P3.8 Consider the two-dimensional stagnation flow of Example 1.10, where $u = Kx$ and $v = -Ky$, with $K > 0$. Evaluate the volume flow Q, per unit depth into the paper, passing through the rectangular surface normal to the paper which stretches from $(x, y) = (0, 0)$ to $(1, 1)$.

P3.9 A laboratory test tank contains seawater of salinity S and density ρ. Water enters the tank at conditions (S_1, ρ_1, A_1, V_1) and is assumed to mix immediately in the tank. Tank water leaves through an outlet A_2 at velocity V_2. If salt is a "conservative" property (neither created nor destroyed), use the Reynolds transport theorem to find an expression for the rate of change of salt mass M_{salt} within the tank.

P3.10 Laminar steady flow, through a tube of radius R and length L, is being heated at the wall. The fluid entered the tube at uniform temperature $T_0 = T_w/3$. As the fluid exits the tube, its axial velocity and enthalpy profiles are approximated by

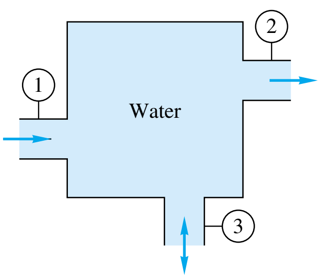
$$u = U_0\left(1 - \frac{r^2}{R^2}\right) \qquad h = \frac{c_p T_w}{2}\left(1 + \frac{r^2}{R^2}\right)$$

$$c_p = \text{const}$$

(*a*) Sketch these profiles and comment on their physical realism. (*b*) Compute the total flux of enthalpy through the exit section.

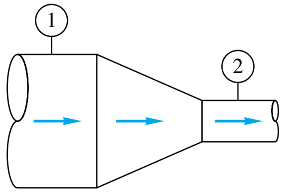
P3.11 A room contains dust of uniform concentration $C = \rho_{dust}/\rho$. It is to be cleaned up by introducing fresh air at velocity V_i through a duct of area A_i on one wall and exhausting the room air at velocity V_0 through a duct A_0 on the opposite wall. Find an expression for the instantaneous rate of change of dust mass within the room.

P3.12 Water at 20°C flows steadily through a closed tank, as in Fig. P3.12. At section 1, $D_1 = 6$ cm and the volume flow is 100 m^3/h. At section 2, $D_2 = 5$ cm and the average velocity is 8 m/s. If $D_3 = 4$ cm, what is (*a*) Q_3 in m^3/h and (*b*) average V_3 in m/s?



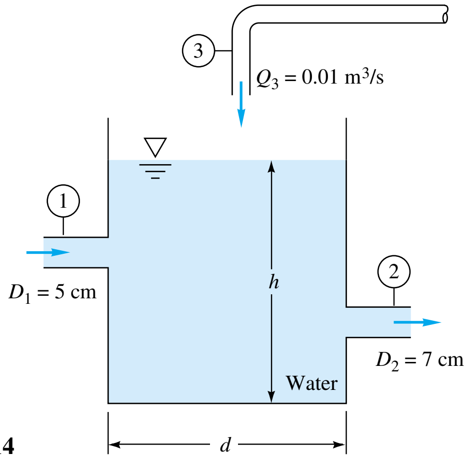
P3.12

P3.13 Water at 20°C flows steadily at 40 kg/s through the nozzle in Fig. P3.13. If $D_1 = 18$ cm and $D_2 = 5$ cm, compute the average velocity, in m/s, at (*a*) section 1 and (*b*) section 2.



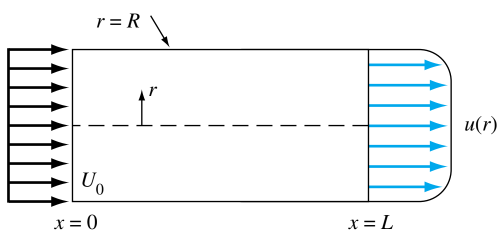
P3.13

P3.14 The open tank in Fig. P3.14 contains water at 20°C and is being filled through section 1. Assume incompressible flow. First derive an analytic expression for the water-level change dh/dt in terms of arbitrary volume flows (Q_1, Q_2, Q_3) and tank diameter d. Then, if the water level h is constant, determine the exit velocity V_2 for the given data $V_1 = 3$ m/s and $Q_3 = 0.01$ m^3/s.



P3.14

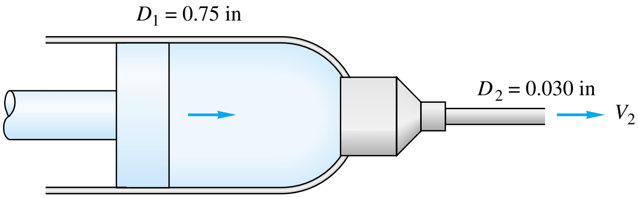
P3.15 Water, assumed incompressible, flows steadily through the round pipe in Fig. P3.15. The entrance velocity is constant, $u = U_0$, and the exit velocity approximates turbulent flow, $u = u_{max}(1 - r/R)^{1/7}$. Determine the ratio U_0/u_{max} for this flow.



P3.15

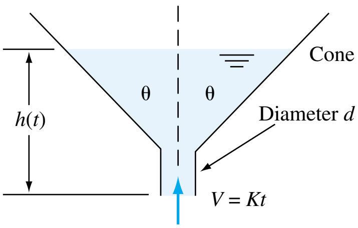
P3.16 An incompressible fluid flows past an impermeable flat plate, as in Fig. P3.16, with a uniform inlet profile $u = U_0$ and a cubic polynomial exit profile

P3.23 The hypodermic needle in Fig. P3.23 contains a liquid serum (SG = 1.05). If the serum is to be injected steadily at 6 cm^3/s, how fast in in/s should the plunger be advanced (*a*) if leakage in the plunger clearance is neglected and (*b*) if leakage is 10 percent of the needle flow?



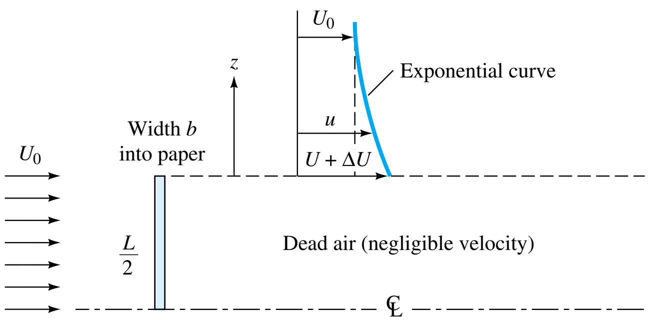
P3.23

***P3.24** Water enters the bottom of the cone in Fig. P3.24 at a uniformly increasing average velocity $V = Kt$. If d is very small, derive an analytic formula for the water surface rise $h(t)$ for the condition $h = 0$ at $t = 0$. Assume incompressible flow.



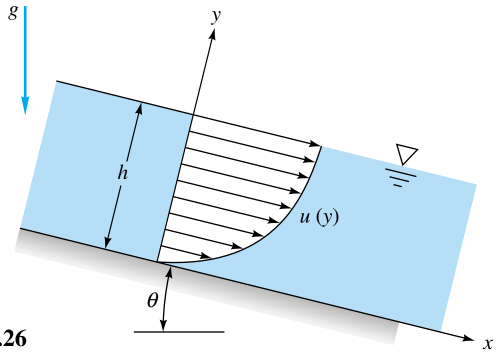
P3.24

P3.25 As will be discussed in Chaps. 7 and 8, the flow of a stream U_0 past a blunt flat plate creates a broad low-velocity wake behind the plate. A simple model is given in Fig. P3.25, with only half of the flow shown due to symmetry. The velocity profile behind the plate is idealized as "dead air" (near-zero velocity) behind the plate, plus a higher velocity, decaying vertically above the wake according to the variation $u \approx U_0 + \Delta U\, e^{-z/L}$, where L is the plate height and $z = 0$ is the top of the wake. Find ΔU as a function of stream speed U_0.



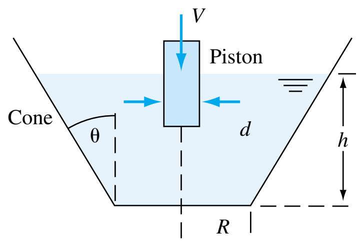
P3.25

P3.26 A thin layer of liquid, draining from an inclined plane, as in Fig. P3.26, will have a laminar velocity profile $u \approx U_0(2y/h - y^2/h^2)$, where U_0 is the surface velocity. If the plane has width b into the paper, determine the volume rate of flow in the film. Suppose that $h = 0.5$ in and the flow rate per foot of channel width is 1.25 gal/min. Estimate U_0 in ft/s.



P3.26

***P3.27** The cone frustum in Fig. P3.27 contains incompressible liquid to depth h. A solid piston of diameter d penetrates the surface at velocity V. Derive an analytic expression for the rate of rise dh/dt of the liquid surface.

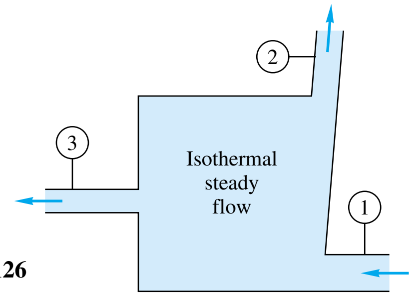


P3.27

P3.28 Consider a cylindrical water tank of diameter D and water depth h. According to elementary theory, the flow rate from a small hole of area A in the bottom of the tank would be $Q \approx CA\sqrt{2gh}$, where $C \approx 0.61$. If the initial water level is h_0 and the hole is opened, derive an expression for the time required for the water level to drop to $\frac{1}{3}h_0$.

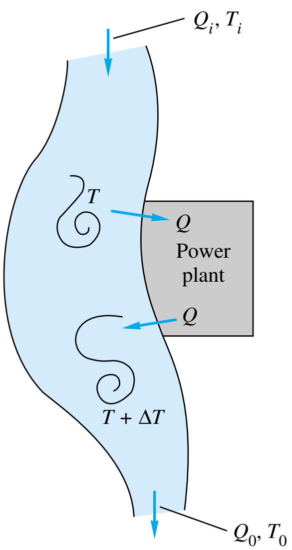
P3.29 In elementary compressible-flow theory (Chap. 9), compressed air will exhaust from a small hole in a tank at the mass flow rate $\dot{m} \approx C\rho$, where ρ is the air density in the tank and C is a constant. If ρ_0 is the initial density in a tank of volume $\mathscr{V}$, derive a formula for the density change $\rho(t)$ after the hole is opened. Apply your formula to the following case: a spherical tank of diameter 50 cm, with initial pressure 300 kPa and temperature 100°C, and a hole whose initial exhaust rate is 0.01 kg/s. Find the time required for the tank density to drop by 50 percent.

P3.126 There is a steady isothermal flow of water at 20°C through the device in Fig. P3.126. Heat-transfer, gravity, and temperature effects are negligible. Known data are $D_1 = 9$ cm, $Q_1 = 220$ m^3/h, $p_1 = 150$ kPa, $D_2 = 7$ cm, $Q_2 = 100$ m^3/h, $p_2 = 225$ kPa, $D_3 = 4$ cm, and $p_3 = 265$ kPa. Compute the rate of shaft work done for this device and its direction.



P3.126

P3.127 A power plant on a river, as in Fig. P3.127, must eliminate 55 MW of waste heat to the river. The river conditions upstream are $Q_i = 2.5$ m^3/s and $T_i = 18$°C. The river is 45 m wide and 2.7 m deep. If heat losses to the atmosphere and ground are negligible, estimate the downstream river conditions (Q_0, T_0).

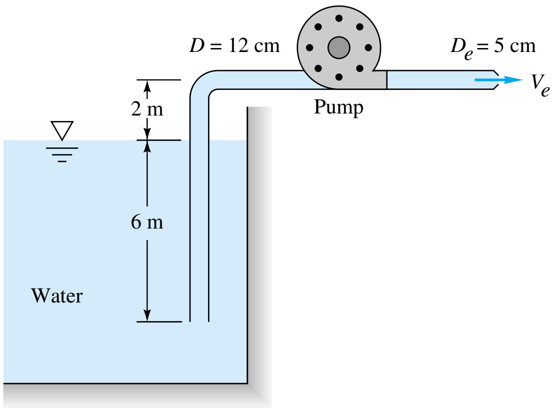


P3.127

P3.128 For the conditions of Prob. 3.127, if the power plant is to heat the nearby river water by no more than 12°C, what should be the minimum flow rate Q, in m^3/s, through the plant heat exchanger? How will the value of Q affect the downstream conditions (Q_0, T_0)?

P3.129 Multnomah Falls in the Columbia River Gorge has a sheer drop of 543 ft. Using the steady-flow energy equation, estimate the water temperature change in °F caused by this drop.

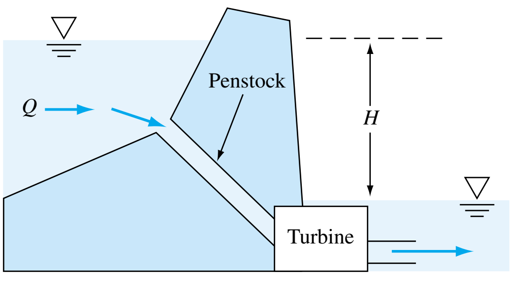
P3.130 When the pump in Fig. P3.130 draws 220 m^3/h of water at 20°C from the reservoir, the total friction head loss is 5 m. The flow discharges through a nozzle to the atmosphere. Estimate the pump power in kW delivered to the water.



P3.130

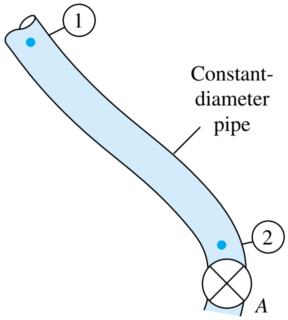
P3.131 When the pump in Fig. P3.130 delivers 25 kW of power to the water, the friction head loss is 4 m. Estimate (*a*) the exit velocity V_e and (*b*) the flow rate Q.

P3.132 Consider a turbine extracting energy from a penstock in a dam, as in Fig. P3.132. For turbulent pipe flow (Chap. 6), the friction head loss is approximately $h_f = CQ^2$, where the constant C depends upon penstock dimensions and the properties of water. Show that, for a given penstock geometry and variable river flow Q, the maximum turbine power possible in this case is $P_{max} = 2\rho gHQ/3$ and occurs when the flow rate is $Q = \sqrt{H/(3C)}$.



P3.132

P3.133 The long pipe in Fig. P3.133 is filled with water at 20°C. When valve A is closed, $p_1 - p_2 = 75$ kPa. When the valve is open and water flows at 500 m^3/h, $p_1 - p_2 = 160$ kPa.

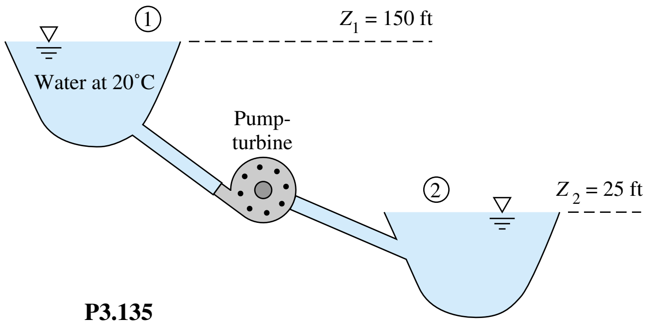


P3.133

What is the friction head loss between 1 and 2, in m, for the flowing condition?

P3.134 A 36-in-diameter pipeline carries oil (SG = 0.89) at 1 million barrels per day (bbl/day) (1 bbl = 42 U.S. gal). The friction head loss is 13 ft/1000 ft of pipe. It is planned to place pumping stations every 10 mi along the pipe. Estimate the horsepower which must be delivered to the oil by each pump.

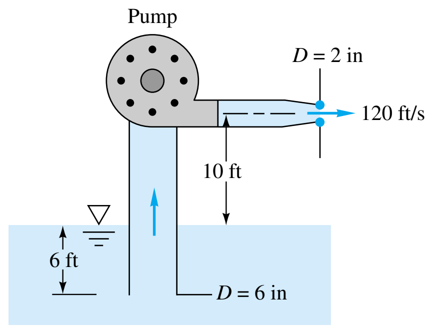
P3.135 The *pump-turbine* system in Fig. P3.135 draws water from the upper reservoir in the daytime to produce power for a city. At night, it pumps water from lower to upper reservoirs to restore the situation. For a design flow rate of 15,000 gal/min in either direction, the friction head loss is 17 ft. Estimate the power in kW (*a*) extracted by the turbine and (*b*) delivered by the pump.



P3.135

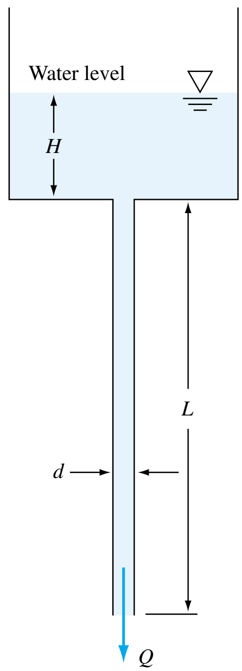
P3.136 A pump is to deliver water at 20°C from a pond to an elevated tank. The pump is 1 m above the pond, and the tank free surface is 20 m above the pump. The head loss in the system is $h_f \approx cQ^2$, where $c = 0.08$ h^2/m^5. If the pump is 72 percent efficient and is driven by a 500-W motor, what flow rate Q m^3/h will result?

P3.137 A fireboat draws seawater (SG = 1.025) from a submerged pipe and discharges it through a nozzle, as in Fig. P3.137. The total head loss is 6.5 ft. If the pump efficiency is 75 percent, what horsepower motor is required to drive it?



P3.137

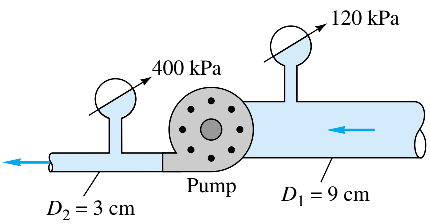
***P3.138** Students in the fluid mechanics laboratory at Penn State use a very simple device to measure the viscosity of water as a function of temperature. The viscometer, shown in Fig. P3.138, consists of a tank, a long vertical capillary tube, a graduated cylinder, a thermometer, and a stopwatch. Because the tube has such a small diameter, the flow remains laminar. Because the tube is so long, entrance losses are negligible. It will be shown in Chap. 6 that the laminar head loss through a long pipe is given by $h_{f,\ \text{laminar}} = (32\mu LV)/(\rho g d^2)$, where V is the average speed through the pipe. (*a*) In a given experiment, diameter d, length L, and water level height H are known, and volume flow rate Q is measured with the stopwatch and graduated cylinder. The temperature of the water is also measured. The water density at this tempera-



P3.138

ture is obtained by weighing a known volume of water. Write an expression for the viscosity of the water as a function of these variables. (*b*) Here are some actual data from an experiment: $T = 16.5°C$, $\rho = 998.7\ kg/m^3$, $d = 0.041$ in, $Q = 0.310$ mL/s, $L = 36.1$ in, and $H = 0.153$ m. Calculate the viscosity of the water in kg/(m · s) based on these experimental data. (*c*) Compare the experimental result with the published value of μ at this temperature, and report a percentage error. (*d*) Compute the percentage error in the calculation of μ which would occur if a student forgot to include the kinetic energy flux correction factor in part (*b*) above (compare results with and without inclusion of kinetic energy flux correction factor). Explain the importance (or lack of importance) of kinetic energy flux correction factor in a problem such as this.

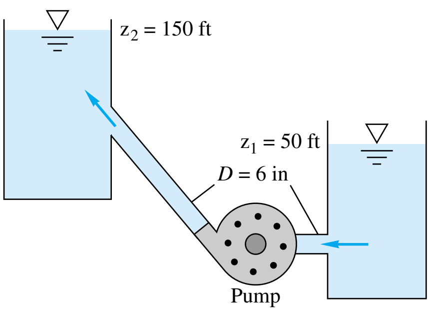
P3.139 The horizontal pump in Fig. P3.139 discharges 20°C water at 57 m^3/h. Neglecting losses, what power in kW is delivered to the water by the pump?



P3.139

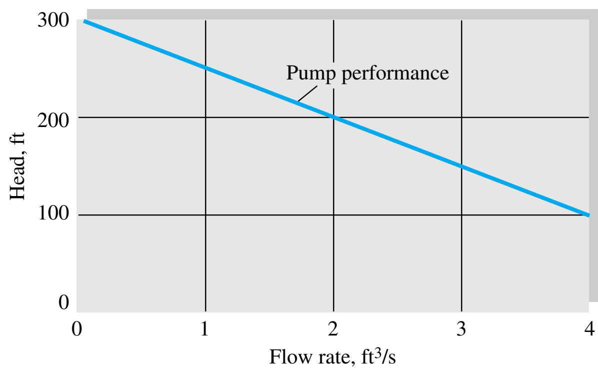
P3.140 Steam enters a horizontal turbine at 350 lbf/in^2 absolute, 580°C, and 12 ft/s and is discharged at 110 ft/s and 25°C saturated conditions. The mass flow is 2.5 lbm/s, and the heat losses are 7 Btu/lb of steam. If head losses are negligible, how much horsepower does the turbine develop?

P3.141 Water at 20°C is pumped at 1500 gal/min from the lower to the upper reservoir, as in Fig. P3.141. Pipe friction losses are approximated by $h_f \approx 27V^2/(2g)$, where V is the average velocity in the pipe. If the pump is 75 percent efficient, what horsepower is needed to drive it?



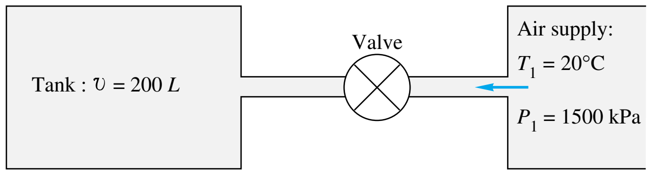
P3.141

P3.142 A typical pump has a head which, for a given shaft rotation rate, varies with the flow rate, resulting in a *pump performance curve* as in Fig. P3.142. Suppose that this pump is 75 percent efficient and is used for the system in Prob. 3.141. Estimate (*a*) the flow rate, in gal/min, and (*b*) the horsepower needed to drive the pump.



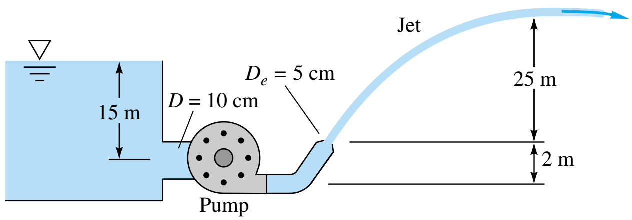
P3.142

P3.143 The insulated tank in Fig. P3.143 is to be filled from a high-pressure air supply. Initial conditions in the tank are $T = 20°C$ and $p = 200$ kPa. When the valve is opened, the initial mass flow rate into the tank is 0.013 kg/s. Assuming an ideal gas, estimate the initial rate of temperature rise of the air in the tank.



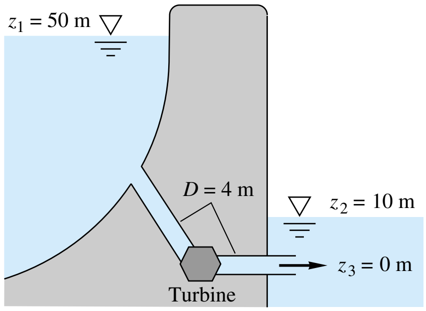
P3.143

P3.144 The pump in Fig. P3.144 creates a 20°C water jet oriented to travel a maximum horizontal distance. System friction head losses are 6.5 m. The jet may be approximated by the trajectory of frictionless particles. What power must be delivered by the pump?

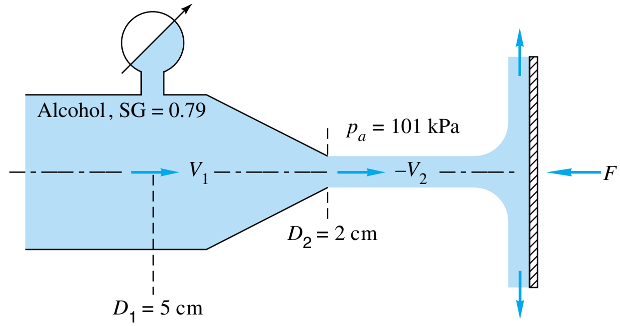


P3.144

P3.145 The large turbine in Fig. P3.145 diverts the river flow under a dam as shown. System friction losses are $h_f = 3.5V^2/(2g)$, where V is the average velocity in the supply



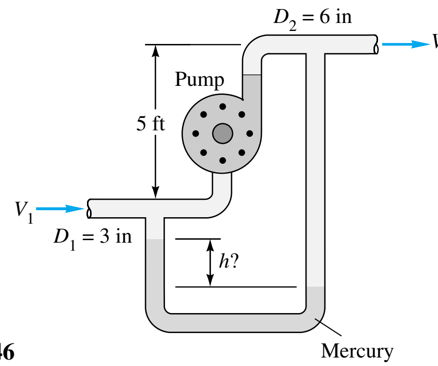
P3.145



P3.149

pipe. For what river flow rate in m^3/s will the power extracted be 25 MW? Which of the *two* possible solutions has a better "conversion efficiency"?

P3.146 Kerosine at 20°C flows through the pump in Fig. P3.146 at 2.3 ft^3/s. Head losses between 1 and 2 are 8 ft, and the pump delivers 8 hp to the flow. What should the mercury-manometer reading h ft be?



P3.146

P3.147 Repeat Prob. 3.49 by assuming that p_1 is unknown and using Bernoulli's equation with no losses. Compute the new bolt force for this assumption. What is the head loss between 1 and 2 for the data of Prob. 3.49?

P3.148 Reanalyze Prob. 3.54 to estimate the manometer reading h if Bernoulli's equation is valid with zero losses. For the reading $h \approx 58$ cm in Prob. 3.54, what is the head loss between sections 1 and 2?

P3.149 A jet of alcohol strikes the vertical plate in Fig. P3.149. A force $F \approx 425$ N is required to hold the plate stationary. Assuming there are no losses in the nozzle, estimate (*a*) the mass flow rate of alcohol and (*b*) the absolute pressure at section 1.

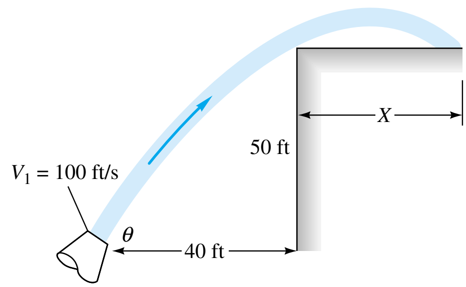
P3.150 Verify that Bernoulli's equation is not valid for the sudden expansion of Prob. 3.59 and that the actual head loss is given by

$$h_f \approx \frac{V_1^2}{2g}\left(1 - \frac{A_1}{A_2}\right)^2$$

See Sec. 6.7 for further details.

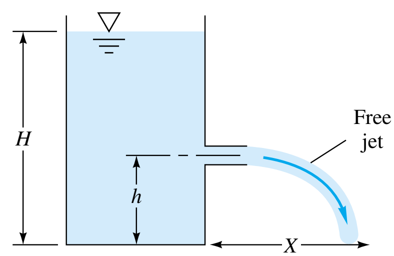
P3.151 In Prob. 3.63 the velocity approaching the sluice gate was assumed to be known. If Bernoulli's equation is valid with no losses, derive an expression for V_1 as a function of only h_1, h_2, and g.

P3.152 A free liquid jet, as in Fig. P3.152, has constant ambient pressure and small losses; hence from Bernoulli's equation $z + V^2/(2g)$ is constant along the jet. For the fire nozzle in the figure, what are (*a*) the minimum and (*b*) the maximum values of θ for which the water jet will clear the corner of the building? For which case will the jet velocity be higher when it strikes the roof of the building?



P3.152

P3.153 For the container of Fig. P3.153 use Bernoulli's equation to derive a formula for the distance X where the free jet



P3.153