53:071 Principles of Hydraulics
Laboratory Experiment #1

ENERGY AND HYDRAULIC GRADE LINES IN WATER PIPE SYSTEMS

Principle

The energy of a real fluid decreases as it moves through a pipe. The energy budget in a pipeline system is materialized by the energy grade line. The hydraulic grade line is lower than the energy line by the velocity head.

Introduction

In the flow process, some of the mechanical energy of the system is converted to thermal energy through viscous action between fluid particles. For a steady incompressible flow through a pipe with friction, without shaft work, the energy equation (Bernoulli's equation) between two cross sections in the flow is

$$\frac{p_1}{\gamma} + \alpha_1 \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_L$$

where z is the elevation above an arbitrary datum, p is the pressure intensity, V is the mean velocity in the pipe, g is the gravitational acceleration, γ is the specific weight of the fluid, α is the kinetic-energy correction factor (for most of the practical cases $\alpha \approx$ 1.05, hence, it will be subsequently omitted), and h_L is the head loss. Subscripts 1 and 2 refer to cross sections normal to the flow field. All the terms in the above equation are heads (or lengths), actually energies per unit weight. Different expression are used for h_L, depending on their type, namely, losses due to frictional resistance of the pipe or losses due to flow transitions in the pipe (such as vanes, fittings, inlets, outlets, etc.).

A useful interpretation of Bernoulli's equation is to sketch two grade lines of the flow, as shown in Figure 1.

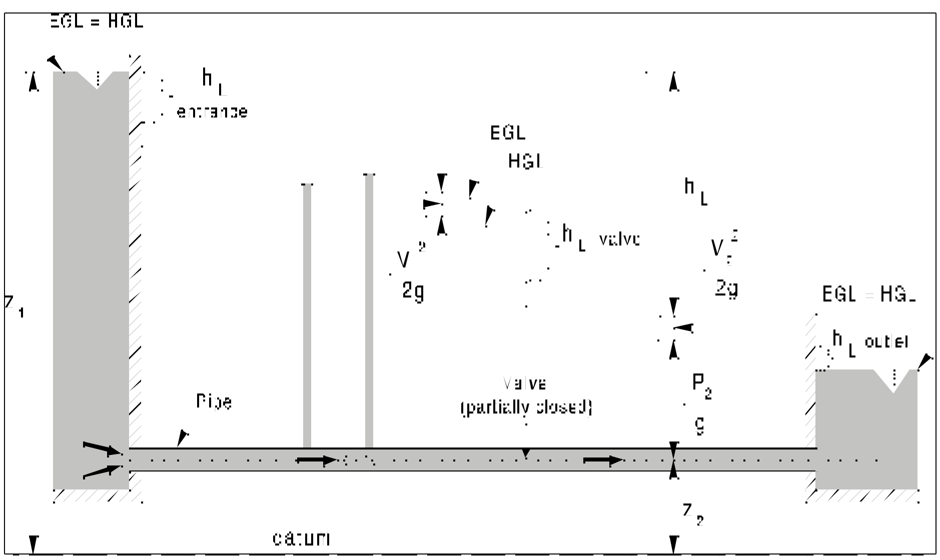

Figure 1. Head losses in a pipe

The energy grade line (EGL) and the hydraulic grade line (HGL) are defined as

$$EGL = h_0 = \frac{p}{g} + \frac{V^2}{2g} + z \qquad (1)$$

$$HGL = \frac{p}{g} + z \qquad (2)$$

EGL shows the height of the total Bernoulli constant while HGL is the height to which liquid would rise in a piezometric tube attached to the pipe (see Figure 1). HGL is obtained as EGL minus the velocity head $V^2/2g$. The fall of the EGL reflects the energy losses in the system. EGL drops slowly due to friction losses and it drops sharply due to a major loss (a valve or transition) or due to work extraction (to a turbine). The EGL can rise only if there is work addition (as from a pump).

The objective of this experiment is to determine the hydraulic and energy lines in an pipeline assembly comprising losses due to friction in conduit as well as head losses due to transitions and fittings.

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.

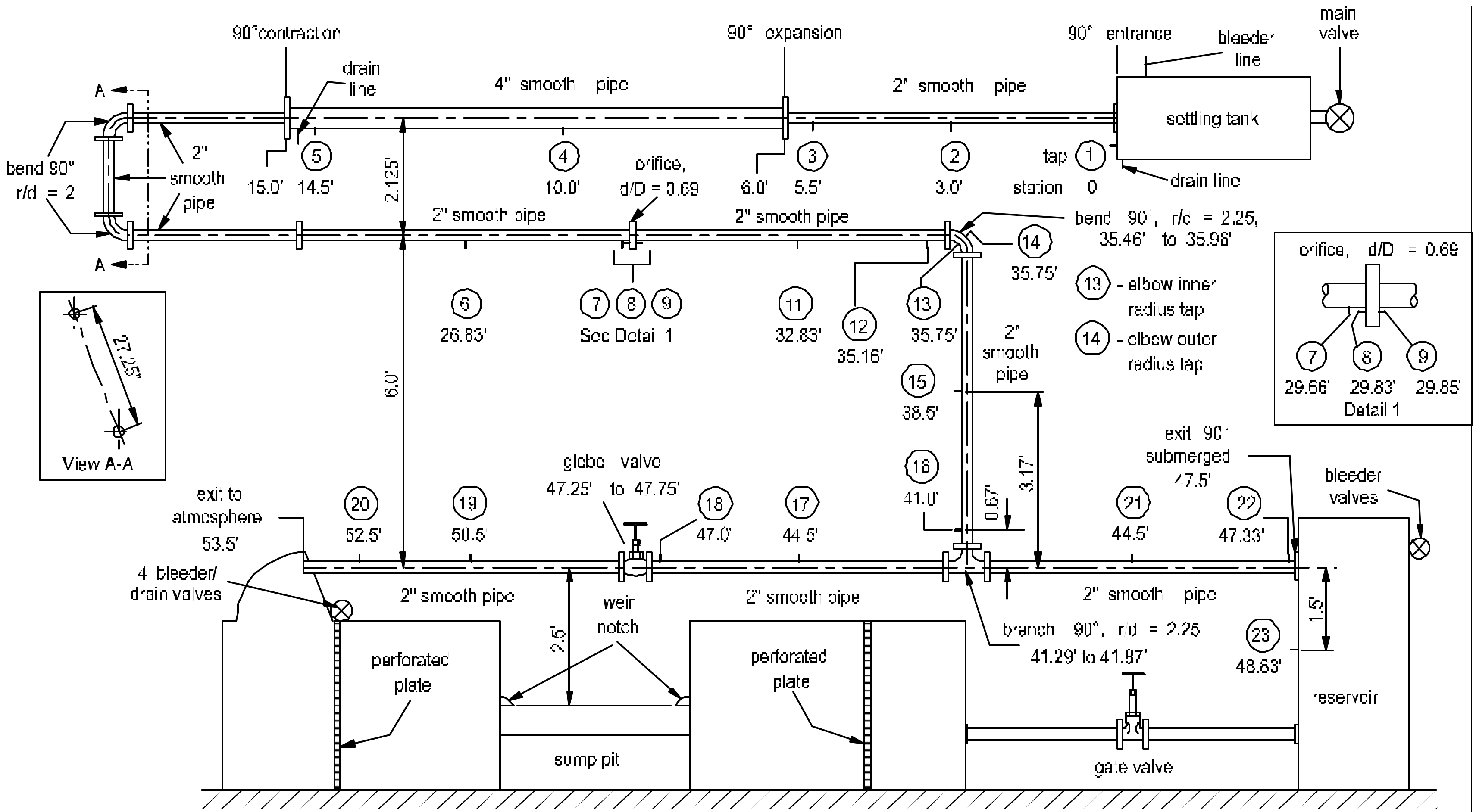

Figure 2.a The standard pipeline assembly

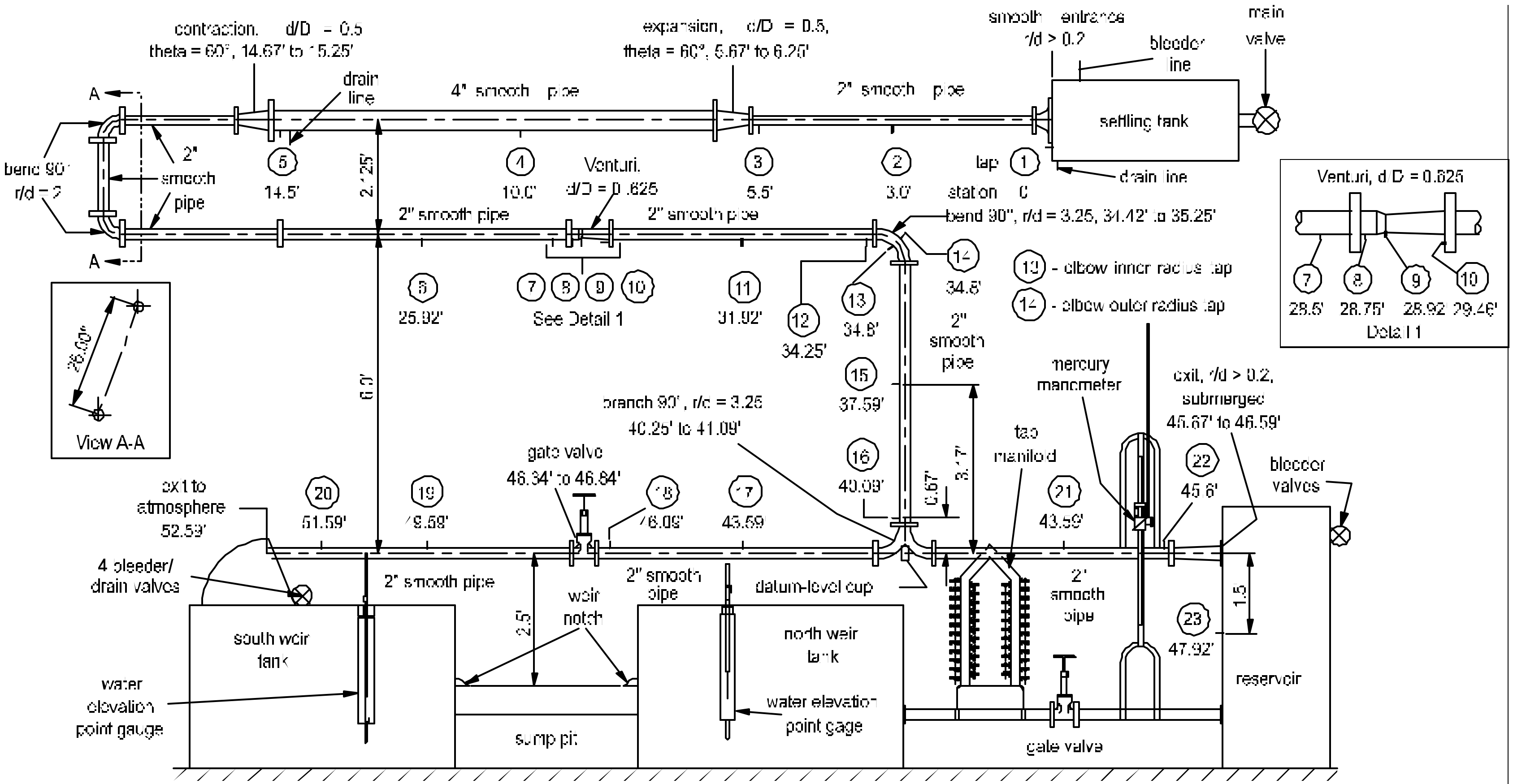

Figure 2.b. The streamlined pipeline assembly

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.

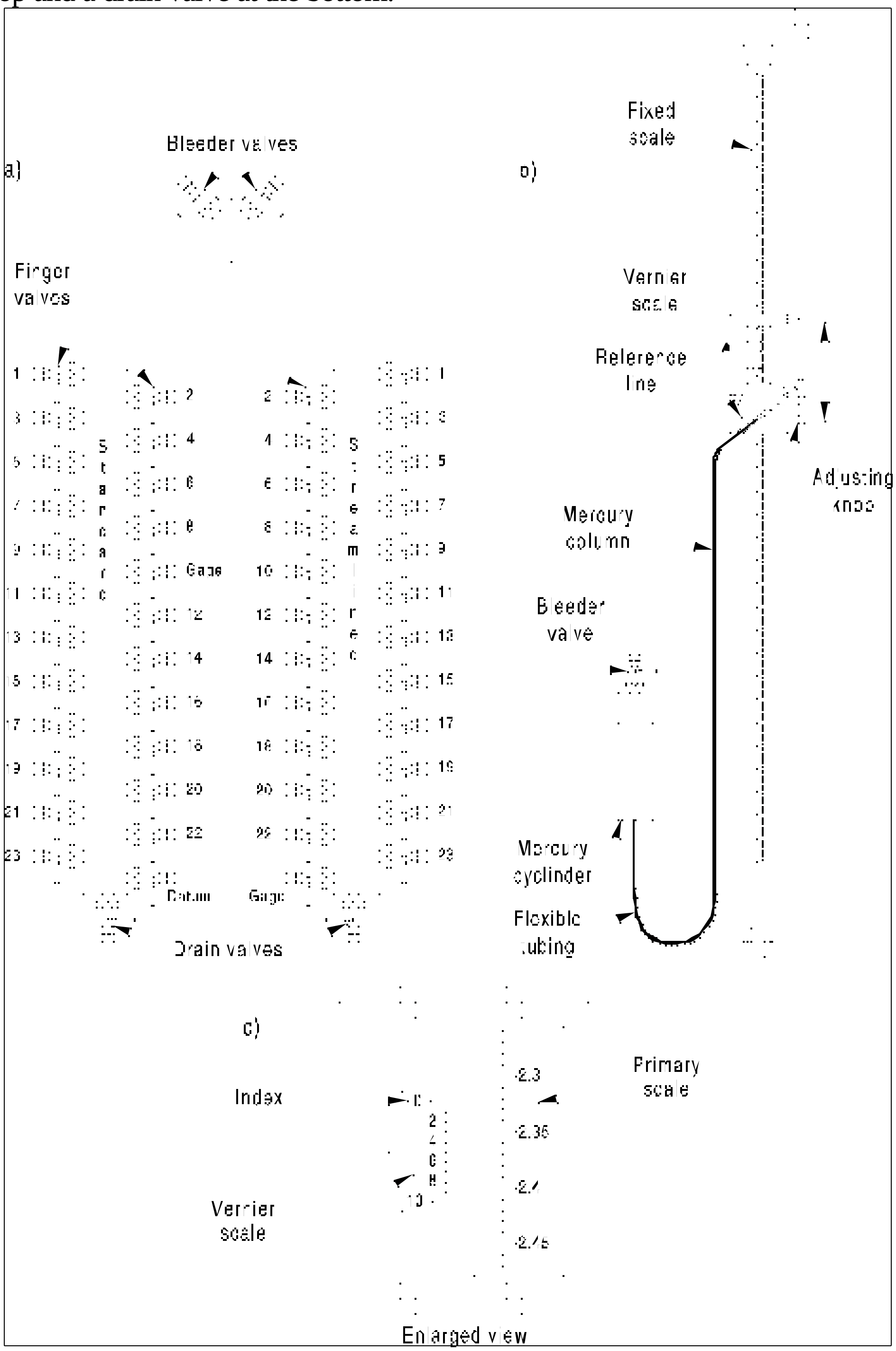

Figure 3. a) Pressure tap valve manifold; b) Simple manometer; c) Vernier

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 calibrated point gauge attached 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 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. For the two identical weirs on this system, $C = 1.434$.

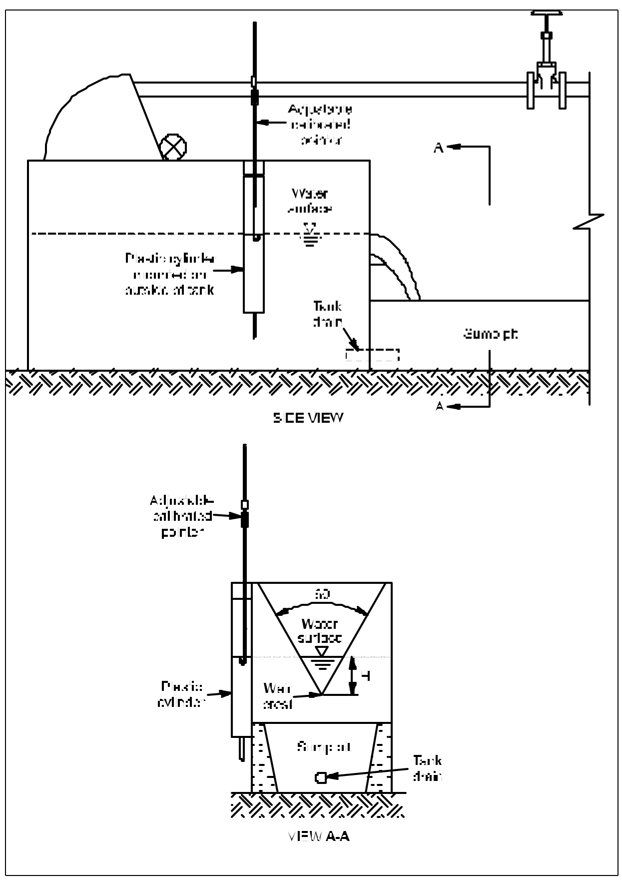

Figure 4. The weir tank and triangular weir

Procedures

The experiment is conducted in either the standard or streamlined water-flow apparatus. Each group will be assigned one of the systems for experimental analysis. The grade lines are obtained at the maximum possible discharge level in the system.

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 mercury cup to be sure an air bubble has not formed at the top of the reservoir.

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.

Measurements

According to procedures described above, measure the quantities specified in the following table. Notations are as shown in Figure 2.a and Figure 2.b.

Weir Notch Elev.	
W.S. Elev: (ft)	
Q (cfs)	

Tap #	Station* (ft)	Elevation* (ft)	Piez. Head (ft Hg)	Piez. Head (ft H_20)	Pipe Diam. (ft)	Vel. Head (ft H_2O)	Energy Level (ft H_2O)
Datum							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10**							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

* data provided in Appendix A

** tap only on the streamlined pipe-flow assembly

Data Analysis

1. Convert the readings of the mercury manometer in heads in feet of water and compute piezometric, velocity heads, and energy heads above datum at each pressure-tap location.
2. Plot the hydraulic and energy grade lines using the computed values at the pressure-tap location, and connecting these data points carefully. Use pipe entrance as origin on the abscissa and piezometric or energy level (in feet of water) on the ordinate. Geometrical characteristics for the standard and streamlined pipeline systems are provided in the enclosed appendices.

   NOTE: 1. The local energy losses are assumed to occur abruptly at the location of the transitions. Therefore, use graphic extrapolations of the total head along the straight uniform reaches of the pipeline, i.e., for the piezometric and energy heads extrapolate the lines determined by pairs of values like 2-3 and 4-5, 6-7 and 11-12, etc., to the physical location of the pipeline transitions.

2. Between pressure taps 5 and 6 on the standard pipe-flow assembly there are three short 2” pipe sections and 2 elbows (90°). On the streamlined pipe-flow assembly there is an additional contraction connecting the 4” pipe to the 2” pipe. Cumulate all energy losses associated with these assembly elements in an equivalent local loss occurring at the contraction between pressure taps 5 and 6, i.e., 15 ft from the assembly origin for the standard assembly (14.67 ft from the origin for the streamlined assembly).

3. Discuss your grade lines with regard to experimental error, and especially with regard to their specific depiction of the tradeoff between potential and kinetic energy, mechanisms of energy loss, etc. observed as you "walk" down the system from upstream to downstream.
4. Calculate the horsepower consumed by the system from the entrance to the v-notch weir.

Further Considerations

Consider the following question:

1. Compare the measured values between the pressure taps with computed ones using empirical values found in your hydraulics or fluids texts. Do not include in the comparison the head losses between pressure taps 5 and 6. Explain discrepancies.

References

Granger, R.A. (1988). *Experiments in Fluid Mechanics*, Holt, Rinehart and Winston, Inc. New York, NY

Rouse, H. (1981). *Laboratory Instruction in the Mechanics of Fluids*, The University of Iowa Studies in Engineering, Bulletin 41, The University of Iowa, Iowa City, IA

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

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