

H Lab Problems

This section contains end-of-the-chapter problems that involve data obtained from various simple laboratory experiments. The problem statements involve the objective of the experiment, the equipment used, the experimental procedure involved, and a discussion of the calculations necessary to obtain the desired results.

The goal of each problem is to present the final results in graphical form. To bring up the EXCEL page with the data for these problems, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson. These data are then given as a page in the EXCEL program so that the necessary calculations and data plotting can be done easily on the computer.

Lab Problems for Chapter 1

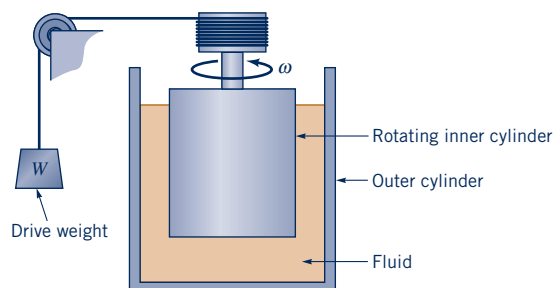
1.1LP Fluid Characterization by Use of a Stormer Viscometer

Objective: As discussed in Section 1.6, some fluids can be classified as Newtonian fluids; others are non-Newtonian. The purpose of this experiment is to determine the shearing stress versus rate of strain characteristics of various liquids and, thus, to classify them as Newtonian or non-Newtonian fluids.

Equipment: Stormer viscometer containing a stationary outer cylinder and a rotating, concentric inner cylinder (see Fig. P1.74); stopwatch; drive weights for the viscometer; three different liquids (silicone oil, latex paint, and corn syrup).

Experimental Procedure: Fill the gap between the inner and outer cylinders with one of the three fluids to be tested. Select an appropriate drive weight (of mass m) and attach it to the end of the cord that wraps around the drum to which the inner cylinder is fastened. Release the brake mechanism to allow the inner cylinder to start to rotate. (The outer cylinder remains stationary.) After the cylinder has reached its steady-state angular velocity, measure the amount of time, t , that it takes the inner cylinder to rotate N revolutions. Repeat the measurements using various drive weights. Repeat the entire procedure for the other fluids to be tested.

Calculations: For each of the three fluids tested, convert the mass, m , of the drive weight to its weight, $W = mg$, where g is the acceleration of gravity. Also determine the angular velocity of the inner cylinder, $\omega = N/t$.



■ Figure P1.104

Graph: For each fluid tested, plot the drive weight, W , as ordinates and angular velocity, ω , as abscissas. Draw a best fit curve through the data.

Results: Note that for the flow geometry of this experiment, the weight, W , is proportional to the shearing stress, τ , on the inner cylinder. This is true because with constant angular velocity, the torque produced by the viscous shear stress on the cylinder is equal to the torque produced by the weight (weight times the appropriate moment arm). Also, the angular velocity, ω , is proportional to the rate of strain, du/dy . This is true because the velocity gradient in the fluid is proportional to the inner cylinder surface speed (which is proportional to its angular velocity) divided by the width of the gap between the cylinders. Based on your graphs, classify each of the three fluids as to whether they are Newtonian, shear thickening, or shear thinning (see Fig. 1.7).

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

m , kg	N , revs	t , s
Silicone Oil Data		
0.02	4	59.3
0.05	12	66.0
0.10	24	64.2
0.15	20	35.0
0.20	24	31.7
0.25	30	31.0
0.30	20	14.4
0.35	25	18.8
0.40	40	26.0
Corn Syrup Data		
0.05	1	28.2
0.10	2	29.2
0.20	4	27.2
0.40	8	25.7
Latex Paint Data		
0.02	2	32.7
0.03	2	20.2
0.04	5	32.2
0.05	10	47.3
0.06	10	37.2
0.07	10	29.8
0.08	10	24.6
0.09	10	20.1
0.10	20	34.0

1.2LP Capillary Tube Viscometer

Objective: The flowrate of a viscous fluid through a small-diameter (capillary) tube is a function of the viscosity of the fluid. For the flow geometry shown in Fig. P1.105, the kinematic viscosity, ν , is inversely proportional to the flowrate, Q . That is, $\nu = K/Q$, where K is the calibration constant for the particular device. The purpose of this experiment is to determine the value of K and to use it to determine the kinematic viscosity of water as a function of temperature.

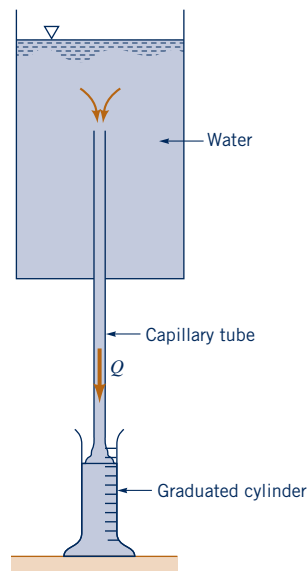
Equipment: Constant temperature water tank, capillary tube, thermometer, stopwatch, graduated cylinder.

Experimental Procedure: Adjust the water temperature to 15.6 °C and determine the flowrate through the capillary tube by measuring the time, t , it takes to collect a volume, V , of water in a small graduated cylinder. Repeat the measurements for various water temperatures, T . Be sure that the water depth, h , in the tank is the same for each trial. Since the flowrate is a function of the depth (as well as viscosity), the value of K obtained will be valid for only that value of h .

Calculations: For each temperature tested, determine the flowrate, $Q = V/t$. Use the data for the 15.6 °C water to determine the calibration constant, K , for this device. That is, $K = \nu Q$, where the kinematic viscosity for 15.6 °C water is given in Table 1.5 and Q is the measured flowrate at this temperature. Use this value of K and your other data to determine the viscosity of water as a function of temperature.

Graph: Plot the experimentally determined kinematic viscosity, ν , as ordinates and temperature, T , as abscissas.

Results: On the same graph, plot the standard viscosity–temperature data obtained from Table B.2.



■ Figure P1.105

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

<i>V</i> , ml	<i>t</i> , s	<i>T</i> , deg. C
9.2	19.8	15.6
9.7	15.8	26.3
9.2	16.8	21.3
9.1	21.3	12.3
9.2	13.1	34.3
9.4	10.1	50.4
9.1	8.9	58.1

Lab Problems for Chapter 2

2.1LP Force Needed to Open a Submerged Gate

Objective: A gate, hinged at the top, covers a hole in the side of a water-filled tank as shown in Fig. P2.122 and is held against the tank by the water pressure. The purpose of this experiment is to compare the theoretical force needed to open the gate to the experimentally measured force.

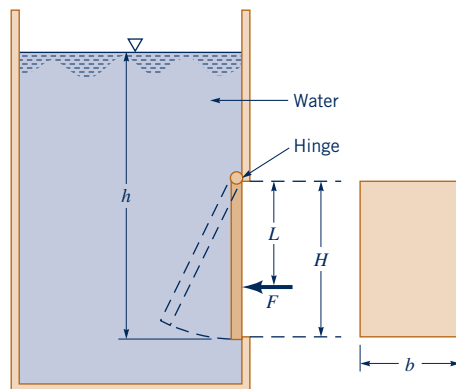
Equipment: Rectangular tank with a rectangular hole in its side; gate that covers the hole and is hinged at the top; force transducer to measure the force needed to open the gate; ruler to measure the water depth.

Experimental Procedure: Measure the height, H , and width, b , of the hole in the tank and the distance, L , from the hinge to the point of application of the force, F , that opens the gate. Fill the tank with water to a depth, h , above the bottom of the gate. Use the force transducer to determine the force, F , needed to slowly open the gate. Repeat the force measurements for various water depths.

Calculations: For arbitrary water depths, h , determine the theoretical force, F , needed to open the gate by equating the moment about the hinge from the water force on the gate to the moment produced by the applied force, F .

Graph: Plot the experimentally determined force, F , needed to open the gate as ordinates and the water depth, h , as abscissas.

Results: On the same graph, plot the theoretical force as a function of water depth.



■ Figure P2.122

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

<i>L</i> , in.	<i>H</i> , in.	<i>b</i> , in.
5.5	6.0	4.0
h, in.	F, lb	
21.1	10.1	
18.5	8.9	
16.2	7.6	
14.5	6.7	
12.8	5.8	
11.1	4.7	
10.1	4.3	
7.4	2.9	

2.2LP Hydrostatic Force on a Submerged Rectangle

Objective: A quarter-circle block with a vertical rectangular end is attached to a balance beam as shown in Fig. P2.123. Water in the tank puts a hydrostatic pressure force on the block, which causes a clockwise moment about the pivot point. This moment is balanced by the counterclockwise moment produced by the weight placed at the end of the balance beam. The purpose of this experiment is to determine the weight, W , needed to balance the beam as a function of the water depth, h .

Equipment: Balance beam with an attached quarter-circle, rectangular cross-sectional block; pivot point directly above the vertical end of the beam to support the beam; tank; weights; ruler.

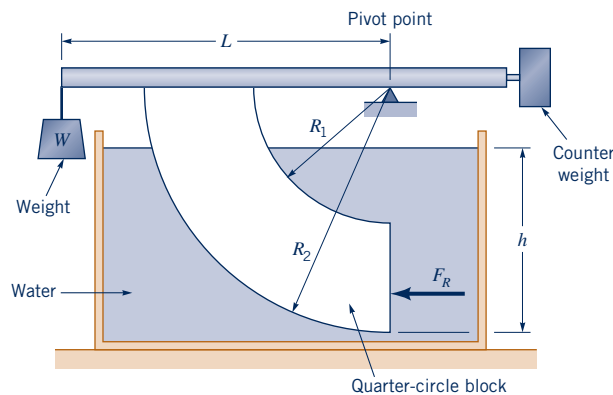
Experimental Procedure: Measure the inner radius, R_1 , outer radius, R_2 , and width, b , of the block. Measure the length, L , of the moment arm between the pivot point and the weight. Adjust the counterweight on the beam so that the beam is level when there is no weight on the beam and no water in the tank. Hang a known mass, m , on the beam and adjust the water level, h , in the tank so that the beam again becomes level. Repeat with different masses and water depths.

Calculations: For a given water depth, h , determine the hydrostatic pressure force, $F_R = \gamma h_c A$, on the vertical end of the block. Also determine the point of action of this force, a distance $y_R - y_c$ below the centroid of the area. Note that the equations for F_R and $y_R - y_c$ are different when the water level is below the end of the block ($h < R_2 - R_1$) than when it is above the end of the block ($h > R_2 - R_1$).

For a given water depth, determine the theoretical weight needed to balance the beam by summing moments about the pivot point. Note that both F_R and W produce a moment. However, because the curved sides of the block are circular arcs centered about the pivot point, the pressure forces on the curved sides of the block (which act normal to the sides) do not produce any moment about the pivot point. Thus, the forces on the curved sides do not enter into the moment equation.

Graph: Plot the experimentally determined weight, W , as ordinates and the water depth, h , as abscissas.

Result: On the same graph plot the theoretical weight as a function of water depth.



■ Figure P2.123

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

R_1 , in.	R_2 , in.	L , in.	b , in.
5.0	9.0	12.0	3.0
m , kg	h , in.		
0.00	0.00		
0.02	1.11		
0.04	1.58		
0.06	1.92		
0.10	2.51		
0.12	2.76		
0.14	2.99		
0.16	3.20		
0.18	3.41		
0.20	3.60		
0.22	3.80		
0.24	3.99		
0.26	4.17		
0.28	4.33		
0.30	4.50		
0.35	4.95		
0.40	5.39		
0.45	5.83		
0.50	6.27		
0.55	6.70		

2.3LP Vertical Uplift Force on an Open-Bottom Box with Slanted Sides

Objective: When a box or form as shown in Fig. P2.124 is filled with a liquid, the vertical force of the liquid on the box tends to lift it off the surface upon which it sits, thus allowing the liquid to drain from the box. The purpose of this experiment is to determine the minimum weight, W , needed to keep the box from lifting off the surface.

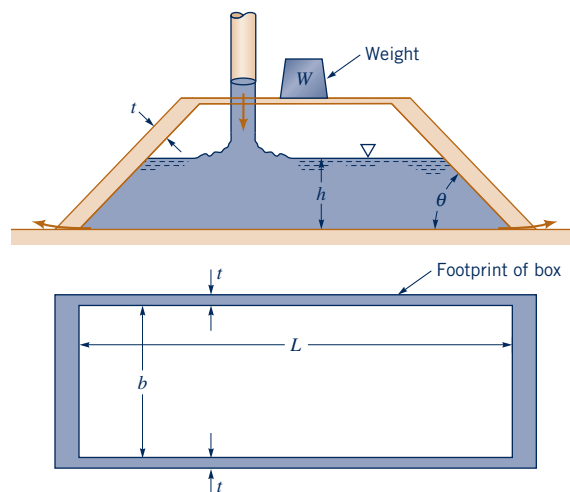
Equipment: An open-bottom box that has vertical side walls and slanted end walls; weights; ruler; scale.

Experimental Procedure: Determine the weight, W_{box} , of the empty box and measure its length, L , width, b , wall thickness, t , and the angle of the ends, θ . Set the box on a smooth surface and place a known mass, m , on it. Slowly fill the box with water and note the depth, h , at which the net upward water force is equal to the total weight, $W + W_{\text{box}}$, where $W = mg$. This condition will be obvious because the friction force between the box and the surface on which it sits will be zero and the box will “float” effortlessly along the surface. Repeat for various masses and water levels.

Calculations: For an arbitrary water depth, h , determine the theoretical weight, W , needed to maintain equilibrium with no contact force between the box and the surface below it. This can be done by equating the total weight, $W + W_{\text{box}}$, to the net vertical hydrostatic pressure force on the box. Calculate this vertical pressure force for two different situations. (1) Assume the vertical pressure force is the vertical component of the pressure forces acting on the slanted ends of the box. (2) Assume the vertical upward force is that from part (1) plus the pressure force acting under the sides and ends of the box because of the finite thickness, t , of the box walls. This additional pressure force is assumed to be due to an average pressure of $p_{\text{avg}} = \gamma h/2$ acting on the “footprint” area of the box walls.

Graph: Plot the experimentally determined total weight, $W + W_{\text{box}}$, as ordinates and the water depth, h , as abscissas.

Results: On the same graph, plot two theoretical total weight versus water depth curves—one involving only the slanted-end pressure force and the other including the slanted end and the finite-thickness wall pressure forces.



■ Figure P2.124

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

θ , deg.	L , in.	b , in.	t , in.	W_{box} , lb
45	10.3	4.0	0.25	0.942
m , kg	h , in.			
0.00	2.06			
0.05	2.23			
0.10	2.42			
0.15	2.53			
0.20	2.67			
0.25	2.81			
0.30	2.94			
0.35	3.06			
0.40	3.16			

2.4LP Air Pad Lift Force

Objective: As shown in Fig. P2.125, it is possible to lift objects by use of an air pad consisting of an inverted box that is pressurized by an air supply. If the pressure within the box is large enough, the box will lift slightly off the surface, air will flow under its edges, and there will be very little frictional force between the box and the surface. The purpose of this experiment is to determine the lifting force, W , as a function of pressure, p , within the box.

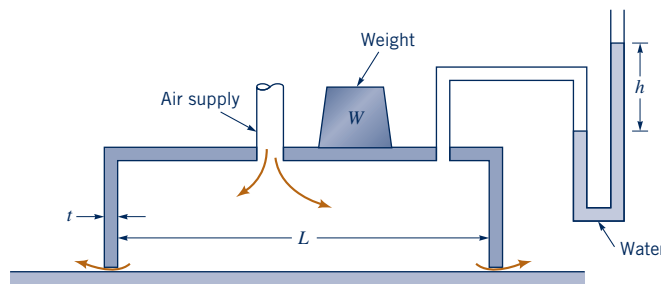
Equipment: Inverted rectangular box; air supply; weights; manometer.

Experimental Procedure: Connect the air source and the manometer to the inverted square box. Determine the weight, W_{box} , of the square box and measure its length and width, L , and the wall thickness, t . Set the inverted box on a smooth surface and place a known mass, m , on it. Increase the air flowrate until the box lifts off the surface slightly and “floats” with negligible frictional force. Record the manometer reading, h , under these conditions. Repeat the measurements with various masses.

Calculations: Determine the theoretical weight that can be lifted by the air pad by equating the total weight, $W + W_{\text{box}}$, to the net vertical pressure force on the box. Here $W = mg$. Calculate this pressure force for two different situations. (1) Assume the pressure force is equal to the area of the box, $A = L^2$, times the pressure, $p = \gamma_m h$, within the box, where γ_m is the specific weight of the manometer fluid. (2) Assume that the net pressure force is that from part (1) plus the pressure force acting under the edges of the box because of the finite thickness, t , of the box walls. This additional pressure force is assumed to be due to an average pressure of $p_{\text{avg}} = \gamma_m h/2$ acting on the “footprint” area of the box walls, $4t(L + t)$.

Graph: Plot the experimentally determined total weight, $W + W_{\text{box}}$, as ordinates and the pressure within the box, p , as abscissas.

Results: On the same graph, plot two theoretical total weight versus pressure curves—one involving only the pressure times box area pressure force and the other including the pressure times box area and the finite-thickness wall pressure forces.



■ Figure P2.125

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

L , in.	t , in.	W_{box} , lb
7.5	0.25	1.25
m , kg	h , in.	
0.0	0.54	
0.1	0.64	
0.2	0.74	
0.3	0.82	
0.4	0.94	
0.5	1.04	
0.6	1.12	
0.7	1.23	
0.8	1.32	
0.9	1.42	
1.0	1.52	
1.1	1.63	
1.2	1.72	
1.3	1.83	
1.4	1.96	
1.5	2.06	
1.6	2.12	
1.7	2.23	
1.8	2.32	

Lab Problems for Chapter 3

3.1LP Pressure Distribution between Two Circular Plates

Objective: According to the Bernoulli equation, a change in velocity can cause a change in pressure. Also, for an incompressible flow, a change in flow area causes a change in velocity. The purpose of this experiment is to determine the pressure distribution caused by air flowing radially outward in the gap between two closely spaced flat plates, as shown in Fig. P3.118.

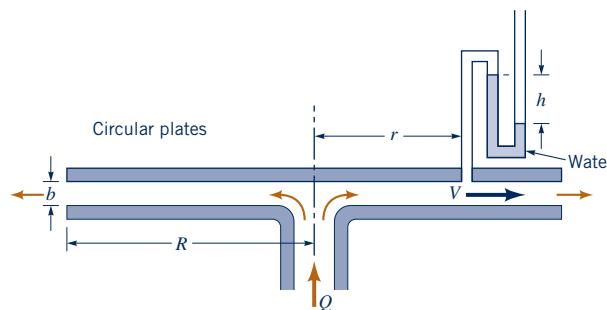
Equipment: Air supply with a flowmeter; two circular flat plates with static pressure taps at various radial locations from the center of the plates; spacers to maintain a gap of height b between the plates; manometer; barometer; thermometer.

Experimental Procedure: Measure the radius, R , of the plates and the gap width, b , between them. Adjust the air supply to provide the desired, constant flowrate, Q , through the inlet pipe and the gap between the flat plates. Attach the manometer to the static pressure tap located a radial distance r from the center of the plates and record the manometer reading, h . Repeat the pressure measurements (for the same Q) at different radial locations. Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: Use the manometer readings to obtain the experimentally determined pressure distribution, $p = p(r)$, within the gap. That is, $p = -\gamma_m h$, where γ_m is the specific weight of the manometer fluid. Also use the Bernoulli equation ($p/\gamma + V^2/2g = \text{constant}$) and the continuity equation ($AV = \text{constant}$, where $A = 2\pi r b$) to determine the theoretical pressure distribution within the gap between the plates. Note that the flow at the edge of the plates ($r = R$) is a free jet ($p = 0$). Also note that an increase in r causes an increase in A , a decrease in V , and an increase in p .

Graph: Plot the experimentally measured pressure head, p/γ , in feet of air as ordinates and radial location, r , as abscissas.

Results: On the same graph, plot the theoretical pressure head distribution as a function of radial location.



■ Figure P3.118

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

Q , ft ³ /s	R , in.	b , in.	H_{atm} , in. Hg	T , deg. F
0.879	5.0	0.125	29.09	83
r , in.	h , in.			
0.7	9.05			
1.0	6.02			
1.5	2.02			
2.0	0.96			
2.5	0.48			
3.0	0.24			
3.5	0.13			
4.0	0.03			
4.5	0.01			
5.0	0.00			

3.2LP Calibration of a Nozzle Flowmeter

Objective: As shown in Section 3.6.3 of the text, the volumetric flowrate, Q , of a given fluid through a nozzle flowmeter is proportional to the square root of the pressure drop across the meter. Thus, $Q = Kh^{1/2}$, where K is the meter calibration constant and h is the manometer reading that measures the pressure drop across the meter (see Fig. P3.119). The purpose of this experiment is to determine the value of K for a given nozzle flowmeter.

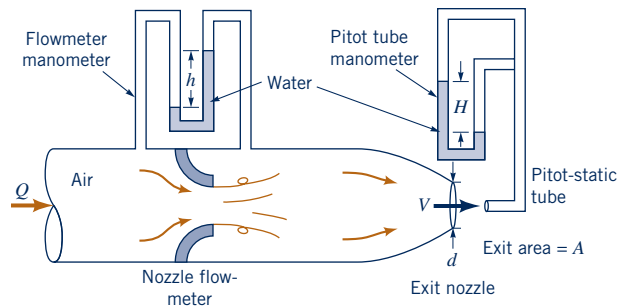
Equipment: Pipe with a nozzle flowmeter; variable-speed fan; exit nozzle to produce a uniform jet of air; Pitot-static tube; manometers; barometer; thermometer.

Experimental Procedure: Adjust the fan speed control to give the desired flowrate, Q . Record the flowmeter manometer reading, h , and the Pitot tube manometer reading, H . Repeat the measurements for various fan settings (i.e., flowrates). Record the nozzle exit diameter, d . Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated from the perfect gas law.

Calculations: For each fan setting determine the flowrate, $Q = VA$, where V and A are the air velocity at the exit and the nozzle exit area, respectively. The velocity, V , can be determined by using the Bernoulli equation and the Pitot tube manometer data, H (see Eq. 3.16).

Graph: Plot flowrate, Q , as ordinates and flowmeter manometer reading, h , as abscissas on a log-log graph. Draw the best-fit straight line with a slope of $1/2$ through the data.

Results: Use your data to determine the calibration constant, K , in the flowmeter equation $Q = Kh^{1/2}$.



■ Figure P3.119

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

d , in.	H_{atm} , in. Hg	T , deg. F
1.169	29.01	75
h , in.	H , in.	
11.6	5.6	
11.1	5.4	
10.7	5.2	
10.1	4.9	
9.6	4.7	
8.8	4.3	
7.9	3.9	
7.2	3.6	
6.1	3.1	
5.4	2.7	
4.5	2.3	
3.8	2.0	
2.9	1.5	
2.1	1.1	
1.0	0.6	

3.3LP Pressure Distribution in a Two-Dimensional Channel

Objective: According to the Bernoulli equation, a change in velocity can cause a change in pressure. Also, for an incompressible flow, a change in flow area causes a change in velocity. The purpose of this experiment is to determine the pressure distribution caused by air flowing within a two-dimensional, variable-area channel as shown in Fig. P3.120.

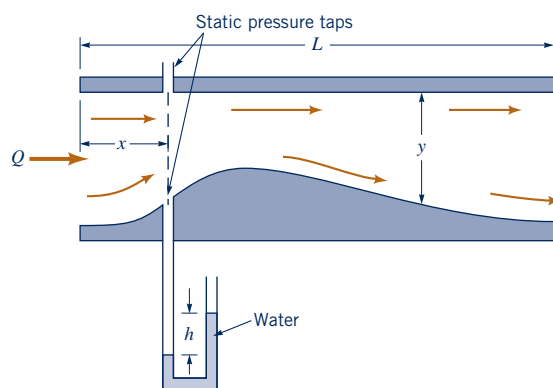
Equipment: Air supply with a flowmeter; two-dimensional channel with one curved side and one flat side; static pressure taps at various locations along both walls of the channel; ruler; manometer; barometer; thermometer.

Experimental Procedure: Measure the constant width, b , of the channel and the channel height, y , as a function of distance, x , along the channel. Adjust the air supply to provide the desired, constant flowrate, Q , through the channel. Attach the manometer to the static pressure tap located a distance, x , from the origin and record the manometer reading, h . Repeat the pressure measurements (for the same Q) at various locations on both the flat and the curved sides of the channel. Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: Use the manometer readings, h , to calculate the pressure within the channel, $p = \gamma_m h$, where γ_m is the specific weight of the manometer fluid. Convert this pressure into the pressure head, p/γ , where $\gamma = g\rho$ is the specific weight of air. Also use the Bernoulli equation ($p/\gamma + V^2/2g = \text{constant}$) and the continuity equation ($AV = Q$, where $A = yb$) to determine the theoretical pressure distribution within the channel. Note that the air leaves the end of the channel ($x = L$) as a free jet ($p = 0$).

Graph: Plot the experimentally determined pressure head, p/γ , as ordinates and the distance along the channel, x , as abscissas. There will be two curves—one for the curved side of the channel and another for the flat side.

Results: On the same graph, plot the theoretical pressure distribution within the channel.



■ Figure P3.120

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

b , in.	Q , ft ³ /s	H_{atm} , in. Hg	T , deg. F	L , in.
2.0	1.32	28.96	71	21.75
x , in.	y , in.	h , in. flat side	h , in. curved side	
0.75	2.00	0.28	0.31	
2.50	2.00	0.21	0.37	
4.00	1.28	−0.42	0.03	
4.63	1.05	−0.77	−1.63	
5.38	1.05	−1.01	−1.05	
8.14	1.29	−0.63	−0.62	
10.75	1.54	−0.32	−0.31	
13.25	1.77	−0.15	−0.15	
15.78	2.00	0.05	0.00	
21.75	2.00	0.00	0.00	

3.4LP Sluice Gate Flowrate

Objective: The flowrate of water under a sluice gate as shown in Fig. P3.121 is a function of the water depths upstream and downstream of the gate. The purpose of this experiment is to compare the theoretical flowrate with the experimentally determined flowrate.

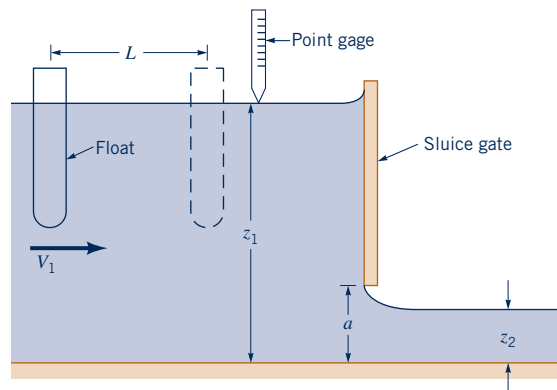
Equipment: Flow channel with pump and control valve to provide the desired flowrate in the channel; sluice gate; point gage to measure water depth; float; stopwatch.

Experimental Procedure: Adjust the vertical position of the sluice gate so that the bottom of the gate is the desired distance, a , above the channel bottom. Measure the width, b , of the channel (which is equal to the width of the gate). Turn on the pump and adjust the control valve to produce the desired water depth upstream of the sluice gate. Insert a float into the water upstream of the gate and measure the water velocity, V_1 , by recording the time, t , it takes the float to travel a distance, L . That is, $V_1 = L/t$. Use a point gage to measure the water depth, z_1 , upstream of the gate. Adjust the control valve to produce various water depths upstream of the gate and repeat the measurements.

Calculations: For each water depth used, determine the flowrate, Q , under the sluice gate by using the continuity equation $Q = A_1 V_1 = b z_1 V_1$. Use the Bernoulli and continuity equations to determine the theoretical flowrate under the sluice gate (see Eq. 3.21). For these calculations assume that the water depth downstream of the gate, z_2 , remains at 61% of the distance between the channel bottom and the bottom of the gate. That is, $z_2 = 0.61a$.

Graph: Plot the experimentally determined flowrate, Q , as ordinates and the water depth, z_1 , upstream of the gate as abscissas.

Results: On the same graph, plot the theoretical flowrate as a function of water depth upstream of the gate.



■ Figure P3.121

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

<i>a</i> , in.	<i>b</i> , in.	<i>L</i> , ft
1.2	6.0	4.0
<i>z</i> ₁ , ft	<i>t</i> , s	
0.183	4.2	
0.267	5.0	
0.343	5.2	
0.453	6.2	
0.569	6.4	
0.725	7.0	
0.877	8.6	

Lab Problems for Chapter 5

5.1LP Force from a Jet of Air Deflected by a Flat Plate

Objective: A jet of a fluid striking a flat plate as shown in Fig. P5.140 exerts a force on the plate. It is the equal and opposite force of the plate on the fluid that causes the fluid momentum change that accompanies such a flow. The purpose of this experiment is to compare the theoretical force on the plate with the experimentally measured force.

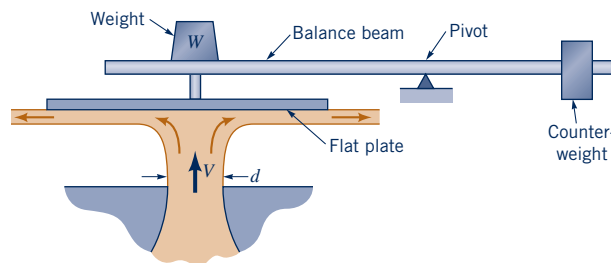
Equipment: Air source with an adjustable flowrate and a flowmeter; nozzle to produce a uniform air jet; balance beam with an attached flat plate; weights; barometer; thermometer.

Experimental Procedure: Adjust the counterweight so that the beam is level when there is no mass, m , on the beam and no flow through the nozzle. Measure the diameter, d , of the nozzle outlet. Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law. Place a known mass, m , on the flat plate and adjust the fan speed control to produce the necessary flowrate, Q , to make the balance beam level again. The flowrate is related to the flowmeter manometer reading, h , by the equation $Q = 0.358 h^{1/2}$, where Q is in ft^3/s and h is in inches of water. Repeat the measurements for various masses on the plate.

Calculations: For each flowrate, Q , calculate the weight, $W = mg$, needed to balance the beam and use the continuity equation, $Q = VA$, to determine the velocity, V , at the nozzle exit. Use the momentum equation for this problem, $W = \rho V^2 A$, to determine the theoretical relationship between velocity and weight.

Graph: Plot the experimentally measured force on the plate, W , as ordinates and airspeed, V , as abscissas.

Results: On the same graph, plot the theoretical force as a function of airspeed.



■ Figure P5.140

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

d , in.	H_{atm} , in. Hg	T , deg. F	$Q = 0.358 h^{0.5}$, with Q in cfs and h in inches of water
1.174	29.25	70	
m , kg	h , in.		
0.010	0.54		
0.020	1.08		
0.030	1.52		
0.040	2.18		
0.050	2.72		
0.060	3.25		
0.070	3.81		
0.080	4.32		
0.090	4.92		
0.100	5.46		
0.150	8.13		
0.200	10.85		
0.250	13.72		

5.2LP Pressure Distribution on a Flat Plate Due to the Deflection of an Air Jet

Objective: In order to deflect a jet of air as shown in Fig. P5.141, the flat plate must push against the air with a sufficient force to change the momentum of the air. This causes an increase in pressure on the plate. The purpose of this experiment is to measure the pressure distribution on the plate and to compare the resultant pressure force to that needed, according to the momentum equation, to deflect the air.

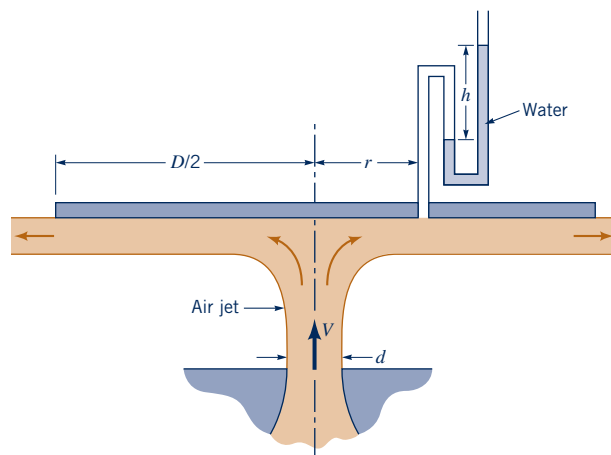
Equipment: Air supply with a flowmeter; nozzle to produce a uniform jet of air; circular flat plate with static pressure taps at various radial locations; manometer; barometer; thermometer.

Experimental Procedure: Measure the diameters of the plate, D , and the nozzle exit, d , and the radial locations, r , of the various static pressure taps on the plate. Carefully center the plate over the nozzle exit and adjust the air flowrate, Q , to the desired constant value. Record the static pressure tap manometer readings, h , at various radial locations, r , from the center of the plate. Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: Use the manometer readings, h , to determine the pressure on the plate as a function of location, r . That is, calculate $p = \gamma_m h$, where γ_m is the specific weight of the manometer fluid.

Graph: Plot pressure, p , as ordinates and radial location, r , as abscissas.

Results: Use the experimentally determined pressure distribution to determine the net pressure force, F , that the air jet puts on the plate. That is, numerically or graphically integrate the pressure data to obtain a value for $F = \int p \, dA = \int p (2\pi r \, dr)$, where the limits of the integration are over the entire plate, from $r = 0$ to $r = D/2$. Compare this force obtained from the pressure measurements to that obtained from the momentum equation for this flow, $F = \rho V^2 A$, where V and A are the velocity and area of the jet, respectively.



■ Figure P5.141

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

D , in.	d , in.	H_{atm} , in. Hg	T , deg. F	Q , ft ³ /s
8.0	1.174	29.25	77	1.41
r , in.	h , in.			
0.00	6.62			
0.39	5.92			
0.79	3.04			
1.24	0.55			
1.59	0.19			
2.04	0.13			
2.41	0.09			
2.85	0.05			
3.23	0.03			
3.67	0.00			

5.3LP Force from a Jet of Water Deflected by a Vane

Objective: A jet of a fluid striking a vane as shown in Fig. P5.142 exerts a force on the vane. It is the equal and opposite force of the vane on the fluid that causes the fluid momentum change that accompanies such a flow. The purpose of this experiment is to compare the theoretical force on the vane with the experimentally measured force.

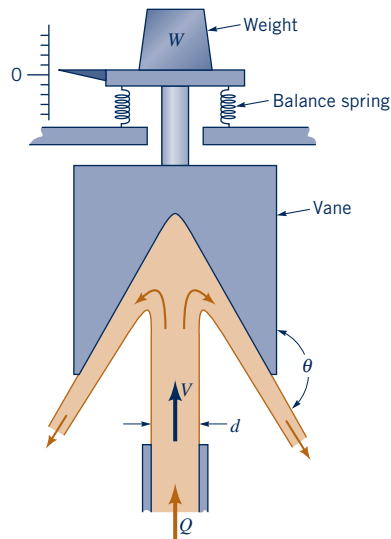
Equipment: Water source; nozzle to produce a uniform jet of water; vanes to deflect the water jet; weigh tank to collect a known amount of water in a measured time period; stopwatch; force balance system.

Experimental Procedure: Measure the outlet diameter, d , of the nozzle. Fasten the $\theta = 90^\circ$ vane to its support and adjust the balance spring to give a zero reading when there is no weight, W , on the platform and no flow through the nozzle. Place a known mass, m , on the platform and adjust the control valve on the pump to provide the necessary flowrate from the nozzle to return the platform to a zero reading. Determine the flowrate by collecting a known weight of water, W_{water} , in the weigh tank during a measured amount of time, t . Repeat the measurements for various masses, m . Repeat the experiment using a $\theta = 180^\circ$ vane.

Calculations: For each data set, determine the weight, $W = mg$, on the platform and the volume flowrate, $Q = W_{\text{water}}/(\gamma t)$, through the nozzle. Determine the exit velocity from the nozzle, V , by using $Q = VA$. Use the momentum equation to determine the theoretical weight that can be supported by the water jet as a function of V and θ .

Graph: For each vane, plot the experimentally determined weight, W , as ordinates and the water velocity, V , as abscissas.

Results: On the same graph plot the theoretical weight as a function of velocity for each vane.



■ Figure P5.142

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

d , in. 0.40		
m , kg	W_{water} , lb	t , s
Data for $\theta = 90$ deg:		
0.02	7.71	29.8
0.07	8.66	18.2
0.17	8.87	10.1
0.12	8.92	12.6
0.22	9.66	10.6
Data for $\theta = 180$ deg:		
0.05	6.81	24.5
0.10	9.02	20.8
0.20	8.84	13.2
0.25	7.88	10.9
0.30	8.86	11.1
0.35	7.97	9.5
0.40	6.37	7.6

5.4LP Force of a Flowing Fluid on a Pipe Elbow

Objective: When a fluid flows through an elbow in a pipe system as shown in Fig. P5.143, the fluid's momentum is changed as the fluid changes direction. Thus, the elbow must put a force on the fluid. Similarly, there must be an external force on the elbow to keep it in place. The purpose of this experiment is to compare the theoretical vertical component of force needed to hold an elbow in place with the experimentally measured force.

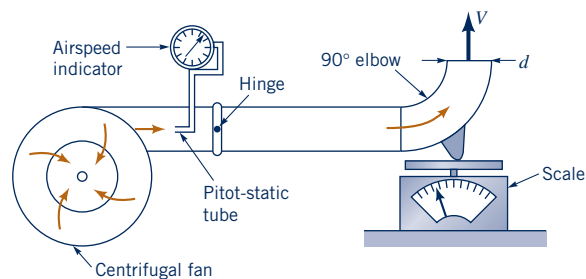
Equipment: Variable-speed fan; Pitot-static tube; airspeed indicator; air duct and 90° elbow; scale; barometer; thermometer.

Experimental Procedure: Measure the diameter, d , of the air duct and adjust the scale to read zero when the elbow rests on it and there is no flow through it. Note that the duct is connected to the fan outlet by a pivot mechanism that is essentially friction free. Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law. Adjust the variable-speed fan to give the desired flowrate. Record the velocity, V , in the pipe as given by the Pitot-static tube, which is connected to an airspeed indicator that reads directly in feet per minute. Record the force, F , indicated on the scale at this airspeed. Repeat the measurements for various airspeeds. Obtain data for two types of elbows: (1) a long radius elbow and (2) a mitered elbow (see Figs. 8.30 and 8.31).

Calculations: For a given airspeed, V , use the momentum equation to calculate the theoretical vertical force, $F = \rho V^2 A$, needed to hold the elbow stationary.

Graph: Plot the experimentally measured force, F , as ordinates and the airspeed, V , as abscissas.

Results: On the same graph, plot the theoretical force as a function of airspeed.



■ Figure P5.143

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

d , in.	H_{atm} , in. Hg	T , deg. F
8.0	29.07	73
V , ft/min	F , lb	
Long Radius	Elbow Data	
1200	0.38	
1420	0.51	
1800	0.79	
2160	1.05	
2440	1.38	
2700	1.65	
2900	1.91	
3100	2.19	
3520	2.83	
3750	3.12	
3950	3.38	
Mitered	Elbow Data	
1400	0.30	
1780	0.55	
2000	0.74	
2300	1.12	
2630	1.44	
2900	1.72	
3150	2.06	
3360	2.38	
3550	2.62	
3620	2.74	

Lab Problems for Chapter 7

7.1LP Flow from a Tank

Objective: When the drain hole in the bottom of the tank shown in Fig. P7.82 is opened, the liquid will drain out at a rate that is a function of many parameters. The purpose of this experiment is to measure the liquid depth, h , as a function of time, t , for two geometrically similar tanks and to learn how dimensional analysis can be of use in such situations.

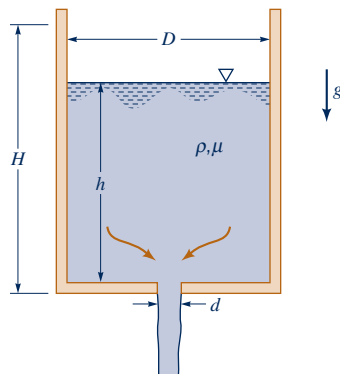
Equipment: Two geometrically similar cylindrical tanks; stopwatch; thermometer; ruler.

Experimental Procedure: Make appropriate measurements to show that the two tanks are geometrically similar. That is, show that the large tank is twice the size of the small tank (twice the height; twice the diameter; twice the hole diameter in the bottom). Fill the large tank with cold water of a known temperature, T , and determine the water depth, h , in the tank as a function of time, t , after the drain hole is opened. Thus, obtain $h = h(t)$. Note that t ranges from $t = 0$ when $h = H$ (where H is the initial depth of the water) to $t = t_{\text{final}}$ when the tank is completely drained ($h = 0$). Repeat the measurements using the small tank with the same temperature water. To ensure geometric similarity, the initial water level in the small tank must be one-half of what it was in the large tank. Repeat the experiment for each tank with hot water. Thus, you will have a total of four sets of $h(t)$ data.

Calculations: Assume that the depth, h , of water in the tank is a function of its initial depth, H , the diameter of the tank, D , the diameter of the drain hole in the bottom of the tank, d , the time, t , after the drain is opened, the acceleration of gravity, g , and the fluid density, ρ , and viscosity, μ . Develop a suitable set of dimensionless parameters for this problem using H , g , and ρ as repeating variables. Use t as the dependent parameter. For each of the four conditions tested, calculate the dimensionless time, $tg^{1/2}/H^{1/2}$, as a function of the dimensionless depth, h/H .

Graph: On a single graph, plot the depth, h , as ordinates and time, t , as abscissas for each of the four sets of data.

Results: On another graph, plot the dimensionless water depth, h/H , as a function of dimensionless time, $tg^{1/2}/H^{1/2}$, for each of the four sets of data. Based on your results, comment on the importance of density and viscosity for your experiment and on the usefulness of dimensional analysis.



■ Figure P7.82

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

<i>H</i> for big tank, in.	<i>H</i> for small tank, in.
16.0	8.0
<i>h</i> , in.	<i>t</i> , s
Big Tank with $T = 57$ deg C	
16.0	0.0
12.0	9.2
8.0	20.0
4.0	33.8
0.0	57.0
Big Tank with $T = 20$ deg C	
16.0	0.0
12.0	9.0
8.0	20.3
4.0	33.0
0.0	57.2
Small Tank with $T = 57$ deg C	
8.0	0.0
7.0	3.1
5.0	9.5
3.0	18.2
1.0	30.1
0.0	41.4
Small Tank with $T = 20$ deg C	
8.0	0.0
7.0	3.0
5.0	10.0
3.0	18.1
1.0	32.5
0.0	43.0

7.2LP Vortex Shedding from a Circular Cylinder

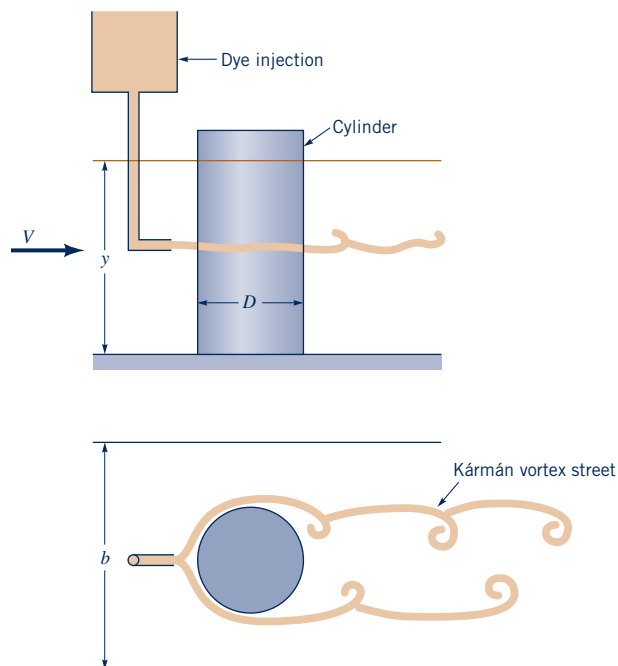
Objective: Under certain conditions, the flow of fluid past a circular cylinder will produce a Kármán vortex street behind the cylinder. As shown in Fig. P7.83, this vortex street consists of a set of vortices (swirls) that are shed alternately from opposite sides of the cylinder and then swept downstream with the fluid. The purpose of this experiment is to determine the shedding frequency, ω cycles (vortices) per second, of these vortices as a function of the Reynolds number, Re , and to compare the measured results with published data.

Equipment: Water channel with an adjustable flowrate; flowmeter; set of four different diameter cylinders; dye injection system; stopwatch.

Experimental Procedure: Insert a cylinder of diameter D into the holder on the bottom of the water channel. Adjust the control valve and the downstream gate on the channel to produce the desired flowrate, Q , and velocity, V . Make sure that the flow-straightening screens (not shown in the figure) are in place to reduce unwanted turbulence in the flowing water. Measure the width, b , of the channel and the depth, y , of the water in the channel so that the water velocity in the channel, $V = Q/(by)$, can be determined. Carefully adjust the control valve on the dye injection system to inject a thin stream of dye slightly upstream of the cylinder. By viewing down onto the top of the water channel, observe the vortex shedding and measure the time, t , that it takes for N vortices to be shed from the cylinder. For a given velocity, repeat the experiment for different diameter cylinders. Repeat the experiment using different velocities. Measure the water temperature so that the viscosity can be looked up in Table B.1.

Calculations: For each of your data sets calculate the vortex shedding frequency, $\omega = N/t$, which is expressed as vortices (or cycles) per second. Also calculate the dimensionless frequency called the Strouhal number, $St = \omega D/V$, and the Reynolds number, $Re = \rho V D/\mu$.

Graph: On a single graph, plot the vortex shedding frequency, ω , as ordinates and the water velocity, V , as abscissas for each of the four cylinders you tested. On another graph, plot the Strouhal number as ordinates and the Reynolds number as abscissas for each of the four sets of data.



■ Figure P7.83

Results: On your Strouhal number versus Reynolds number graph, plot the results taken from the literature and shown in the following table.

St	Re
0	<50
0.16	100
0.18	150
0.19	200
0.20	300
0.21	400
0.21	600
0.21	800

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

T , deg. F 70	b , ft 0.50			
Q , ft ³ /s	y , ft	D , ft	N	t , s
0.036	0.82	0.0202	10.0	13.2
0.036	0.82	0.0314	10.0	19.9
0.036	0.82	0.0421	10.0	24.5
0.036	0.82	0.0518	10.0	30.1
0.062	0.79	0.0202	10.0	6.3
0.062	0.79	0.0314	10.0	9.6
0.062	0.79	0.0421	10.0	12.5
0.062	0.79	0.0518	10.0	15.1
0.029	0.86	0.0202	10.0	19.2
0.029	0.86	0.0314	10.0	28.2
0.029	0.86	0.0421	10.0	33.1
0.029	0.86	0.0518	10.0	36.7
0.018	0.92	0.0202	10.0	31.2
0.018	0.92	0.0314	10.0	41.3
0.018	0.92	0.0421	10.0	52.2
0.018	0.92	0.0518	10.0	65.3

7.3LP Head Loss across a Valve

Objective: A valve in a pipeline like that shown in Fig. P7.84 acts like a variable resistor in an electrical circuit. The amount of resistance or head loss across a valve depends on the amount that the valve is open. The purpose of this experiment is to determine the head loss characteristics of a valve by measuring the pressure drop, Δp , across the valve as a function of flowrate, Q , and to learn how dimensional analysis can be of use in such situations.

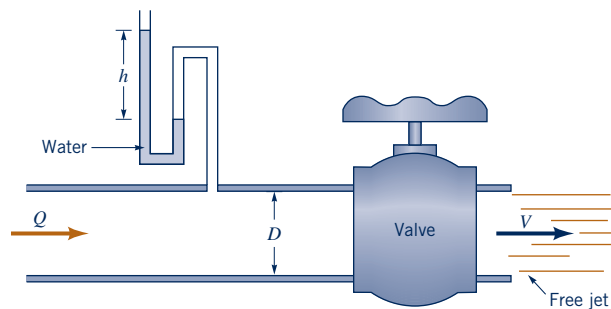
Equipment: Air supply with flowmeter; valve connected to a pipe; manometer connected to a static pressure tap upstream of the valve; barometer; thermometer.

Experimental Procedure: Measure the pipe diameter, D . Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law. Completely close the valve and then open it N turns from its closed position. Adjust the air supply to provide the desired flowrate, Q , of air through the valve. Record the manometer reading, h , so that the pressure drop, Δp , across the valve can be determined. Repeat the measurements for various flowrates. Repeat the experiment for various valve settings, N , ranging from barely open to wide open.

Calculations: For each data set calculate the average velocity in the pipe, $V = Q/A$, where $A = \pi D^2/4$ is the pipe area. Also calculate the pressure drop across the valve, $\Delta p = \gamma_m h$, where γ_m is the specific weight of the manometer fluid. For each data set also calculate the loss coefficient, K_L , where the head loss is given by $h_L = \Delta p/\gamma = K_L V^2/2g$ and γ is the specific weight of the flowing air.

Graph: On a single graph, plot the pressure drop, Δp , as ordinates and the flowrate, Q , as abscissas for each of the valve settings, N , tested.

Results: On another graph, plot the loss coefficient, K_L , as a function of valve setting, N , for all of the data sets.



■ Figure P7.84

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

D , in.	H_{atm} , in. Hg	T , deg. F
0.81	28.7	70
h , in.	Q , ft ³ /s	
$N = 2$ Turns Open Data		
9.20	0.235	
6.50	0.195	
5.04	0.169	
$N = 3$ Turns Open Data		
9.40	0.479	
6.33	0.386	
5.01	0.341	
3.62	0.289	
1.92	0.214	
$N = 4$ Turns Open Data		
9.35	0.827	
7.65	0.767	
6.01	0.691	
4.32	0.578	
3.24	0.504	
2.62	0.456	
1.85	0.391	
0.98	0.283	
$N = 5$ Turns Open Data		
3.03	0.897	
2.37	0.799	
1.79	0.701	
1.39	0.618	
0.97	0.517	
0.64	0.426	

7.4LP Calibration of a Rotameter

Objective: The flowrate, Q , through a rotameter can be determined from the scale reading, SR , which indicates the vertical position of the float within the tapered tube of the rotameter as shown in Fig. P7.85. Clearly, for a given scale reading, the flowrate depends on the density of the flowing fluid. The purpose of this experiment is to calibrate a rotameter so that it can be used for both water and air.

Equipment: Rotameter, air supply with a calibrated flowmeter, water supply, weighing scale, stopwatch, thermometer, barometer.

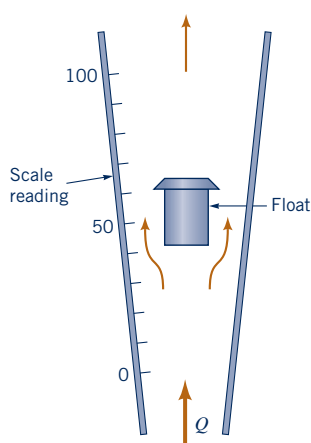
Experimental Procedure: Connect the rotameter to the water supply and adjust the flowrate, Q , to the desired value. Record the scale reading, SR , on the rotameter and measure the flowrate by collecting a given weight, W , of water that passes through the rotameter in a given time, t . Repeat for several flowrates.

Connect the rotameter to the air supply and adjust the flowrate to the desired value as indicated by the flowmeter. Record the scale reading on the rotameter. Repeat for several flowrates. Record the barometer reading, H_{atm} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: For the water portion of the experiment, use the weight, W , and time, t , data to determine the volumetric flowrate, $Q = W/\gamma t$. The equilibrium position of the float is a result of a balance between the fluid drag force on the float, the weight of the float, and the buoyant force on the float. Thus, a typical dimensionless flowrate can be written as $Q/[d(\rho/Vg(\rho_f - \rho))^{1/2}]$, where d is the diameter of the float, V is the volume of the float, g is the acceleration of gravity, ρ is the fluid density, and ρ_f is the float density. Determine this dimensionless flowrate for each condition tested.

Graph: On a single graph, plot the flowrate, Q , as ordinates and scale reading, SR , as abscissas for both the water and air data.

Results: On another graph, plot the dimensionless flowrate as a function of scale reading for both the water and air data. Note that the scale reading is a percent of full scale and, hence, is a dimensionless quantity. Based on your results, comment on the usefulness of dimensional analysis.



■ Figure P7.85

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

d , in.	V , in. ³	ρ_f , slug/ft ³	H_{atm} , in. Hg	T , deg. F
1.40	1.50	15.1	29.05	78
Air Flow Data				
SR	Q , ft ³ /s			
14.6	0.229			
21.5	0.321			
28.1	0.413			
33.6	0.491			
39.2	0.564			
44.8	0.644			
50.2	0.714			
55.9	0.798			
63.1	0.888			
68.6	0.973			
73.5	1.05			
76.2	1.08			
Water Flow Data				
SR	W , lb	t , s		
13.1	6.52	19.9		
18.5	8.01	17.7		
24.2	7.02	10.4		
28.2	7.81	10.1		
37.1	8.20	8.4		
45.7	9.21	7.5		
52.6	8.19	5.7		

Lab Problems for Chapter 8

8.1LP Friction Factor for Laminar and Transitional Pipe Flow

Objective: Theoretically, the friction factor, f , for laminar pipe flow is given by $f = 64/\text{Re}$, where the Reynolds number, $\text{Re} = \rho V D / \mu$, is based on the average velocity, V , within the pipe and the pipe diameter, D . Also, the flow is normally laminar for $\text{Re} < 2100$. The purpose of this experiment is to use the device shown in Fig. P8.126 to investigate these two properties.

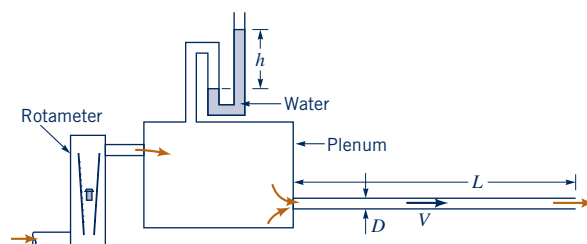
Equipment: Small-diameter metal tubes (pipes), air supply with flow regulator, rotameter flowmeter, manometer.

Experimental Procedure: Attach a tube of length L and diameter D to the plenum. Adjust the flow regulator to obtain the desired flowrate as measured by the rotameter. Record the manometer reading, h , so that the pressure difference between the plenum (tank) and the free jet at the end of the tube can be determined. Repeat for several different flowrates and tube diameters. Record the barometer reading, H_{bar} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: For each of the data sets determine the pressure difference, $\Delta p = \gamma_m h$, between the plenum pressure and the free jet pressure. Here γ_m is the specific weight of the manometer fluid. Use the energy equation, Eq. 5.84, to determine the friction factor, f . Assume the loss coefficient for the pipe entrance is $K_L = 0.8$. Also calculate the Reynolds number, Re , for each data set.

Graph: On a log-log graph, plot the experimentally determined friction factor, f , as ordinates and the Reynolds number, Re , as abscissas.

Results: On the same graph, plot the theoretical friction factor for laminar flow, $f = 64/\text{Re}$, as a function of the Reynolds number. Based on the experimental data, determine the maximum value of the Reynolds number for which the flow in these pipes is laminar.



■ Figure P8.126

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

L , in.	H_{atm} , in. Hg	T , deg. F
24	28.9	73
h , in.	Q , ml/min	
$D = 0.108$ in. Data		
7.5	6600	
6.75	6200	
6.26	6000	
5.54	5650	
4.66	5150	
4.29	5000	
3.92	4860	
3.48	4600	
3.21	4500	
2.34	3700	
1.86	2900	
1.11	1800	
0.63	1100	
$D = 0.046$ in. Data		
9.52	560	
7.68	475	
7.08	425	
5.26	315	
3.39	221	
2.61	165	
$D = 0.063$ in. Data		
4.58	925	
3.32	680	
2.51	530	
1.48	325	
0.86	190	

8.2LP Calibration of an Orifice Meter and a Venturi Meter

Objective: Because of various real-world, nonideal conditions, neither orifice meters nor Venturi meters operate exactly as predicted by a simple theoretical analysis. The purpose of this experiment is to use the device shown in Fig. P8.127 to calibrate an orifice meter and a Venturi meter.

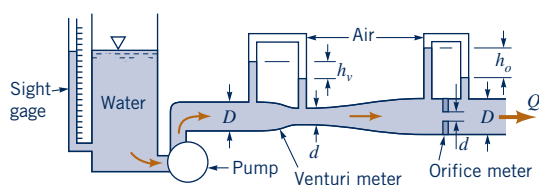
Equipment: Water tank with sight gage, pump, Venturi meter, orifice meter, manometers.

Experimental Procedure: Determine the pipe diameter, D , and the throat diameter, d , for the flowmeters. Note that each meter has the same values of D and d . Make sure that the tubes connecting the manometers to the flowmeters do not contain any unwanted air bubbles. This can be verified by noting that the manometer readings, h_v and h_o , are zero when the system is full of water and the flowrate, Q , is zero. Turn on the pump and adjust the valve to give the desired flowrate. Record the time, t , it takes for a given volume, V , of water to be pumped from the tank. The volume can be determined from using the sight gage on the tank. At this flowrate record the manometer readings. Repeat for several different flowrates.

Calculations: For each data set determine the volumetric flowrate, $Q = V/t$, and the pressure differences across each meter, $\Delta p = \gamma_m h$, where γ_m is the specific weight of the manometer fluid. Use the flowmeter equations (see Section 8.6.1) to determine the orifice discharge coefficient, C_o , and the Venturi discharge coefficient, C_v , for these meters.

Graph: On a log–log graph, plot flowrate, Q , as ordinates and pressure difference, Δp , as abscissas.

Result: On the same graph, plot the ideal flowrate, Q_{ideal} (see Eq. 8.37), as a function of pressure difference.



■ Figure P8.127

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

d , in.	D , in.	V , gallons
0.625	1.025	2.00
t , s	h_o , in.	h_v , in.
27.0	9.3	3.8
13.2	37.1	14.5
34.2	5.5	1.9
16.6	23.9	10.1
12.0	43.2	18.1
11.7	51.3	21.7
15.4	27.9	11.2
25.1	10.1	4.2
20.4	14.7	6.2
17.3	21.4	8.7
15.7	26.7	11.2

8.3LP Flow from a Tank through a Pipe System

Objective: The rate of flow of water from a tank is a function of the pipe system used to drain the tank. The purpose of this experiment is to use a pipe system as shown in Fig. P8.128 to investigate the importance of major and minor head losses in a typical pipe flow situation.

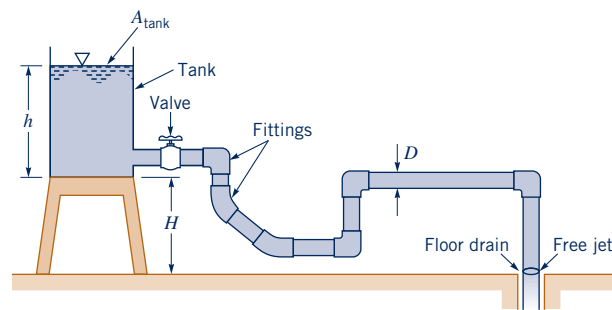
Equipment: Water tank; various lengths of galvanized iron pipe; various threaded pipe fittings (valves, elbows, etc.); pipe wrenches; stopwatch; thermometer.

Experimental Procedure: Use the pipe segments and pipe fittings to construct a suitable pipeline through which the tank water may flow into a floor drain. Measure the pipe diameter, D , and the various pipe lengths and note the various valves and fittings used. Measure the elevation difference, H , between the bottom of the tank and the outlet of the pipe. Also determine the cross-sectional area of the tank, A_{tank} . Fill the tank with water and record the water temperature, T . With the pipeline valve wide open, measure the water depth, h , in the tank as a function of time, t , as the tank drains.

Calculations: Calculate the experimentally determined flowrate, Q_{ex} , from the tank as $Q_{\text{ex}} = -A_{\text{tank}} dh/dt$, where the time rate of change of water depth, dh/dt , is obtained from the slope of the h versus t graph. Select a typical water depth, h_1 , for this calculation.

Graph: Plot the water depth, h , in the tank as ordinates and time, t , as abscissas.

Results: For the pipe system used in this experiment, use the energy equation to calculate the theoretical flowrate, Q_{th} , based on three different assumptions. Use the same typical water depth, h_1 , for the theoretical calculations as was used in determining Q_{ex} . First, calculate Q_{th} under the assumption that all losses are negligible. Second, calculate Q_{th} if only major losses (pipe friction) are important. Third, calculate Q_{th} if both major and minor losses are important.



■ Figure P8.128

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

The pipe is galvanized iron with threaded fittings.

The system contains:

- one sharp edged entrance
- one fully open globe valve
- two 45-deg elbows
- four 90-deg elbows

D , in.	A_{tank} , ft ²	H , ft	Total pipe length, in.	T , deg. F
0.595	0.654	1.00	135	71
h , ft	t , s			
1.00	0			
0.90	13			
0.80	26			
0.70	40			
0.60	54			
0.50	67			
0.40	81			

8.4LP Flow of Water Pumped from a Tank and through a Pipe System

Objective: The rate of flow of water pumped from a tank is a function of the pump properties and of the pipe system used. The purpose of this experiment is to use a pump and pipe system as shown schematically in Fig. P8.129 to investigate the rate at which the water is pumped from the tank.

Equipment: Water tank; centrifugal pump; various lengths of galvanized iron pipe; various threaded pipe fittings (valves, elbows, unions, etc.); pipe wrenches; stopwatch; thermometer.

Experimental Procedure: Use the pipe segments and pipe fittings to construct a suitable pipeline through which the tank water may be pumped into a sink. Measure the pipe diameter, D , and the various pipe lengths and note the various valves and fittings used. Measure the elevation difference, H , between the bottom of the tank and the outlet of the pipe. Also determine the cross-sectional area of the tank, A_{tank} . Fill the tank with water and record the water temperature, T . With the pipeline valves wide open, measure the water depth, h , in the tank as a function of time, t , as water is pumped from the tank.

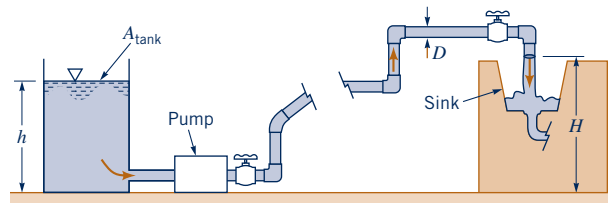
Calculations: Calculate the experimentally determined flowrate, Q_{ex} , from the tank as $Q_{\text{ex}} = -A_{\text{tank}} dh/dt$, where the time rate of change of water depth, dh/dt , is obtained from the slope of the h versus t graph.

Graph: Plot the water depth, h , in the tank as ordinates and time, t , as abscissas.

Results: For the pipe system used in this experiment, use the energy equation to calculate the pump head, h_p , needed in order to produce a given flowrate, Q . For these calculations include all major and minor losses in the pipe system. Plot the system curve (i.e., pump head as ordinates and flowrate as abscissas) based on the results of these calculations. On the same graph, plot the pump curve (i.e., h_p as a function of Q) as supplied by the pump manufacturer. For the pump used, this curve is given by

$$h_p = -2.44 \times 10^5 Q^2 + 51.0 Q + 12.5$$

where Q is in ft^3/s and h_p is in ft. From the intersection of the system curve and the pump curve, determine the theoretical flowrate that the pump should provide for the pipe system used.



■ Figure P8.129

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

The pipe is galvanized iron with threaded fittings.

The system contains:

one sharp entrance
 eight 90-deg elbows
 two 45-deg elbows
 two globe valves
 one union

D , in.	A_{tank} , ft ²	H , ft	Total pipe length, in.	T , deg. F
0.625	0.647	3.50	242	62
h , in.	t , s			
25	0			
24	7.6			
23	16.1			
22	25.2			
21	32.3			
20	40.8			
19	48.9			
18	57.7			
17	65.7			
16	74.9			
15	82.7			

8.5LP Pressure Distribution in the Entrance Region of a Pipe

Objective: The pressure distribution in the entrance region of a pipe is different than that in the fully developed portion of the pipe. The purpose of this experiment is to use an apparatus, as shown in Fig. P8.130, to determine the pressure distribution and the head loss in the pipe entrance region.

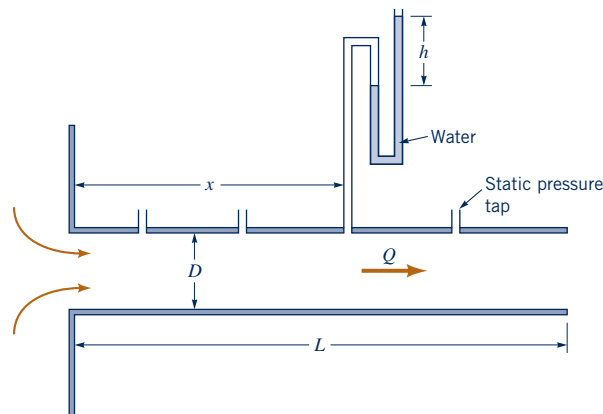
Equipment: Air supply with flowmeter, pipe with static pressure taps, manometer, ruler, barometer, thermometer.

Experimental Procedure: Measure the diameter, D , and length, L , of the pipe and the distance, x , from the pipe inlet to the various static pressure taps. Adjust the flowrate, Q , to the desired value. Record the manometer readings, h , at the various distances from the pipe entrance. Record the barometer reading, H_{bar} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: Determine the average velocity, $V = Q/A$, in the pipe and the pressure $p = \gamma_m h$ at the various locations, x , along the pipe. Here γ_m is the specific weight of the manometer fluid.

Graph: Plot the pressure, p , within the pipe as ordinates and the axial location, x , as abscissas.

Result: Use the graph to determine the entrance length, L_e , for the pipe. This can be done by noting the approximate location at which the pressure distribution becomes linear with distance along the pipe (i.e., where dp/dx becomes constant). Use the experimental data to determine the friction factor for fully developed flow in this pipe. Also determine the entrance loss coefficient, K_{Lent} .



■ Figure P8.130

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

D , in.	L , in.	Q , ft ³ /s	H_{atm} , in. Hg	T , deg. F
0.74	50	0.481	29.7	75
x , in.	h , in.			
0	9.98			
1	7.21			
2	6.61			
4	6.19			
6	5.82			
10	5.15			
15	4.23			
20	3.64			
30	2.28			
40	1.09			
50	0			

8.6LP Power Loss in a Coiled Pipe

Objective: The amount of power, P , dissipated in a pipe depends on the head loss, h_L , and the flowrate, Q . The purpose of this experiment is to use an apparatus as shown in Fig. P8.131 to determine the power loss in a coiled pipe and to determine how the coiling of the pipe affects the power loss.

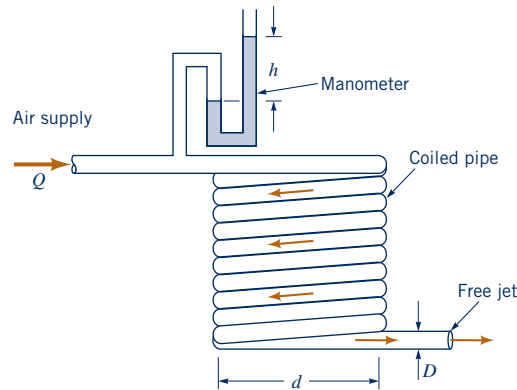
Equipment: Air supply with a flowmeter; flexible pipe that can be used either as a straight pipe or formed into a coil; manometer; barometer; thermometer.

Experimental Procedure: Straighten the pipe and fasten it to the air supply exit. Measure the diameter, D , and length, L , of the pipe. Adjust the flowrate, Q , to the desired value and determine the manometer reading, h . Repeat the measurements for various flowrates. Form the pipe into a coil of diameter d and repeat the flowrate–pressure measurements. Record the barometer reading, H_{bar} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: Use the manometer data to determine the pressure drop, $\Delta p = \gamma_m h$, and head loss, $h_L = \Delta p / \gamma$, as a function of flowrate, Q , for both the straight and coiled pipes. Here γ_m is the specific weight of the manometer fluid and γ is the specific weight of the flowing air. Also calculate the power loss, $P = \gamma Q h_L$, for both the straight and coiled pipes.

Graph: Plot head loss, h_L , as ordinates and flowrate, Q , as abscissas.

Results: On a log–log graph, plot the power loss, P , as a function of flowrate for both the straight and coiled pipes. Determine the best-fit straight lines through the data.



■ Figure P8.131

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

D , in.	L , ft	H_{atm} , in. Hg	T , deg. F
1.44	18	29.9	80
h , in.	Q , ft ³ /s		
Straight Pipe Data ($d = \text{infinity}$)			
10.0	1.19		
8.0	1.06		
6.0	0.913		
4.0	0.731		
2.0	0.505		
Coiled Pipe Data ($d = 8$ in.)			
10.0	0.835		
8.0	0.745		
6.0	0.641		
4.0	0.517		
2.0	0.357		

Lab Problems for Chapter 9

9.1LP Boundary Layer on a Flat Plate

Objective: A boundary layer is formed on a flat plate when air blows past the plate. The thickness, δ , of the boundary layer increases with distance, x , from the leading edge of the plate. The purpose of this experiment is to use an apparatus, as shown in Fig. P9.112, to measure the boundary layer thickness.

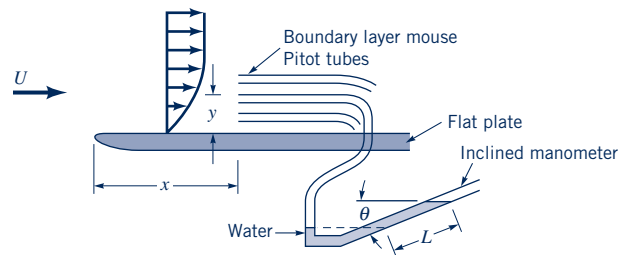
Equipment: Wind tunnel; flat plate; boundary layer mouse consisting of ten Pitot tubes positioned at various heights, y , above the flat plate; inclined multiple manometer; measuring calipers; barometer, thermometer.

Experimental Procedure: Position the tips of the Pitot tubes of the boundary layer mouse a known distance, x , downstream from the leading edge of the plate. Use calipers to determine the distance, y , between each Pitot tube and the plate. Fasten the tubing from each Pitot tube to the inclined multiple manometer and determine the angle of inclination, θ , of the manometer board. Adjust the wind tunnel speed, U , to the desired value and record the manometer readings, L . Move the boundary layer mouse to a new distance, x , downstream from the leading edge of the plate and repeat the measurements. Record the barometer reading, H_{bar} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: For each distance, x , from the leading edge, use the manometer data to determine the airspeed, u , as a function of distance, y , above the plate (see Eq. 3.13). That is, obtain $u = u(y)$ at various x locations. Note that both the wind tunnel test section and the open end of the manometer tubes are at atmospheric pressure.

Graph: Plot speed, u , as ordinates and distance from the plate, y , as abscissas for each location, x , tested.

Results: Use the $u = u(y)$ results to determine the approximate boundary layer thickness as a function of distance, $\delta = \delta(x)$. Plot a graph of boundary layer thickness as a function of distance from the leading edge. Note that the airflow within the wind tunnel is quite turbulent so that the measured boundary layer thickness is not expected to match the theoretical laminar boundary layer thickness given by the Blasius solution (see Eq. 9.15).



■ Figure P9.112

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

θ , deg.	H_{atm} , in. Hg	T , deg. F	
25	29.09	80	
y, in.	L, in.	y, in.	L, in.
Data for $x = 7.75$ in.		Data for $x = 5.75$ in.	
0.020	0.20	0.020	0.15
0.035	0.35	0.035	0.35
0.044	0.48	0.044	0.45
0.060	0.70	0.060	0.71
0.096	0.95	0.096	1.20
0.110	1.06	0.110	1.30
0.138	1.21	0.138	1.56
0.178	1.44	0.178	1.77
0.230	1.70	0.230	1.95
0.270	1.85	0.270	2.00
Data for $x = 5.75$ in.		Data for $x = 1.75$ in.	
0.020	0.20	0.020	0.20
0.035	0.42	0.035	0.50
0.044	0.50	0.044	0.68
0.060	0.71	0.060	0.90
0.096	0.98	0.096	1.51
0.110	1.06	0.110	1.70
0.138	1.30	0.138	1.90
0.178	1.54	0.178	1.95
0.230	1.76	0.230	2.00
0.270	1.88	0.270	2.00

9.2LP Pressure Distribution on a Circular Cylinder

Objective: Viscous effects within the boundary layer on a circular cylinder cause boundary layer separation, thereby causing the pressure distribution on the rear half of the cylinder to be different than that on the front half. The purpose of this experiment is to use an apparatus, as shown in Fig. P9.113, to determine the pressure distribution on a circular cylinder.

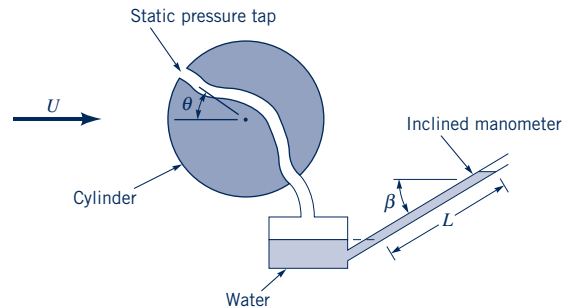
Equipment: Wind tunnel; circular cylinder with 18 static pressure taps arranged equally from the front to the back of the cylinder; inclined multiple manometer; barometer; thermometer.

Experimental Procedure: Mount the circular cylinder in the wind tunnel so that a static pressure tap points directly upstream. Measure the angle, β , of the inclined manometer. Adjust the wind tunnel fan speed to give the desired free-stream speed, U , in the test section. Attach the tubes from the static pressure taps to the multiple manometer and record the manometer readings, L , as a function of angular position, θ . Record the barometer reading, H_{bar} , in inches of mercury and the air temperature, T , so that the air density can be calculated by use of the perfect gas law.

Calculations: Use the data to determine the pressure coefficient, $C_p = (p - p_0)/(\rho U^2/2)$, as a function of position, θ . Here $p_0 = 0$ is the static pressure upstream of the cylinder in the free stream of the wind tunnel, and $p = \gamma_m L \sin \beta$ is the pressure on the surface of the cylinder.

Graph: Plot the pressure coefficient, C_p , as ordinates and the angular location, θ , as abscissas.

Results: On the same graph, plot the theoretical pressure coefficient, $C_p = 1 - 4 \sin^2 \theta$, obtained from ideal (inviscid) theory (see Section 6.6.3).



■ Figure P9.113

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

β , deg.	H_{atm} , in. Hg	T , deg. F
25	29.97	75
θ , deg	L , in.	
0	1.2	
10	1.1	
20	0.7	
30	0.1	
40	−0.6	
50	−1.6	
60	−2.4	
70	−3.1	
80	−3.0	
90	−2.7	
100	−2.7	
110	−2.6	
120	−2.6	
130	−2.6	
140	−2.6	
150	−2.6	
160	−2.7	
170	−2.7	
180	−2.8	

Lab Problems for Chapter 10

10.1LP Calibration of a Triangular Weir

Objective: The flowrate over a weir is a function of the weir head. The purpose of this experiment is to use a device as shown in Fig. P10.114 to calibrate a triangular weir and determine the relationship between flowrate, Q , and weir head, H .

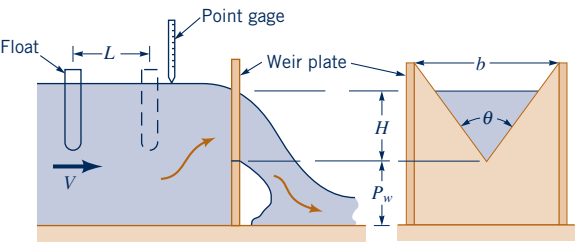
Equipment: Water channel (flume) with a pump and a flow control valve; triangular weir; float; point gage; stopwatch.

Experimental Procedure: Measure the width, b , of the channel, the distance, P_w , between the channel bottom and the bottom of the V-notch in the weir plate, and the angle, θ , of the V-notch. Fasten the weir plate to the channel bottom, turn on the pump, and adjust the control valve to produce the desired flowrate, Q , over the weir. Use the point gage to measure the weir head, H . Insert the float into the water well upstream from the weir and measure the time, t , it takes for the float to travel a known distance, L . Repeat the measurements for various flowrates (i.e., various weir heads).

Calculations: For each set of data, determine the experimental flowrate as $Q = VA$, where $V = L/t$ is the velocity of the float (assumed to be equal to the average velocity of the water upstream of the weir) and $A = b(P_w + H)$ is the flow area upstream of the weir.

Graph: On log-log graph paper, plot flowrate, Q , as ordinates and weir head, H , as abscissas. Draw the best-fit line with a slope of $5/2$ through the data.

Results: Use the flowrate–weir head data to determine the triangular weir coefficient, C_{wf} , for this weir (see Eq. 10.32). For this experiment, assume that the weir coefficient is a constant, independent of weir head.



■ Figure P10.114

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

θ , deg.	b , in.	P_w , in.	L , ft
90	6.00	6.55	1.50
H , ft	t , s		
0.231	8.2		
0.224	8.5		
0.211	10.7		
0.192	12.5		
0.176	16.5		
0.156	19.5		
0.136	27.1		
0.106	48.2		
0.091	62.9		
0.088	68.1		

10.2LP Calibration of a Rectangular Weir

Objective: The flowrate over a weir is a function of the weir head. The purpose of this experiment is to use a device as shown in Fig. P10.115 to calibrate a rectangular weir and determine the relationship between flowrate, Q , and weir head, H .

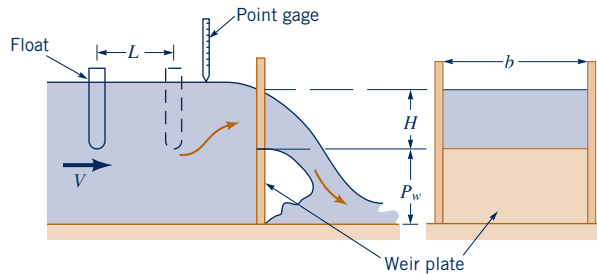
Equipment: Water channel (flume) with a pump and a flow control valve; rectangular weir; float; point gage; stopwatch.

Experimental Procedure: Measure the width, b , of the channel and the distance, P_w , between the channel bottom and the top of the weir plate. Fasten the weir plate to the channel bottom, turn on the pump, and adjust the control valve to produce the desired flowrate, Q , over the weir. Use the point gage to measure the weir head, H . Insert the float into the water well upstream from the weir and measure the time, t , it takes for the float to travel a known distance, L . Repeat the measurements for various flowrates (i.e., various weir heads).

Calculations: For each set of data, determine the experimental flowrate as $Q = VA$, where $V = L/t$ is the velocity of the float (assumed to be equal to the average velocity of the water upstream of the weir) and $A = b(P_w + H)$ is the flow area upstream of the weir.

Graph: On log-log graph paper, plot flowrate, Q , as ordinates and weir head, H , as abscissas. Draw the best-fit line with a slope of $3/2$ through the data.

Results: Use the flowrate-weir head data to determine the rectangular weir coefficient, C_{wr} , for this weir (see Eq. 10.30). For this experiment, assume that the weir coefficient is a constant, independent of weir head.



■ Figure P10.115

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

b , in.	P_w , in.	L , ft
6.00	6.00	1.40
H , ft	t , s	
0.254	2.2	
0.216	2.7	
0.184	3.0	
0.162	4.2	
0.151	4.5	
0.111	6.6	
0.060	15.8	
0.046	23.8	
0.031	38.4	

10.3LP Hydraulic Jump Depth Ratio

Objective: Under certain conditions, if the flow in a channel is supercritical a hydraulic jump will form. The purpose of this experiment is to use an apparatus as shown in Fig. P10.116 to determine the depth ratio, y_2/y_1 , across the hydraulic jump as a function of the Froude number upstream of the jump, Fr_1 .

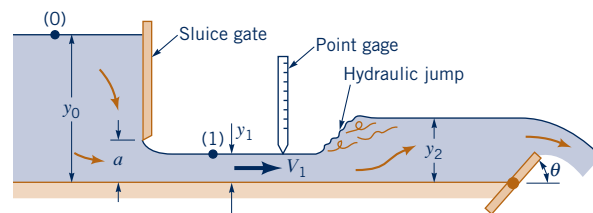
Equipment: Water channel (flume) with a pump and a flow control valve; sluice gate; point gage; adjustable tailgate.

Experimental Procedure: Position the sluice gate so that the distance, a , between the bottom of the gate and the bottom of the channel is approximately 1 in. Adjust the flow control valve to produce a flowrate that causes the water to back up to the desired depth, y_0 , upstream of the sluice gate. Carefully adjust the angle, θ , of the tailgate so that a hydraulic jump forms at the desired location downstream from the sluice gate. Note that if θ is too small, the jump will be washed downstream and disappear. If θ is too large, the jump will migrate upstream and will be swallowed by the sluice gate. With the jump in place, use the point gage to determine the depth upstream from the sluice gate, y_0 , the depth just upstream from the jump, y_1 , and the depth downstream from the jump, y_2 . Repeat the measurements for various flowrates (i.e., various y_0 values).

Calculations: For each data set, use the Bernoulli and continuity equations between points (0) and (1) to determine the velocity, V_1 , and Froude number, $Fr_1 = V_1/(gy_1)^{1/2}$, just upstream from the jump (see Eq. 3.21). Also use the measured depths to determine the depth ratio, y_2/y_1 , across the jump.

Graph: Plot the depth ratio, y_2/y_1 , as ordinates and Froude number, Fr_1 , as abscissas.

Results: On the same graph, plot the theoretical depth ratio as a function of Froude number (see Eq. 10.24).



■ Figure P10.116

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

y_0 , ft	y_1 , ft	y_2 , ft
0.855	0.055	0.404
0.759	0.055	0.386
0.691	0.055	0.367
0.578	0.055	0.337
0.492	0.055	0.308
0.414	0.055	0.280
0.289	0.055	0.233
0.248	0.055	0.211

10.4LP Hydraulic Jump Head Loss

Objective: Under certain conditions, if the flow in a channel is supercritical, a hydraulic jump will form. The purpose of this experiment is to use an apparatus as shown in Fig. P10.117 to determine the head loss ratio, h_L/y_1 , across the hydraulic jump as a function of the Froude number upstream of the jump, Fr_1 .

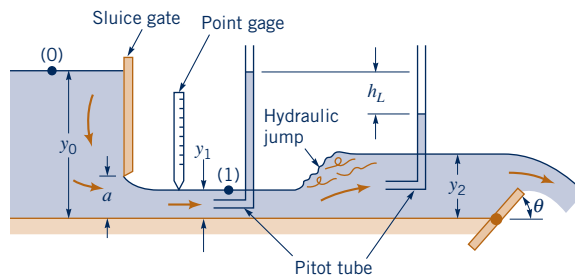
Equipment: Water channel (flume) with a pump and a flow control valve; sluice gate; point gage; Pitot tubes; adjustable tailgate.

Experimental Procedure: Position the sluice gate so that the distance, a , between the bottom of the gate and the bottom of the channel is approximately 1 in. Adjust the flow control valve to produce a flowrate that causes the water to back up to the desired depth, y_0 , upstream of the sluice gate. Carefully adjust the angle, θ , of the tailgate so that a hydraulic jump forms at the desired location downstream from the sluice gate. Note that if θ is too small, the jump will be washed downstream and disappear. If θ is too large, the jump will migrate upstream and be swallowed by the sluice gate. With the jump in place, use the point gage to determine the depth upstream from the sluice gate, y_0 , and the depth just upstream from the jump, y_1 . Also measure the head loss, h_L , as the difference in the water elevations in the piezometer tubes connected to the two Pitot tubes located upstream and downstream of the jump. Repeat the measurements for various flowrates (i.e., various y_0 values).

Calculations: For each data set, use the Bernoulli and continuity equations between points (0) and (1) to determine the velocity, V_1 , and the Froude number, $Fr_1 = V_1/(gy_1)^{1/2}$, just upstream from the jump. Also calculate the dimensionless head loss, h_L/y_1 , for each data set.

Graph: Plot the dimensionless head loss across the jump, h_L/y_1 , as ordinates and the Froude number, Fr_1 , as abscissas.

Results: On the same graph, plot the theoretical dimensionless head loss as a function of Froude number (see Eqs. 10.24 and 10.25).



■ Figure P10.117

Data: To proceed, print this page for reference when you work the problem. To bring up an EXCEL page with the data for this problem, go to the section titled “EXCEL data for laboratory problems” on the book’s web site www.wiley.com/college/munson.

y_0 , ft	y_1 , ft	y_2 , ft	h_L , ft
0.855	0.055	0.404	0.364
0.759	0.055	0.386	0.313
0.691	0.055	0.367	0.271
0.578	0.055	0.337	0.201
0.492	0.055	0.308	0.152
0.414	0.055	0.280	0.117
0.289	0.055	0.233	0.058
0.248	0.055	0.211	0.042