53:071 Principles of Hydraulics
Laboratory Experiment #2

LOCAL LOSSES IN PIPE FLOWS

Principle

Change in flow velocity due to change in the geometry of a pipe system (i.e., change in cross-section, bends, and other pipe fittings) sets up eddies in the flow resulting in energy losses.

Introduction

Pipe systems often include inlets, outlets, bends, and other pipe fittings in the flow that create eddies resulting in head losses (also termed minor losses) in addition to those due to pipe friction. The primary effect of the presence of a pipe fitting is a drop in the energy grade line (EGL) and, consequently, in the hydraulic grade line (HGL), as it is shown in Figure 1 for a partially closed valve. Generally, this drop occurs over a distance upstream and (mostly) downstream from the location of the transition. Even though many transitions produce grade lines that have interesting local details, it is common as a gross indication to simply show abrupt changes in the EGL and HGL.

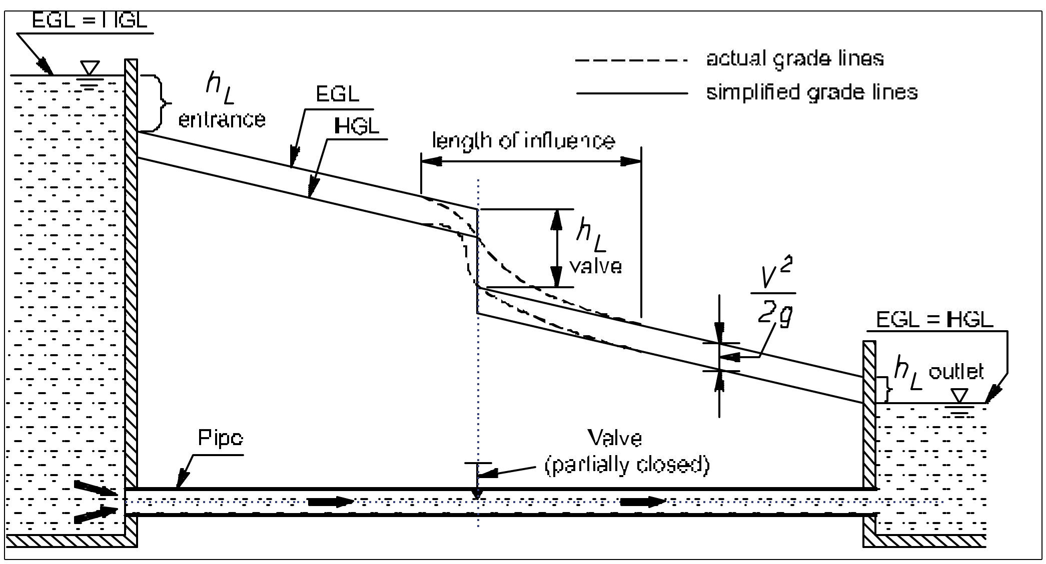

Figure 1. Local head loss through a partially closed vane

The local head loss produced by a device obstructing the pipe flow is characterized by the local loss coefficient, K, usually expressed as the ratio of the head loss through the device, h_d , to the velocity head, $V^2/2g$

$$K = \frac{h_d}{V^2/2g} \tag{1}$$

The above expression can also be re-written in terms of pipe discharge as

$$h_d = K\frac{Q^2}{2gA^2} \qquad (2)$$

The head loss coefficient, K is dimensionless, and is a function of Reynolds number. In the standard literature the head loss coefficient is not usually correlated with Reynolds number and roughness but simply with its geometry and the diameter of the pipe, implicitly assuming that the pipe flow is turbulent. This experiment is designed to determine the head loss coefficient for a designated pipe fitting and its Reynolds' number dependence.

Apparatus

The water pipe-flow assembly is located along the East wall, in the Model Annex (MA) of the Iowa Institute of Hydraulic Research (IIHR) and consists of two pipeline systems that are assembled in parallel in the same experimental facility. The first pipeline system comprises standard (rough) transitions and fittings (Figure 2.a and Appendix A). The second pipeline system has similar elements but with a streamlined (smooth) configuration (Figure 2.b and Appendix B). A pump located in a pit under IIHR's sediment flume supplies water to the pipe assembly. Water is pumped from the main storage sump, located near the pump, to the settling tank located at the upper part of the experimental setup. The role of the tank is to provide a well-conditioned flow in the pipe system. Both pipelines branch at a point to allow the user a choice of options. The right branch directs the flow to a large enclosed reservoir and then back to a weir (South weir tank) located on the right. The branch directing flow to the left delivers flow to the weir (North weir tank) located on the left. Valves control flows in either pipeline system. Two gate valves are set on the streamlined pipe system and a gate and a globe valves on the standard pipe system. Flow should exist in only one pipeline and branch at a time, therefore only one of the valves should be open

Pressure taps are located throughout the system to allow measurement of the pressure-head in the various sections of the system. The piezometric lines from the pressure taps are connected to a manifold that controls which tap is to be measured. A small cylinder located under the pipe line systems acts as a datum and is also connected to the manifold. Pressure head measurements are taken with a simple mercury manometer. The discharge is measured by triangular weirs located on the weir tanks. Water flows from the weir tanks to the pump sump. Short descriptions of some of the equipment included in the facility follow.

Pressure Tap Valve Manifold (see Figure 3.a). The manifold consists of two halves that are marked "standard" and "streamlined". The finger valves controlling the pressure taps are numbered 1-23 (note that there is no tap #10 on the standard side). For each half of the manifold there is a gage valve, a bleeding valve (at the top) and a drain valve (at the bottom).

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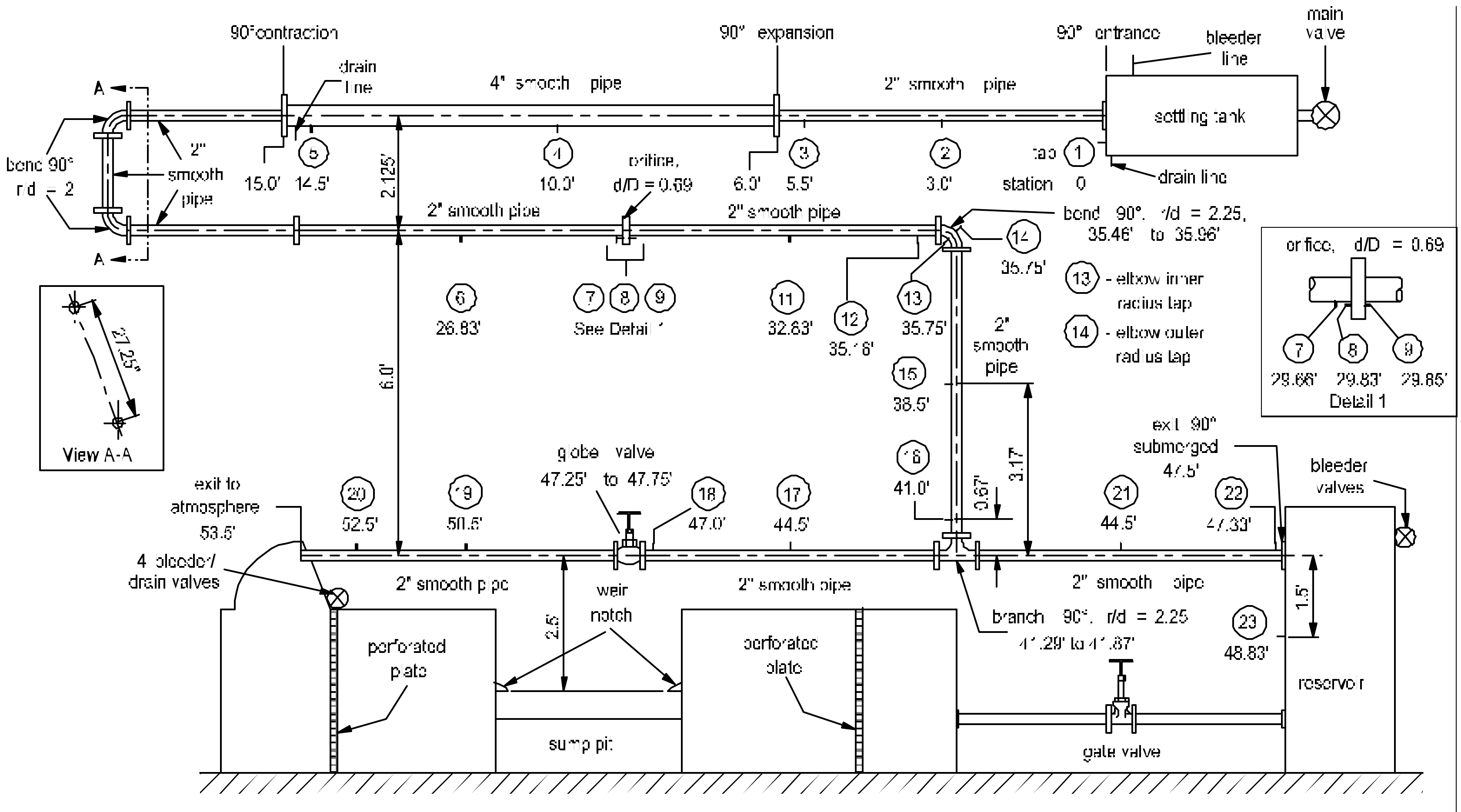

Figure 2.a. The standard pipeline assembly

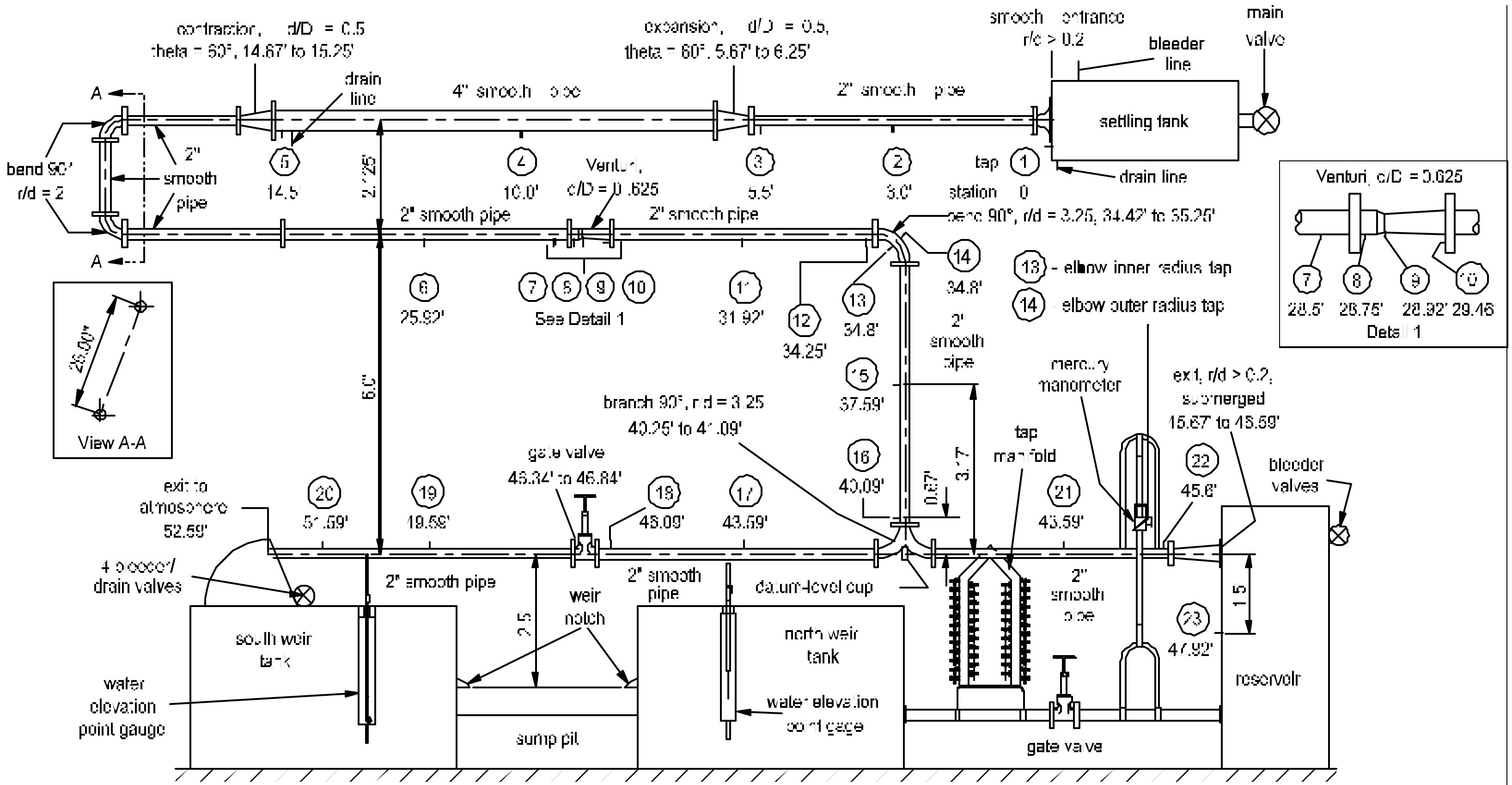

Figure 2.b. The streamlined pipeline assembly

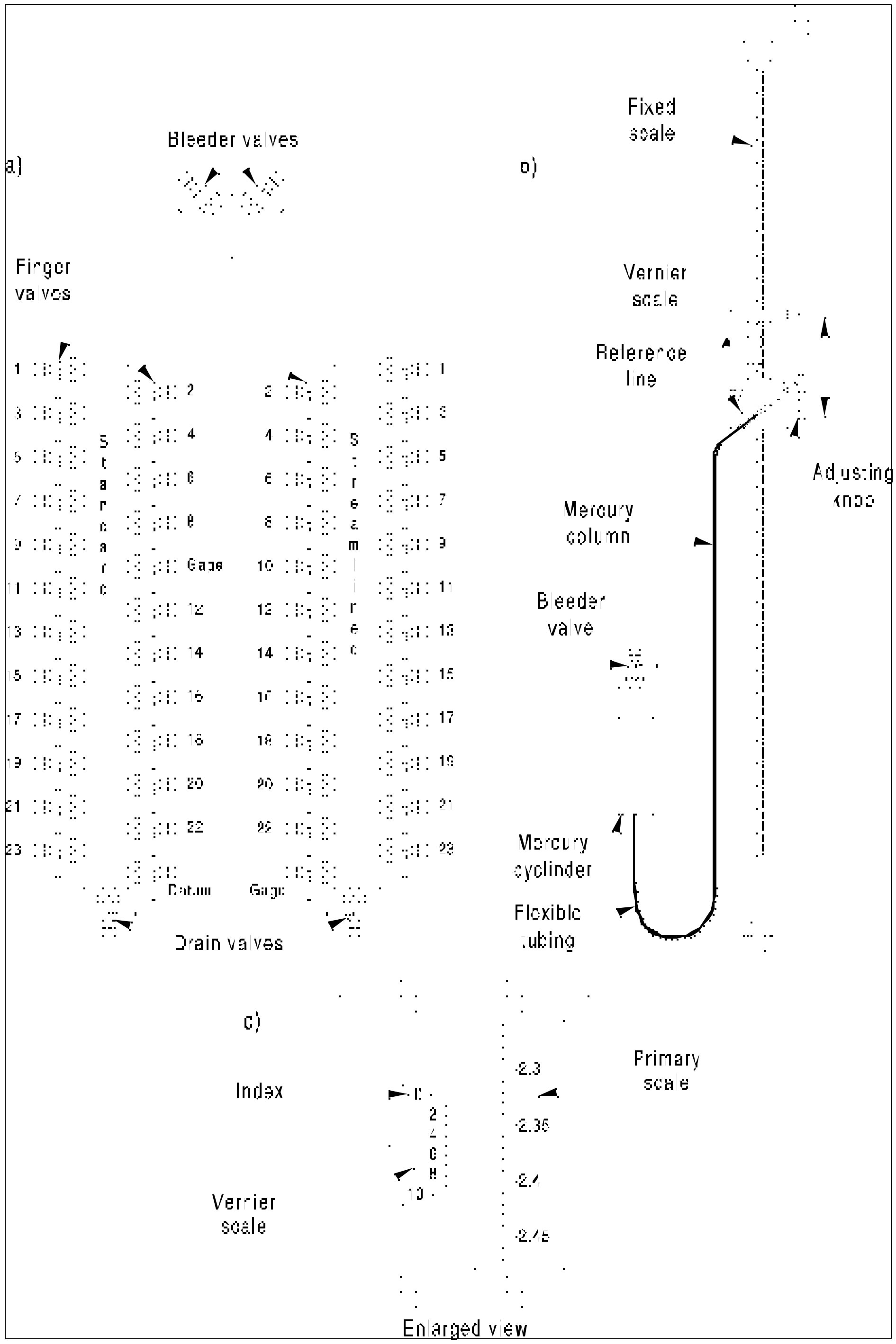
a)
Bleeder valves
Finger valves
Datum
Gage
Drain valves
b)
Fixed scale
Vernier scale
Reference line
Adjusting knob
Mercury column
Bleeder valve
Mercury cylinder
Flexible tubing
c)
Index
Vernier scale
Primary scale
Enlarged view

Figure 3. a) Pressure tap valve manifold; b) Simple manometer; c) Vernier

Simple Mercury Manometer (see Figure 3.b). This manometer measures the piezometric head at any tap along the pipelines. The manometer uses a vernier scale to allow a measurement precision up to 0.001 feet. The increments on the primary scale are 0.01 feet. The vernier scale has 10 equal increments and a total length of 0.009 feet. Therefore, the two scales do not line up exactly. The reading on the vernier corresponding to the coincident graduation on the vernier and the primary scale represents the third significant digit in the reading of the primary scale. For the example shown in Figure 3.c, the reading would be 2.323 feet.

Triangular Weir (see Figure 4). To find the discharge through the system, the flow is passed over a triangular weir. The flow discharge is a function of the water head flowing over the weir. The two weirs, located north and south on the assembly, are identical with a 60° openings. A point gauge attached to the tank is used to measure water elevations in the tank. Crest elevation of the weir is measured by allowing the weir tank to drain to the respective level of the crest. Subtracting the crest elevation from that of the water-surface elevation during the tests upstream of the v-notch weir gives the head on the weir in feet of water. The discharge, Q [cfs], over a triangular weir is given as $Q = C \times H^{5/2}$, where H is the head on the weir and C is a constant, i.e., $C = 1.434$.

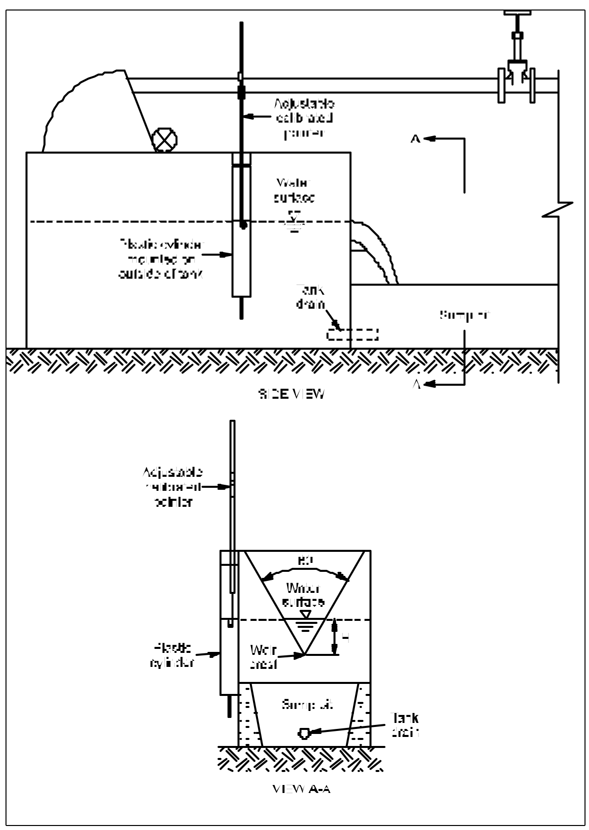

Figure 4. The weir tank and triangular weir

Procedures

Each group will be assigned one of the following pipe fittings for experimental analysis

Standard Pipe	Station	Streamlined Pipe	Station
1. Entrance from settling tank	1	1. Entrance from settling tank	1
2. Sudden expansion	3, 4	2. Sudden Expansion	3, 4
3. Orifice meter	8, 9	3. Venturi Meter	7, 11
4. 90° Bend	12, 15	4. 90° Bend	12, 15

NOTE: Only the Venturi and orifice meters have pressure tabs located immediately upstream and downstream the flow obstruction device. For all other situations localized energy losses at the fitting (assumed to occur abruptly at the location of the transitions) are determined using graphic extrapolations of the total head along the straight uniform reaches of the pipeline upstream and downstream the fitting. For example, for the sudden expansion in Figure 2 the local loss is obtained by extrapolating the lines determined by pairs of head values 2-3 and 4-5 to the physical location of the expansion.

In the experiment, the head loss coefficient, *K*, is determined for at least five different discharges, covering the full range available on the experimental apparatus described in the accompanying equipment description. The largest discharge should be the maximum allowed by the apparatus; the smallest discharge should be about 20% of the maximum.

A. Establish stabilized maximum discharge in the system. With the settings established by the TAs open completely the controlling gate or globe valve located on the streamlines or standard pipe system, respectively.

NOTE: At high discharges, the pressure at some locations (e.g., in the Venturi throat in the streamlined pipeline system) may be so low that they suck air back into the water-mercury manometer. If this occurs, the system must be re-bled, and this tap is unusable at the high discharge.

C. Measure the datum. Measuring the datum head will give a reference point for the heads to be calculated. To fill the datum cylinder with flow through the standard pipeline, open any tap valve and the datum valve at the same time. Close valves when the water meniscus reaches the line on the cylinder. The drain valve below the cylinder may be used to adjust the water level if the datum cylinder is overfilled. Open the standard gage valve and the datum valve to take the measurement. Take care to make certain the datum level stays constant before proceeding with measurements. Leave the datum valve closed.

NOTE: The mercury level in the plexiglas manometer reservoir must always be clearly above the bottom of the reservoir. Otherwise, the manometer readings will be false. Frequently check the reservoir to be sure that air bubble has not formed at the top of it.

D. Measure and record the pressure head. Begin an experiment with all the valves on the pressure tap valve manifold closed. Open the gage valve corresponding to the pipeline in use (standard or streamlined). For each pressure head measurement on the half-manifold we should have opened the gage plus the finger values corresponding to the pressure tap of interest. Now any valve related to a desired tap on the selected pipeline, or datum using the standard side, may be opened and a head measurement taken. Before proceeding with measurements, the bleeding valve located on top of the mercury cylinder should be closed. With the gage and respective tap valve open, use the knob to adjust the column on the scale until the top of the mercury is even with the line on the tube. Read and record the head readings (in feet of mercury) of the pressure taps located upstream and downstream the device (for pressure taps numbering, see the above table).

NOTE: Only one pressure tap valve on the half of the manifold being used should be open at a time. Close all valves on one side of the manifold before using the other side.

E. Measure the head on weir. The following directions pertain to both weirs. The drain at the bottom of the tank must be closed. Read the water-surface elevation in the reservoir using the calibrated point gauge attached outside of the tank. To obtain the crest elevation, read the point gage when the flow has stopped flowing over the weir.

Repeat steps D and E for the four smaller discharges.

Measurements

According to the procedure described above, measure the quantities specified in the following tables. Notations are those indicated in Figure 2.a and Figure 2.b.

Trial #		**1**	**2**	**3**	**4**	**5**
Water Temperature (F)						
Weir Noch Elevation (ft)						
Water Surface Elevation (ft)						
Weir Q (cfs)						
Velocity (fps)						
Kinematic Viscosity, n **(ft^2/s)**						
Reynolds Number						
Upstream heads (ft Hg)	**Tap 1**					
	Tap 2					
Downstrean heads (ft Hg)	**Tap 1**					
	Tap 2					
Head drop (ft Hg)						
Head drop (ft H_2O)						

Upstream vel. head (ft H_2O)					
Downstream vel. head (ft H_2O)					
Energy Drop (ft H_2O)					
Pipe-loss corr. (ft H_2O)					
K					

Data Analysis

Determination of the coefficient K consists of plotting the experimental local loss coefficients versus the corresponding Reynolds numbers ($\boldsymbol{Re} = VD/n$, where D is the pipe diameter and n is the kinematic viscosity) for known discharges through the device. Once the head loss characteristics of the devices included in a pipe systems are known, they may be used in design calculations to determine the amount of head loss in the system, and consequently, the needed source pressure or energy to satisfy the design objective).

1. Calculate the piezometric heads from the manometer readings.
2. Calculate velocities in the pipes using the discharge and the known interior pipe diameter provided in the appendices. Calculate then velocity heads, total heads, and Reynolds numbers.
3. Calculate the loss coefficient for the pipe fitting under consideration using equation (2) and plot them as a function of the respective Reynolds numbers. Use the larger velocity always when there is a change in the mean velocity at the transition.
4. Compare the experimental results with empirical values and trends found in your hydraulics or fluids text.

Note: Piezometric readings 13 and 14 illustrate the effect of the curvature of the flow through a bend or an elbow, rather than the behavior of the h- and H-lines along the pipe line. Some of the readings close to the orifice and Venturi meters are subject to similar remarks. Give interpretations for the measurements at all these special tap locations

Further Considerations

Consider the following questions:

1. Discuss the Reynolds-number dependence of your loss coefficient, its agreement (or disagreement) with published values and trends, its expected Reynolds-number dependence, and any other features you deem to be important.
3. If the device and approach pipe are taken to be a 1:50 scale model of a prototype situation, calculate the prototype horsepower that would be required to overcome the losses in the prototype device.

References

Gupta, R. S. (1989). *Hydrology and Hydraulic Systems*, Waveland Press, NY

Rouse, H. (1949). *Engineering Hydraulics*, John Wiley and Sons, NY

White, F.M. (1994). *Fluid Mechanics*, 3rd edition, McGraw-Hill, Inc., New York, NY.

Appendix A

Standard Pipeline Characteristics

Tap #	Item and Description	Station (in)	Elev. from Datum (in)
1	Settling Tank	0	91.5
	Entrance (90 deg)	0	97.5
2		36	97.5
	Pipe: 2-inch, smooth	-	97.5
3		66	97.5
	Expansion: 90 deg.	72	97.5
4		120	97.5
	Pipe: 4-inch, smooth	-	97.5
5		174	97.5
	Contraction: 90 deg.	180	97.5
	Pipe: 2-inch, smooth; 2 bends 90 deg, r/d = 2	-	97.5 - 72
6		322	72
	Pipe: 2-inch, smooth	-	72
7		356	72
8		358	72
	Orifice: d/D = 0.69	-	72
9		358.25	72
	Pipe: 2-inch, smooth	-	72
11		394	72
	Pipe: 2-inch, smooth	-	72
12		422	72
	Bend: 90 deg., r/d = 2.25	425.5 – 432.5	-
13	Elbow Meter Inner Radius Tap	429	-
14	Elbow Meter Outer Radius Tap	429	-
15		462	38
	Pipe: 2-inch, smooth	-	
16		492	8
	Branch: 90 deg., r/d = 2.25	495.5 – 502.5	-
17		534	0
	Pipe: 2-inch, smooth	-	0
18		564	0
	Globe Valve	567 – 573	0
19		606	0
	Pipe: 2-inch, smooth	-	0
20		630	0
	Exit to Atmosphere	642	0
	Weir Notch	-	-30
Second Branch Stationing From Tap 16			
	Branch: 90 deg., r/d = 2.25	495.5 – 502.5	-
21		534	0
	Pipe: 2-inch, smooth	-	0
22		568	0
	Exit: 90 deg., submerged	570	0
23	Reservoir	570	-18

Appendix B

Streamlined Pipeline Characteristics

Tap #	Item and Description	Station (in)	Elev. from Datum (in)
1	Settling Tank	0	91.5
	Entrance: r/d > 0.2	0 - 4	97.5
2		36	97.5
	Pipe: 2-inch, smooth	-	97.5
3		66	97.5
	Expansion: d/D = 0.5, theta = 60 deg.	68 - 75	97.5
4		120	97.5
	Pipe: 4-inch, smooth	-	97.5
5		174	97.5
	Contraction: d/D = 0.5, theta = 60 deg.	176 - 183	97.5
	Pipe: 2-inch, smooth; 2 bends 90 deg, r/d = 2		97.5 - 72
6		311	72
	Pipe: 2-inch, smooth	-	72
7		342	72
8		345	72
	Venturi: d/D = 0.625	-	72
9		347	72
	Pipe: 2-inch, smooth	-	72
11		383	72
	Pipe: 2-inch, smooth	-	72
12		411	72
	Bend: 90-deg., r/d = 3.25	413 – 423	-
13	Elbow Meter Inner Radius Tap	417.5	-
14	Elbow Meter Outer Radius Tap	417.5	-
15		451	38
	Pipe: 2-inch, smooth	-	-
16		481	8
	Branch: r/d = 3.25	483 – 493	-
17		523	0
	Pipe: 2-inch, smooth	-	0
18		553	0
	Gate Valve	556 – 562	0
19		595	0
	Pipe: 2-inch, smooth	-	0
20		619	0
	Exit to Atmosphere	631	0
	Weir Notch	-	-30
Second Branch Stationing From Tap 16			
	Branch: r/d = 3.25	483 – 493	-
21		523	0
	Pipe: 2-inch, smooth	-	0
22		546	0
	Exit: r/d > 0.2, submerged	548 – 559	0
23	Reservoir	559	-18