compare the head losses through different size pipes at the same flow rate.

III. Anticipated Results

At a minimum, you should be able to anticipate:

1) Authoritative K values for the valves and the meters.
2) Mathematically determine the Z and n values for each pipe size.
3) The relative roughness of the pipe.

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IV. Apparatus

1) Constant head tank and pump.
2) Copper drawn-tubing pipes with gate valves and pressure taps.
3) Piezometric tubes attached to a differential manometer. The differential manometer is read by taking the difference between the two readings. Note that at some points, one or both of the readings may be “negative” on the scale. Make sure that the total difference is being recorded.
4) Control valve.
5) Orifice and venturi meters.
6) Flow rate calibration chart.
7) Thermometer, yard stick.

V. Procedure

1) Measure the distance between the pipeline pressure taps. Measure and record the cross-sectional area of the meter test sections.
2) Check the water level in the reservoir and measure the water temperature (use ambient air temperature if it is not possible to measure the water temperature). There should be enough water in the tank to fill the pipes at full flow and maintain a sufficient amount of head above the pump inlet.
3) Study the conduit flow system starting at the pump and identify potential pathways for water flow.
4) Close all valves. Identify and open all valves which will route the water from the pump, through the 1” test section, through the meters, and back to the storage tank. The 1” line will be tested first. Ensure that the control valve (located immediately downstream from the meters) is open.
5) Start the pump. If water does not begin to travel through the meters within a short period of time, shutdown the pump and reevaluate the valve status.
6) Bleed the system of air (wait a few moments while the system runs). Visually inspect the meters to insure that air is out of the system.
7) Connect the manometer tubing to the calibration taps (the middle and upstream taps) of the Venturi meter. Determine the flow rate using the calibration chart.
8) For this experiment, four flowrates will be required. “Good” flow rates range from 250 to 420 gph. Choose four flowrates spread over this range (e.g. 250, 300, 350, 400). Adjust the control valve as needed to obtain the first flow rate.
9) Connect the manometer tubing to the calibration taps (the middle and upstream taps) of the orifice meter. Check the flow using the observed deflection. If the flow rates match, the flow rate has been calibrated successfully.
10) Connect the manometer tubing to the headloss taps (the outer taps) on one of the meters and record the manometer reading. Repeat for the second meter.
11) Connect the manometer tubing to the first and second pipeline taps of the 1” line. Record the deflection.
12) Connect the manometer tubing to the second and third taps of the same line and record the deflection.
13) Connect the manometer tubing to the pressure taps on both sides of the 1” gate valve. Record the deflections at fully open and half open. Use the sample valve hanging on the instrument to determine how many turns are needed for

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half open.

14) Perform data control before changing the flow rate.
15) Open the valves for the 3/4” line and then close the valves for the 1” line. Attach the manometer tubing to the Venturi meter and readjust to the selected flow rate. Repeat steps 11 through 13 for the 3/4” pipe and gate valve.
16) Repeat steps 7 through 15 for four flowrates within the “good” range.

VI. Data Control

Data control consists of a) obtaining the same discharge from each of the two meters; and b) obtaining the same rate of energy loss (head loss per unit length) along the length of each pipe.

VII. Results

1) Calculate the Reynolds number and the friction factor from Table 1 for each run. Plot this data on a copy of the Moody diagram (a better copy of the moody diagram is in your textbook). What relative roughness does the pipe appear to possess? Compare to your expected value.
2) Determine the anticipated values of Z and n for the conditions of this experiment. Use (1), Table 1, and (2) to solve for Z and n algebraically (hint: start by setting (1) and (2) equal, remember $ax^b = cx^d$, only if $a = c$ and $b = d$), then compare to your lab data by using the method described in "Analysis of Log-Log Plots" on page 9. What does this say about the headloss in the 3/4” pipe as compared to the 1” pipe. How does this compare to your expected results?

3a) Calculate the head loss coefficient, K, for the venturi meter using (3) for each flow rate. Report a representative K value for the meter. Justify your representative K value based on your calculations. Compare to known values.

3b) Repeat step 3a for the orifice meter.

4a) Repeat step 3a for the half-open gate valve,

4b) Repeat step 3a for the fully-open gate valve.

5) Draw, to scale, the energy and hydraulic grade lines for the maximum and minimum flowrates in the 1 inch pipe. Show the velocity head, pressure head, elevation head and energy lost between taps 1 and 2 on the pipe. Hint: the manometer measures the relative static head; you may need to assume an elevation value.

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VIII. Suggested Data Sheet Headings ([ ] indicate the units of measurement)

Flow meters

Run #	Flow Rate	Meter Type	Calibration Taps Manometer [ ]			Headloss Taps Manometer [ ]		
	[ ]		RHS	LHS	Δh	RHS	LHS	Δh

Pipes

Run #	FlowRate	Pipe Diameter	Tap #	Manometer [ ]		
	[ ]	[ ]	( ) to ( )	LHS	RHS	Δh

Gate Valves

Run #	FlowRate	Pipe Diameter	Gate Opening	Manometer [ ]		
	[ ]	[ ]	1/2 or full	LHS	RHS	Δh

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