- Cavitation is usually undesirable because it can cause reduced performance Cavitation can cause erosion or pitting of solid materials, noise, vibrations, and structural failures.
- Cavitation is most likely to occur in regions of high velocity, in inlet regions of centrifugal pumps, and at locations of high elevations.
- To reduce the probability of cavitation, designers can specify that components that are susceptible to cavitation (e.g., values and centrifugal pumps) be situated at low elevations.

REFERENCES

1. Knapp, R.T., J. W. Daily, and F. G. Hammitt. *Cavitation*. New York: McGraw-Hill, 1970.

2. Brennen, C. E. *Cavitation and Bubble Dynamics*. New York: Oxford University Press, 1995.

3. Young, F. R. *Cavitation*. New York: McGraw-Hill, 1989.

PROBLEMS

PLUS Problem available in *WileyPLUS* at instructor's discretion.

GO Guided Online (GO) Problem, available in *WileyPLUS* at instructor's discretion.

Characterizing Flow Rates (§5.1)

5.1 Consider filling the gasoline tank of an automobile at a gas station. (a) Estimate the discharge in L/min. (b) Using the same nozzle, estimate the time to put 190 L in the tank. (c) Estimate the cross-sectional area of the nozzle and calculate the velocity at the nozzle exit.

5.2 The average flow rate (release) through Grand Coulee Dam is 3100 m^3/s. The width of the river downstream of the dam is 90 m. Making a reasonable estimate of the river velocity, estimate the river depth.

5.3 Taking a jar of known volume, fill with water from your household tap and measure the time to fill. Calculate the discharge from the tap. Estimate the cross-sectional area of the faucet outlet, and calculate the water velocity issuing from the tap.

5.4 PLUS Another name for the volume flow rate equation could be:

a. the discharge equation

b. the mass flow rate equation

c. either a or b

5.5 A liquid flows through a pipe with a constant velocity. If a pipe twice the size is used with the same velocity, will the flow rate be (a) halved, (b) doubled, (c) quadrupled? Explain.

5.6 PLUS For flow of a gas in a pipe, which form of the continuity equation is more general?

a. $V_1A_1 = V_2A_2$

b. $\rho_1V_1A_1 = \rho_2V_2A_2$

c. both are equally applicable

5.7 PLUS The discharge of water in a 35-cm-diameter pipe is 0.06 m^3/s. What is the mean velocity?

5.8 PLUS A pipe with a 46 cm diameter carries water having a velocity of 1.2 m/s. What is the discharge in cubic meters per second and in liters per minute?

5.9 A pipe with a 2 m diameter carries water having a velocity of 4 m/s. What is the discharge in cubic meters per second?

5.10 PLUS A pipe whose diameter is 6 cm transports air with a temperature of 20°C and pressure of 180 kPa absolute at 19 m/s. Determine the mass flow rate.

5.11 PLUS Natural gas (methane) flows at 25 m/s through a pipe with a 0.84 m diameter. The temperature of the methane is 15°C, and the pressure is 160 kPa gage. Determine the mass flow rate.

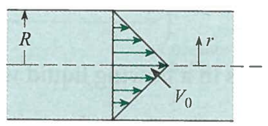
5.12 An aircraft engine test pipe is capable of providing a flow rate of 180 kg/s at altitude conditions corresponding to an absolute pressure of 50 kPa and a temperature of −18°C. The velocity of air through the duct attached to the engine is 255 m/s. Calculate the diameter of the duct.

5.13 A heating and air-conditioning engineer is designing a system to move 1000 m^3 of air per hour at 100 kPa abs, and 30°C. The duct is rectangular with cross-sectional dimensions of 1 m by 20 cm. What will be the air velocity in the duct?

5.14 The hypothetical velocity distribution in a circular duct is

$$\frac{V}{V_0} = 1 - \frac{r}{R}$$

where r is the radial location in the duct, R is the duct radius, and V_0 is the velocity on the axis. Find the ratio of the mean velocity to the velocity on the axis.

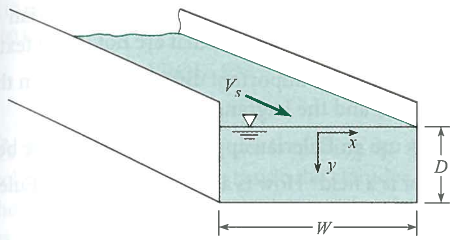


PROBLEM 5.14

5.15 Water flows in a two-dimensional channel of width W and depth D as shown in the diagram. The hypothetical velocity profile for the water is

$$V(x, y) = V_s\left(1 - \frac{4x^2}{W^2}\right)\left(1 - \frac{y^2}{D^2}\right)$$

where V_s is the velocity at the water surface midway between the channel walls. The coordinate system is as shown; x is measured from the center plane of the channel and y downward from the water surface. Find the discharge in the channel in terms of V_s, D, and W.



PROBLEM 5.15

5.16 GO Water flows in a pipe that has a 1.2 m diameter and the following hypothetical velocity distribution: The velocity is maximum at the centerline and decreases linearly with r to a minimum at the pipe wall. If $V_{max} = 4.5$ m/s and $V_{min} = 3.6$ m/s, what is the discharge in cubic meters per second and in liters per minute?

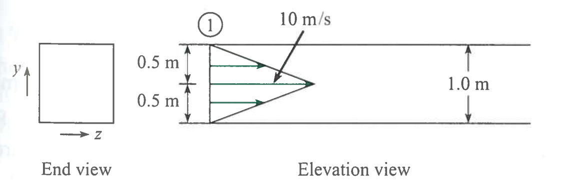
5.17 In Prob. 5.16, if $V_{max} = 8$ m/s, $V_{min} = 6$ m/s, and $D = 2$ m, what is the discharge in cubic meters per second and the mean velocity?

5.18 GO Air enters this square duct at section 1 with the velocity distribution as shown. Note that the velocity varies in the y direction only (for a given value of y, the velocity is the same for all values of z).

a. What is the volume rate of flow?

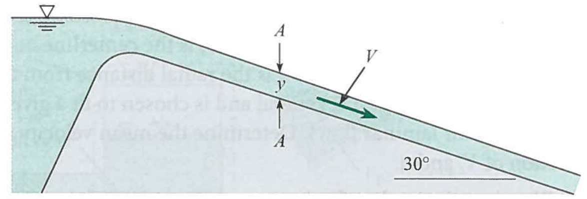
b. What is the mean velocity in the duct?

c. What is the mass rate of flow if the mass density of the air is 1.2 kg/m^3?



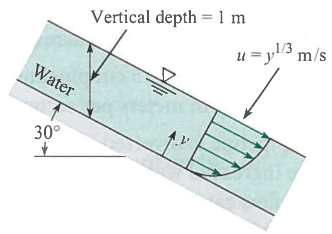
PROBLEM 5.18

5.19 PLUS The velocity at section A-A is 4.5 m/s, and the vertical depth y at the same section is 1.2 m. If the width of the channel is 8.5 m, what is the discharge in cubic meter per second?



PROBLEM 5.19

5.20 PLUS The rectangular channel shown is 1.2 m wide. What is the discharge in the channel?



PROBLEM 5.20

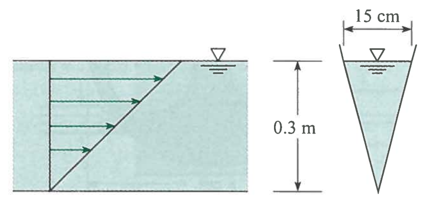
5.21 If the velocity in the channel of Prob. 5.20 is given as $u = 8[\exp(y) - 1]$ m/s and the channel width is 2 m, what is the discharge in the channel and what is the mean velocity?

5.22 PLUS Water from a pipe is diverted into a weigh tank for exactly 20 min. The increased weight in the tank is 20 kN. What is the discharge in cubic meters per second? Assume $T = 20$°C.

5.23 Water enters the lock of a ship canal through 180 ports, each port having a 0.6 m by 0.6 m cross section. The lock is 275 m long and 32 m wide. The lock is designed so that the water surface in it will rise at a maximum rate of 1.8 m/min. For this condition, what will be the mean velocity in each port?

5.24 GO An empirical equation for the velocity distribution in a horizontal, rectangular, open channel is given by $u = u_{max}(y/d)^n$, where u is the velocity at a distance y meters above the floor of the channel. If the depth d of flow is 1.2 m, $u_{max} = 3$ m/s, and $n = 1/6$, what is the discharge in cubic meters per second per meter of width of channel? What is the mean velocity?

5.25 The hypothetical water velocity in a V-shaped channel (see the accompanying figure) varies linearly with depth from zero at the bottom to maximum at the water surface. Determine the discharge if the maximum velocity is 1.8 m/s.



PROBLEM 5.25

5.26 The velocity of flow in a circular pipe varies according to the equation $V/V_c = (1 - r^2/r_0^2)^n$, where V_c is the centerline velocity, r_0 is the pipe radius, and r is the radial distance from the centerline. The exponent n is general and is chosen to fit a given profile ($n = 1$ for laminar flow). Determine the mean velocity as a function of V_c and n.

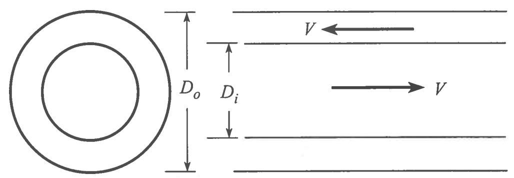
5.27 Plot the velocity distribution across the pipe, and determine the discharge of a fluid flowing through a pipe 1 m in diameter that has a velocity distribution given by $V = 12(1 - r^2/r_0^2)$ m/s. Here r_0 is the radius of the pipe, and r is the radial distance from the centerline. What is the mean velocity?

5.28 Water flows through a 10 cm-diameter pipeline at 0.57 kg/s. Calculate the mean velocity. Assume $T = 15.5°C$.

5.29 WILEY PLUS Water flows through a 15 cm pipeline at 700 kg/min. Calculate the mean velocity in meters per second if $T = 20°C$.

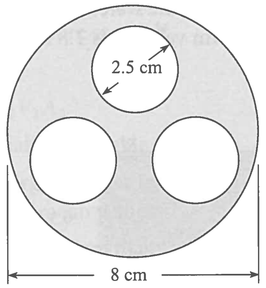
5.30 Water from a pipeline is diverted into a weigh tank for exactly 15 min. The increased weight in the tank is 21 kN. What is the average flow rate in liters per minute and in cubic meters per second? Assume $T = 15.5°C$.

5.31 A shell and tube heat exchanger consists of a one pipe inside another pipe as shown. The liquid flows in opposite directions in each pipe. If the speed of the liquid is the same in each pipe, what is the ratio of the outer pipe diameter to the inner pipe diameter if the discharge in each pipe is the same?



PROBLEM 5.31

5.32 WILEY PLUS The cross section of a heat exchanger consists of three circular pipes inside a larger pipe. The internal diameter of the three smaller pipes is 2.5 cm, and the pipe wall thickness is 3 mm. The inside diameter of the larger pipe is 8 cm. If the velocity of the fluid in region between the smaller pipes and larger pipe is 10 m/s, what is the discharge in m^3/s?



PROBLEM 5.32

5.33 WILEY PLUS The mean velocity of water in a 15 cm pipe is 2.6 m/s. Determine the flow in kilograms per second and liters per minute, if $T = 15.5°C$.

Lagrangian and Eulerian Approaches (§5.2)

5.34 Read §4.2, §5.2 and the internet to find answers to the following questions.

a. What does the Lagrangian approach mean? What are three real-world examples that illustrate the Lagrangian approach? (Use examples that are not in the text.)

b. What does the Eulerian approach mean? What are three real-world examples that illustrate the Eulerian approach? (Use examples that are not in the text.)

c. What are three important differences between the Eulerian and the Lagrangian approaches?

d. Why use an Eulerian approach? What are the benefits?

e. What is a field? How is a field related to the Eulerian approach?

f. What are the shortcomings of describing a flow field using the Lagrangian description?

5.35 What is the difference between an intensive and extensive property? Give an example of each.

5.36 WILEY PLUS State whether each of the following quantities is extensive or intensive:

a. mass

b. volume

c. density

d. energy

e. specific energy

5.37 WILEY PLUS What type of property do you get when you divide an extensive property by another extensive property—extensive or intensive? Hint: Consider density.

The Control Volume Approach (§5.2)

5.38 What is a control surface and a control volume? Can mass pass through a control surface?

5.39 WILEY PLUS In Fig 5.11 on p. 181 of §5.2,

a. the CV is passing through the system.

b. the system is passing through the CV.

5.40 What is the purpose of the Reynolds transport theorem?

5.41 WILEY PLUS Gas flows into and out of the chamber as shown. For the conditions shown, which of the following statement(s) are true of the application of the control volume equation to the continuity principle?

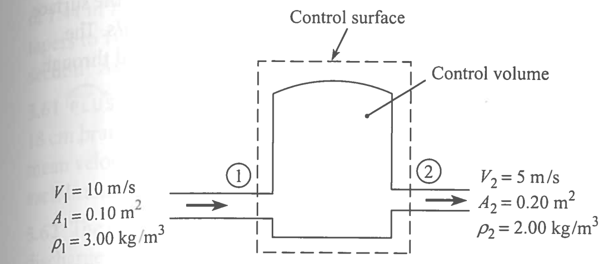
a. $B_{sys} = 0$

b. $dB_{sys}/dt = 0$

c. $\sum_{cs} b\rho \mathbf{V} \cdot \mathbf{A} = 0$

d. $\frac{d}{dt}\int_{cv} \rho \, d\forall = 0$

e. $b = 0$



PROBLEM 5.41

5.42 WILEY PLUS The piston in the cylinder is moving up. Assume that the control volume is the volume inside the cylinder above the piston (the control volume changes in size as the piston moves). A gaseous mixture exists in the control volume. For the given conditions, indicate which of the following statements are true.

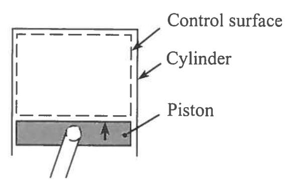
a. $\sum_{cs} \rho \mathbf{V} \cdot \mathbf{A}$ is equal to zero.

b. $\frac{d}{dt}\int_{cv} \rho \, d\forall$ is equal to zero.

c. The mass density of the gas in the control volume is increasing with time.

d. The temperature of the gas in the control volume is increasing with time.

e. The flow inside the control volume is unsteady.



PROBLEM 5.42

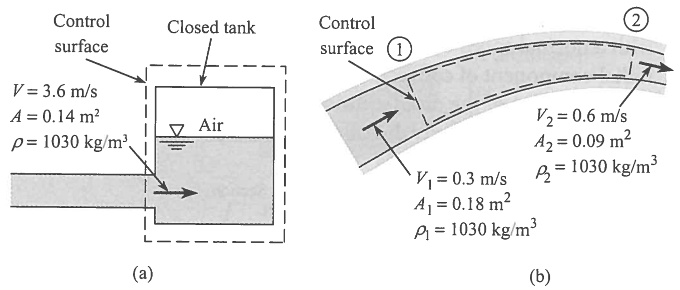
5.43 WILEY PLUS For cases a and b shown in the figure, respond to the following questions and statements concerning the application of the Reynolds transport theorem to the continuity equation.

a. What is the value of b?

b. Determine the value of dB_{sys}/dt.

c. Determine the value of $\sum_{cs} b\rho \mathbf{V} \cdot \mathbf{A}$.

d. Determine the value of $d/dt \int_{cv} b\rho \, d\forall$.



PROBLEM 5.43

Continuity Equation (Theory) (§5.3)

5.44 WILEY PLUS The law of conservation of mass for a closed system requires that the mass of the system is

a. constant

b. zero

Applying the Continuity Equation (§5.4)

5.45 WILEY PLUS **part a only** Consider the simplified form of the continuity equation, Eq. 5.29 on p. 183 of §5.3. An engineer is using this equation to find the Q_C of a creek at the confluence with a large river because she has automatic electronic measurements of the river discharge upstream, Q_{Ru}, and downstream, Q_{Rd}, of the creek confluence.

a. Which of the three terms on the left-hand side of Eq. 5.29 will the engineer assume is zero? Why?

b. Sketch the creek and the river and sketch the CV you would select to solve this problem.

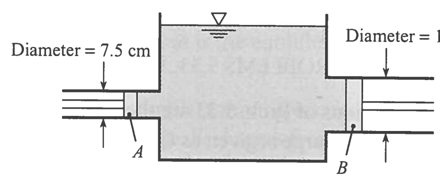
5.46 A pipe flows full with water. Is it possible for the volume flow rate into the pipe to be different than the flow rate out of the pipe? Explain.

5.47 Air is pumped into one end of a tube at a certain mass flow rate. Is it necessary that the same mass flow rate of air comes out the other end of the tube? Explain.

5.48 If an automobile tire develops a leak, how does the mass of air and density change inside the tire with time? Assuming the temperature remains constant, how is the change in density related to the tire pressure?

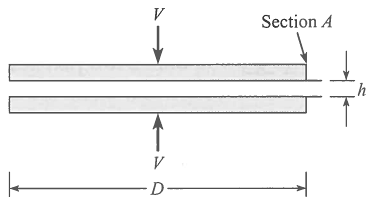
5.49 WILEY PLUS Two pipes are connected together in series. The diameter of one pipe is twice the diameter of the second pipe. With liquid flowing in the pipes, the velocity in the large pipe is 4 m/s. What is the velocity in the smaller pipe?

5.50 Both pistons are moving to the left, but piston A has a speed twice as great as that of piston B. Then is the water level in the tank (a) rising, (b) not moving up or down, or (c) falling?



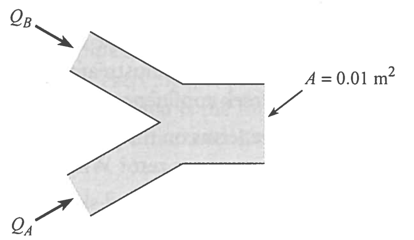
PROBLEM 5.50

5.51 Two parallel disks of diameter D are brought together, each with a normal speed of V. When their spacing is h, what is the radial component of convective acceleration at the section just inside the edge of the disk (section A) in terms of V, h, and D? Assume uniform velocity distribution across the section.



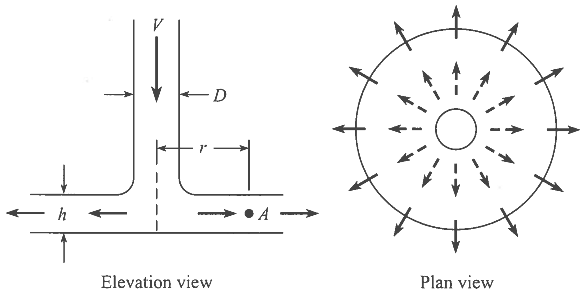
PROBLEM 5.51

5.52 PLUS Two streams discharge into a pipe as shown. The flows are incompressible. The volume flow rate of stream A into the pipe is given by $Q_A = 0.04t$ m^3/s and that of stream B by $Q_B = 0.006\,t^2$ m^3/s, where t is in seconds. The exit area of the pipe is 0.01 m^2. Find the velocity and acceleration of the flow at the exit at $t = 1$ s.



PROBLEM 5.52

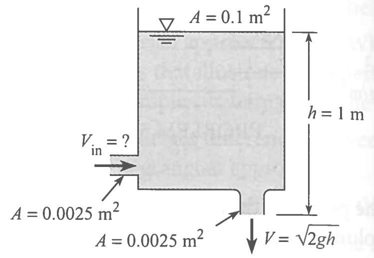
5.53 Air discharges downward in the pipe and then outward between the parallel disks. Assuming negligible density change in the air, derive a formula for the acceleration of air at point A, which is a distance r from the center of the disks. Express the acceleration in terms of the constant air discharge Q, the radial distance r, and the disk spacing h. If $D = 10$ cm, $h = 0.6$ cm, and $Q = 0.380$ m^3/s, what are the velocity in the pipe and the acceleration at point A where $r = 20$ cm?



PROBLEMS 5.53, 5.54

5.54 All the conditions of Prob. 5.53 are the same except that $h = 1$ cm and the discharge is given as $Q = Q_0(t/t_0)$, where $Q_0 = 0.1$ m^3/s and $t_0 = 1$ s. For the additional conditions, what will be the acceleration at point A when $t = 2$ s and $t = 3$ s?

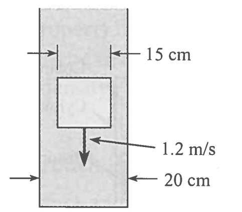
5.55 GO A tank has a hole in the bottom with a cross-sectional area of 0.0025 m^2 and an inlet line on the side with a cross-sectional area of 0.0025 m^2, as shown. The cross-sectional area of the tank is 0.1 m^2. The velocity of the liquid flowing out the bottom hole is $V = \sqrt{2gh}$, where h is the height of the water surface in the tank above the outlet. At a certain time the surface level in the tank is 1 m and rising at the rate of 0.1 cm/s. The liquid is incompressible. Find the velocity of the liquid through the inlet.



PROBLEM 5.55

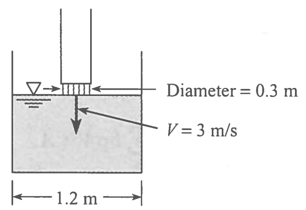
5.56 PLUS A mechanical pump is used to pressurize a bicycle tire. The inflow to the pump is 0.02 m^3/min. The density of the air entering the pump is 1.2 kg/m^3. The inflated volume of a bicycle tire is 0.0009 m^3. The density of air in the inflated tire is 6.4 kg/m^3. How many seconds does it take to pressurize the tire if there initially was no air in the tire?

5.57 A 15-cm cylinder falls at a rate of 1.2 m/s in a 20-cm-diameter tube containing an incompressible liquid. What is the mean velocity of the liquid (with respect to the tube) in the space between the cylinder and the tube wall?



PROBLEM 5.57

5.58 PLUS This circular tank of water is being filled from a pipe as shown. The velocity of flow of water from the pipe is 3 m/s. What will be the rate of rise of the water surface in the tank?



PROBLEM 5.58

5.59 A sphere 20 cm in diameter falls at 1.2 m/s downward axially through water in a 30 cm-diameter container. Find the upward speed of the water with respect to the container wall at the midsection of the sphere.

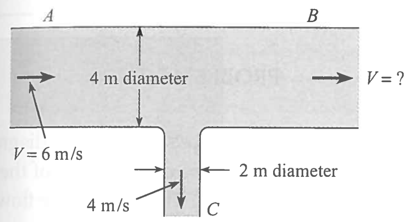
5.60 PLUS A rectangular air duct 20 cm by 60 cm carries a flow of 1.44 m^3/s. Determine the velocity in the duct. If the duct tapers to 10 cm by 40 cm, what is the velocity in the latter section? Assume constant air density.

5.61 PLUS A 30 cm pipe divides into a 20 cm branch and a 15 cm branch. If the total discharge is 0.40 m^3/s and if the same mean velocity occurs in each branch, what is the discharge in each branch?

5.62 The conditions are the same as in Prob. 5.61 except that the discharge in the 20 cm branch is twice that in the 15 cm branch. What is the mean velocity in each branch?

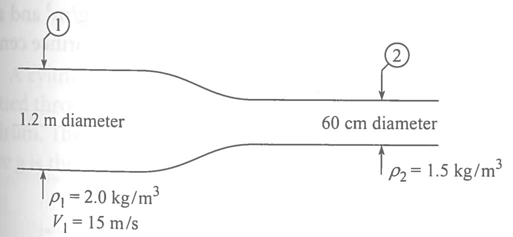
5.63 PLUS Water flows in a 25 cm pipe that is connected in series with a 15 cm pipe. If the rate of flow is 3400 liters per minute, what is the mean velocity in each pipe?

5.64 What is the velocity of the flow of water in leg B of the tee shown in the figure?



PROBLEM 5.64

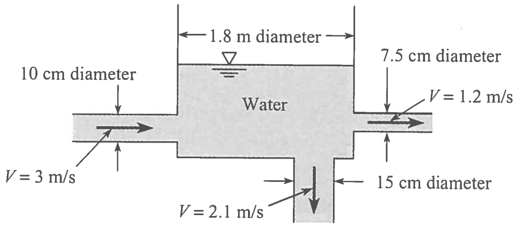
5.65 PLUS For a steady flow of gas in the conduit shown, what is the mean velocity at section 2?



PROBLEM 5.65

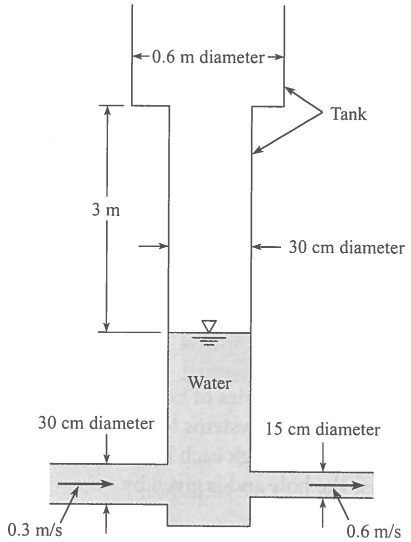
5.66 Two pipes, A and B, are connected to an open water tank. The water is entering the bottom of the tank from pipe A at 0.28 m^3/min. The water level in the tank is rising at 2.5 cm/min, and the surface area of the tank is 7.4 m^2. Calculate the discharge in a second pipe, pipe B, that is also connected to the bottom of the tank. Is the flow entering or leaving the tank from pipe B?

5.67 Is the tank in the figure filling or emptying? At what rate is the water level rising or falling in the tank?



PROBLEM 5.67

5.68 GO Given: Flow velocities as shown in the figure and water surface elevation (as shown) at $t = 0$ s. At the end of 22 s, will the water surface in the tank be rising or falling, and at what speed?



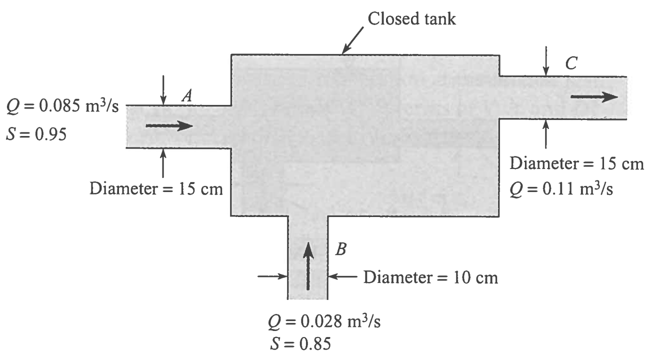
PROBLEM 5.68

5.69 GO A lake with no outlet is fed by a river with a constant flow of 3.4 m^3/s. Water evaporates from the surface at a constant rate of 0.037 m^3/s per square kilometer surface area. The area varies with depth h (meter) as A (square kilometers) = 4.5 + 5.5h. What is the equilibrium depth of the lake? Below what river discharge will the lake dry up?

5.70 A stationary nozzle discharges water against a plate moving toward the nozzle at half the jet velocity. When the discharge from the nozzle is 0.14 m^3/s, at what rate will the plate deflect water?

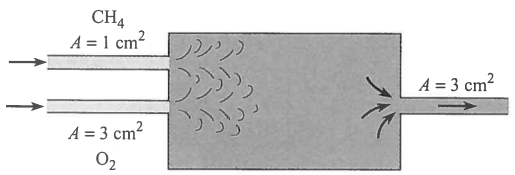
5.71 An open tank has a constant inflow of 0.57 m^3/s. A 30 cm-diameter drain provides a variable outflow velocity V_{out} equal to $\sqrt{(2gh)}$ m/s. What is the equilibrium height h_{eq} of the liquid in the tank?

5.72 Assuming that complete mixing occurs between the two inflows before the mixture discharges from the pipe at C, find the mass rate of flow, the velocity, and the specific gravity of the mixture in the pipe at C.



PROBLEM 5.72

5.73 WILEY PLUS Oxygen and methane are mixed at 200 kPa absolute pressure and 100°C. The velocity of the gases into the mixer is 5 m/s. The density of the gas leaving the mixer is 1.9 kg/m³. Determine the exit velocity of the gas mixture.

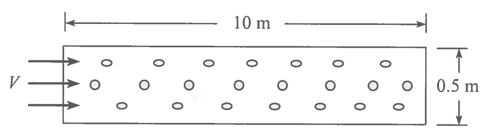


PROBLEM 5.73

5.74 WILEY PLUS A pipe with a series of holes as shown in the figure is used in many engineering systems to distribute gas into a system. The volume flow rate through each hole depends on the pressure difference across the hole and is given by

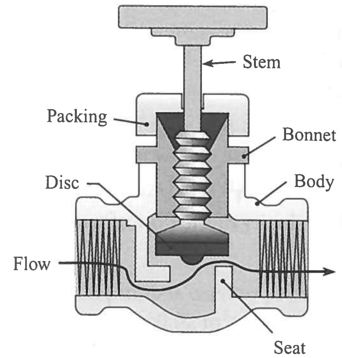
$$Q = 0.67\, A_o\left(\frac{2\Delta p}{\rho}\right)^{1/2}$$

where A_o is the area of the hole, Δp is the pressure difference across the hole, and ρ is the density of the gas in the pipe. If the pipe is sufficiently large, the pressure will be uniform along the pipe. A distribution pipe for air at 20° C is 0.5 meters in diameter and 10 m long. The gage pressure in the pipe is 100 Pa. The pressure outside the pipe is atmospheric at 1 bar. The hole diameter is 2.5 cm, and there are 50 holes per meter length of pipe. The pressure is constant in the pipe. Find the velocity of the air entering the pipe.



PROBLEM 5.74

5.75 The globe valve shown in the figure is a very common device to control flow rate. The flow comes through the pipe at the left and then passes through a minimum area formed by the disc and valve seat. As the valve is closed, the area for flow between the disc and valve is reduced. The flow area can be approximated by the annular region between the disc and the seat. The pressure drop across the valve can be estimated by application of the Bernoulli equation between the upstream pipe and the opening between the disc and valve seat. Assume there is a 38 liters per minute flow of water at 15.5°C through the valve. The inside diameter of the upstream pipe is 2.5 cm. The distance across the opening from the disc to the seat is 3.2 mm and the diameter of the opening is 12.5 mm. What is the pressure drop across the valve in kPa?

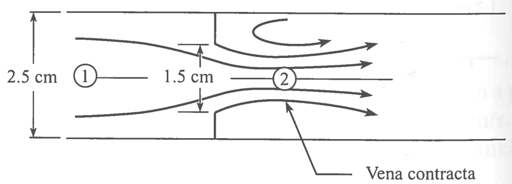


PROBLEM 5.75

5.76 In the flow through an orifice shown in the diagram the flow goes through a minimum area downstream of the orifice. This is called the "vena contracta." The ratio of the flow area at the vena contracta to the area of the orifice is 0.64.

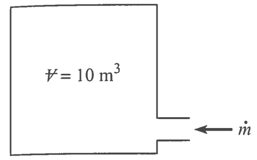
a. Derive an equation for the discharge through the orifice in the form $Q = CA_o(2\Delta p/\rho)^{1/2}$, where A_o is the area of the orifice, Δp is the pressure difference between the upstream flow and the vena contracta, and ρ is the fluid density. C is a dimensionless coefficient.

b. Evaluate the discharge for water at 1000 kg/m³ and a pressure difference of 10 kPa for a 1.5 cm orifice centered in a 2.5-cm-diameter pipe.



PROBLEM 5.76

5.77 WILEY PLUS A compressor supplies gas to a 10 m³ tank. The inlet mass flow rate is given by $\dot{m} = 0.5\,\rho_0/\rho$ (kg/s), where ρ is the density in the tank and ρ_0 is the initial density. Find the time it would take to increase the density in the tank by a factor of 2 if the initial density is 2 kg/m³. Assume the density is uniform throughout the tank.

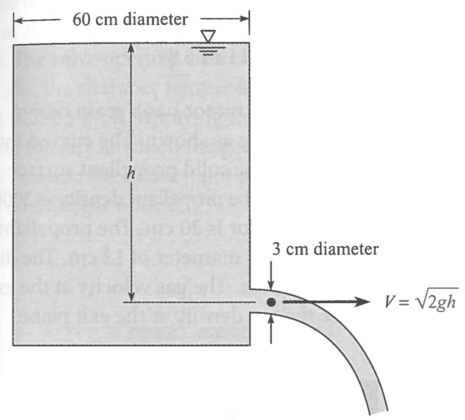


PROBLEM 5.77

5.78 A slow leak develops in a tire (assume constant volume), in which it takes 3 hr for the pressure to decrease from 205 kPa gage to 170 kPa gage. The air volume in the tire is 0.015 m³. and the temperature remains constant at 15.5°C. The mass flow rate of air is given by $\dot{m} = 0.68\, pA/\sqrt{RT}$. Calculate the area of the hole in the tire. Atmospheric pressure is 96 kPa abs.

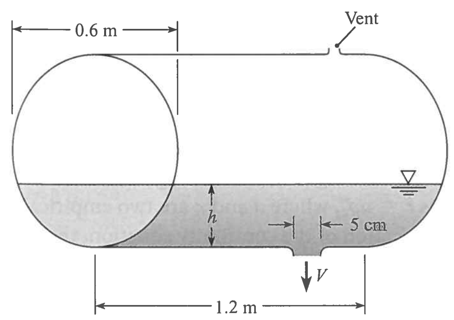
5.79 WILEY PLUS Oxygen leaks slowly through a small orifice in an oxygen bottle. The volume of the bottle is 0.1 m³, and the diameter of the orifice is 0.12 mm. The temperature in the tank remains constant at 18°C, and the mass-flow rate is given by $\dot{m} = 0.68\, pA/\sqrt{RT}$. How long will it take the absolute pressure to decrease from 10 to 5 MPa?

5.80 How long will it take the water surface in the tank shown to drop from $h = 3$ m to $h = 50$ cm?



PROBLEM 5.80

5.81 A cylindrical drum of water, lying on its side, is being emptied through a 5 cm–diameter short pipe at the bottom of the drum. The velocity of the water out of the pipe is $V = \sqrt{2gh}$, where g is the acceleration due to gravity and h is the height of the water surface above the outlet of the tank. The tank is 1.2 m long and 0.6 m in diameter. Initially the tank is half full. Find the time for the tank to empty.

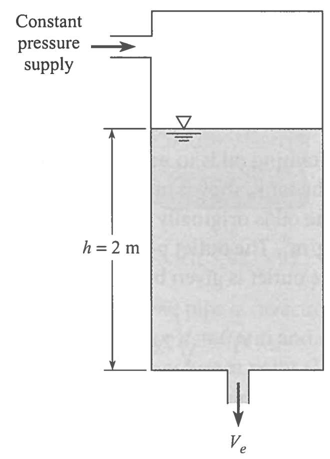


PROBLEM 5.81

5.82 WILEY GO Water is draining from a pressurized tank as shown in the figure. The exit velocity is given by

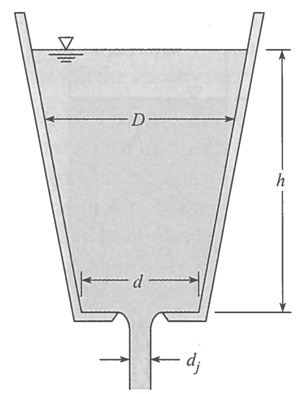
$$V_e = \sqrt{\frac{2p}{\rho} + 2gh}$$

where p is the pressure in the tank, ρ is the water density, and h is the elevation of the water surface above the outlet. The depth of the water in the tank is 2 m. The tank has a cross-sectional area of 1 m², and the exit area of the pipe is 10 cm². The pressure in the tank is maintained at 10 kPa. Find the time required to empty the tank. Compare this value with the time required if the tank is not pressurized.



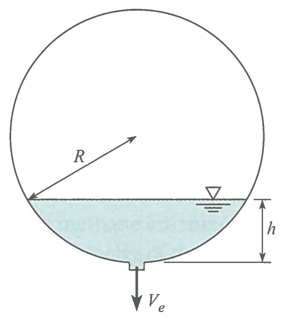
PROBLEM 5.82

5.83 For the type of tank shown, the tank diameter is given as $D = d + C_1h$, where d is the bottom diameter and C_1 is a constant. Derive a formula for the time of fall of liquid surface from $h = h_0$ to $h = h$ in terms of d_j, d, h_0, h, and C_1. Solve for t if $h_0 = 1$ m, $h = 20$ cm, $d = 20$ cm, $C_1 = 0.3$, and $d_j = 5$ cm. The velocity of water in the liquid jet exiting the tank is $V_e = \sqrt{2gh}$.



PROBLEM 5.83

5.84 WileyPLUS A spherical tank with a diameter of 1 m is half filled with water. A port at the bottom of the tank is opened to drain the tank. The hole diameter is 1 cm, and the velocity of the water draining from the hole is $V_e = \sqrt{2gh}$, where h is the elevation of the water surface above the hole. Find the time required for the tank to empty.



PROBLEM 5.84

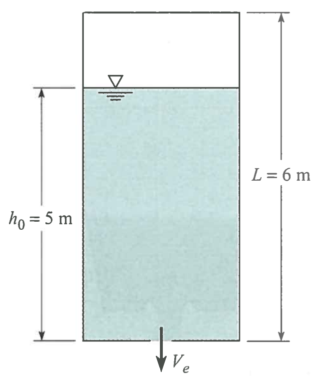
5.85 A tank containing oil is to be pressurized to decrease the draining time. The tank, shown in the figure, is 2 m in diameter and 6 m high. The oil is originally at a level of 5 m. The oil has a density of 880 kg/m^3. The outlet port has a diameter of 2 cm, and the velocity at the outlet is given by

$$V_e = \sqrt{2gh + \frac{2p}{\rho}}$$

where p is the gage pressure in the tank, ρ is the density of the oil, and h is the elevation of the surface above the hole. Assume during the emptying operation that the temperature of the air in the tank is constant. The pressure will vary as

$$p = (p_0 + p_{\text{atm}})\frac{(L - h_0)}{(L - h)} - p_{\text{atm}}$$

where L is the height of the tank, p_{atm} is the atmospheric pressure, and the subscript 0 refers to the initial conditions. The initial pressure in the tank is 300 kPa gage, and the atmospheric pressure is 100 kPa.



PROBLEM 5.85

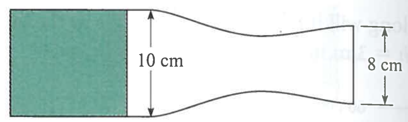
Applying the continuity equation to this problem, one finds

$$\frac{dh}{dt} = -\frac{A_e}{A_T}\sqrt{2gh + \frac{2p}{\rho}}$$

Integrate this equation to predict the depth of the oil with time for a period of one hour.

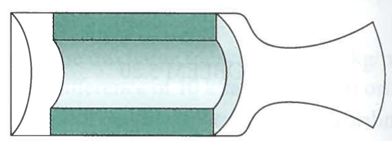
5.86 *Rocket Propulsion.* To prepare for Problems 5.87, 5.88, and 5.89, use the Internet or other resources and define the following terms in the context of rocket propulsion: (a) solid fuel, (b) grain, and (c) surface regression. Also explain how a solid-fuel rocket engine works.

5.87 WileyPLUS An end-burning rocket motor has a chamber diameter of 10 cm and a nozzle exit diameter of 8 cm. The density of the solid propellant is 1800 kg/m^3, and the propellant surface regresses at the rate of 1.5 cm/s. The gases crossing the nozzle exit plane have a pressure of 10 kPa abs and a temperature of 2200°C. The gas constant of the exhaust gases is 415 J/kg K. Calculate the gas velocity at the nozzle exit plane.



PROBLEM 5.87

5.88 A cylindrical-port rocket motor has a grain design consisting of a cylindrical shape as shown. The curved internal surface and both ends burn. The solid propellant surface regresses uniformly at 1 cm/s. The propellant density is 2000 kg/m^3. The inside diameter of the motor is 20 cm. The propellant grain is 40 cm long and has an inside diameter of 12 cm. The diameter of the nozzle exit plane is 20 cm. The gas velocity at the exit plane is 1800 m/s. Determine the gas density at the exit plane.



PROBLEM 5.88

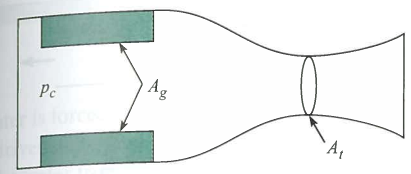
5.89 The mass flow rate through a rocket nozzle (shown) is given by

$$\dot{m} = 0.65\frac{p_c A_t}{\sqrt{RT_c}}$$

where p_c and T_c are the pressure and temperature in the rocket chamber and R is the gas constant of the gases in the chamber. The propellant burning rate (surface regression rate) can be expressed as $\dot{r} = ap_c^n$, where a and n are two empirical constants. Show, by application of the continuity equation, that the chamber pressure can be expressed as

$$p_c = \left(\frac{a\rho_p}{0.65}\right)^{1/(1-n)}\left(\frac{A_g}{A_t}\right)^{1/(1-n)}(RT_c)^{1/[2(1-n)]}$$

where ρ_p is the propellant density and A_g is the grain surface burning area. If the operating chamber pressure of a rocket motor is 3.5 MPa and $n = 0.3$, how much will the chamber pressure increase if a crack develops in the grain, increasing the burning area by 20%?

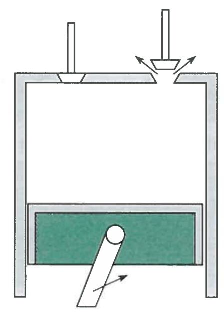


PROBLEM 5.89

5.90 The piston shown is moving up during the exhaust stroke of a four-cycle engine. Mass escapes through the exhaust port at a rate given by

$$\dot{m} = 0.65\frac{p_c A_v}{\sqrt{RT_c}}$$

where p_c and T_c are the cylinder pressure and temperature, A_v is the valve opening area, and R is the gas constant of the exhaust gases. The bore of the cylinder is 10 cm, and the piston is moving upward at 30 m/s. The distance between the piston and the head is 10 cm. The valve opening area is 1 cm^2, the chamber pressure is 300 kPa abs, the chamber temperature is 600°C, and the gas constant is 350 J/kg K. Applying the continuity equation, determine the rate at which the gas density is changing in the cylinder. Assume the density and pressure are uniform in the cylinder and the gas is ideal.



PROBLEM 5.90

5.91 WileyPLUS Gas is flowing from Location 1 to 2 in the pipe expansion shown. The inlet density, diameter and velocity are ρ_1, D_1, and V_1 respectively. If D_2 is $2D_1$ and V_2 is half of V_1, what is the magnitude of ρ_2?

a. $\rho_2 = 4\rho_1$

b. $\rho_2 = 2\rho_1$

c. $\rho_2 = ½\rho_1$

d. $\rho_2 = \rho_1$

5.92 WileyPLUS Air is flowing from a ventilation duct (cross section 1) as shown, and is expanding to be released into a room at cross section 2.

The area at cross section 2, A_2, is 3 times A_1. Assume that the density is constant. The relation between Q_1 and Q_2 is:

a. $Q_2 = ⅓ Q_1$

b. $Q_2 = Q_1$

c. $Q_2 = 3 Q_1$

d. $Q_2 = 9 Q_1$

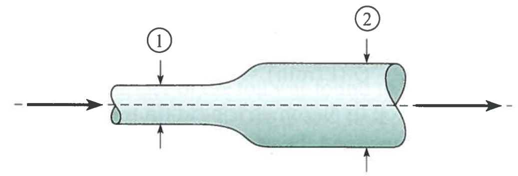
5.93 WileyPLUS Water is flowing from Location 1 to 2 in this pipe expansion. D_1 and V_1 are known at the inlet. D_2 and P_2 are known at the outlet. What equation(s) do you need to solve for the inlet pressure P_1? Neglect viscous effects.

a. The continuity equation

b. The continuity equation and the flow rate equation

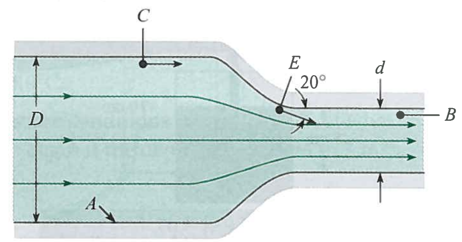
c. The continuity equation, the flow rate equation, and the Bernoulli equation

d. There is insufficient information to solve the problem



PROBLEMS 5.91, 5.92, 5.93

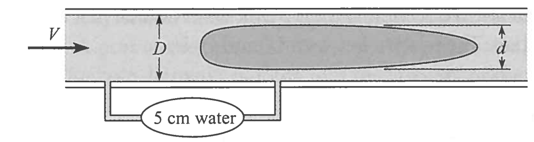
5.94 The flow pattern through the pipe contraction is as shown, and the Q of water is 1.7 m^3/s. For $d = 0.6$ m and $D = 1.8$ m, what is the pressure at point B if the pressure at point C is 153 kPa?



PROBLEM 5.94

5.95 Water flows through a rigid contraction section of circular pipe in which the outlet diameter is one-half the inlet diameter. The velocity of the water at the inlet varies with time as $V_{\text{in}} = (10\text{ m/s})[1 - \exp(-t/10)]$. How will the velocity vary with time at the outlet?

5.96 WileyPLUS The annular venturimeter is useful for metering flows in pipe systems for which upstream calming distances are limited. The annular venturimeter consists of a cylindrical section mounted inside a pipe as shown. The pressure difference is measured between the upstream pipe and at the region adjacent to the cylindrical section. Air at standard conditions flows in the system. The pipe diameter is 15 cm. The ratio of the cylindrical section diameter to the inside pipe diameter is 0.8. A pressure difference of 5 cm of water is measured. Find the volume flow rate. Assume the flow is incompressible, inviscid, and steady and that the velocity is uniformly distributed across the pipe.

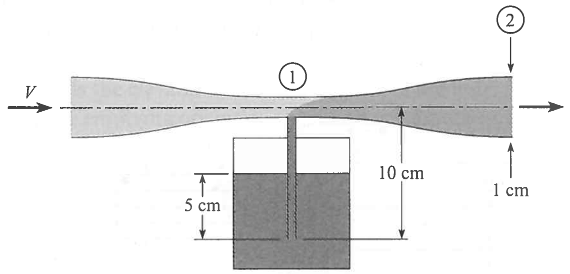


PROBLEM 5.96

5.97 Venturi-type applicators are frequently used to spray liquid fertilizers. Water flowing through the venturi creates a subatmospheric pressure at the throat, which in turn causes the liquid fertilizer to flow up the feed tube and mix with the water in the throat region. The venturi applicator shown uses water at 20°C to spray a liquid fertilizer with the same density. The venturi exhausts to the atmosphere, and the exit diameter is 1 cm. The ratio of exit area to throat area (A_2/A_1) is 2. The flow rate of water through the venturi is 8 L/m (liters/min). The bottom of the feed tube in the reservoir is 5 cm below the liquid fertilizer surface and 10 cm below the centerline of the venturi. The pressure at the liquid fertilizer surface is atmospheric. The flow rate through the feed tube between the reservoir and venturi throat is

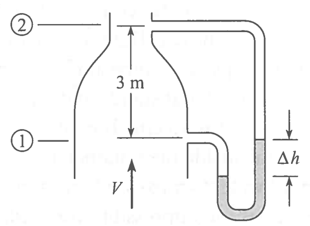
$$Q_l(\text{L/min}) = 0.5\sqrt{\Delta h}$$

where Δh is the drop in piezometric head (in meters) between the feed tube entrance and the venturi centerline. Find the flow rate of liquid fertilizer in the feed tube, Q_l. Also find the concentration of liquid fertilizer in the mixture, $[Q_l/(Q_l + Q_w)]$, at the end of the sprayer.



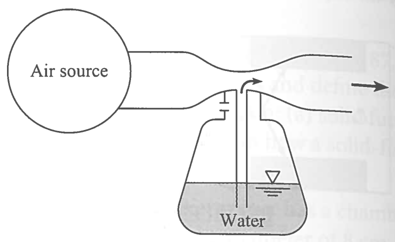
PROBLEM 5.97

5.98 Air with a density of 1 kg/m³ is flowing upward in the vertical duct, as shown. The velocity at the inlet (station 1) is 24 m/s, and the area ratio between stations 1 and 2 is 0.5 ($A_2/A_1 = 0.5$). Two pressure taps, 3 m apart, are connected to a manometer, as shown. The specific weight of the manometer liquid is 18.9 kN/m³. Find the deflection, Δh, of the manometer.



PROBLEM 5.98

5.99 An atomizer utilizes a constriction in an air duct as shown. Design an operable atomizer making your own assumptions regarding the air source.



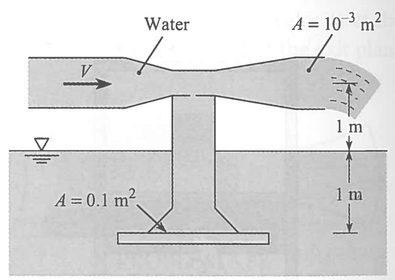
PROBLEM 5.99

5.100 A suction device is being designed based on the venturi principle to lift objects submerged in water. The operating water temperature is 15°C. The suction cup is located 1 m below the water surface, and the venturi throat is located 1 m above the water. The atmospheric pressure is 100 kPa. The ratio of the throat area to the exit area is 1/4, and the exit area is 0.001 m². The area of the suction cup is 0.1 m².

a. Find the velocity of the water at the exit for maximum lift condition.

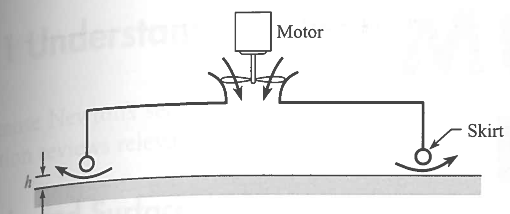
b. Find the discharge through the system for maximum lift condition.

c. Find the maximum load the suction cup can support.



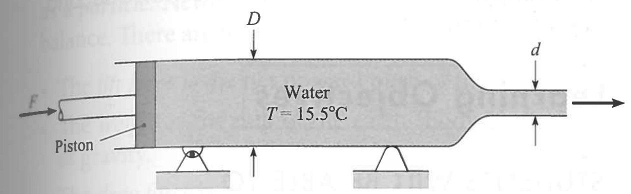
PROBLEM 5.100

5.101 A design for a hovercraft is shown in the figure. A fan brings air at 15.5°C into a chamber, and the air is exhausted between the skirts and the ground. The pressure inside the chamber is responsible for the lift. The hovercraft is 4.5 m long and 2.1 m wide. The weight of the craft including crew, fuel, and load is 8.9 kN. Assume that the pressure in the chamber is the stagnation pressure (zero velocity) and the pressure where the air exits around the skirt is atmospheric. Assume the air is incompressible, the flow is steady, and viscous effects are negligible. Find the airflow rate necessary to maintain the skirts at a height of 7.5 cm above the ground.



PROBLEM 5.101

5.102 Water is forced out of this cylinder by the piston. If the piston is driven at a speed of 1.8 m/s, what will be the speed of efflux of the water from the nozzle if $d = 5$ cm and $D = 10$ cm? Neglecting friction and assuming irrotational flow, determine the force F that will be required to drive the piston. The exit pressure is atmospheric pressure.



PROBLEM 5.102

5.103 Air flows through a constant-area heated pipe. At the entrance, the velocity is 10 m/s, the pressure is 100 kPa absolute, and the temperature is 20°C. At the outlet, the pressure is 80 kPa absolute, and the temperature is 50°C. What is the velocity at the outlet? Can the Bernoulli equation be used to relate the pressure and velocity changes? Explain.

Predicting Cavitation (§5.5)

5.104 Sometimes driving your car on a hot day, you may encounter a problem with the fuel pump called pump cavitation. What is happening to the gasoline? How does this affect the operation of the pump?

5.105 What is cavitation? Why does the tendency for cavitation in a liquid increase with increased temperatures?

5.106 The following questions have to do with cavitation.

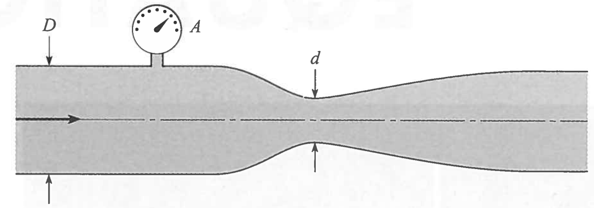
a. Is it more correct to say that cavitation has to do with (i) vacuum pressures, or (ii) vapor pressures?

b. Is cavitation more likely to occur on the low pressure (suction) side of a pump, or the high pressure (discharge) side? Why?

c. What does the word cavitation have to do with cavities, like the ones we get in our teeth? Is this aspect of cavitation the (i) cause, or the (ii) result of the phenomenon?

d. When water goes over a waterfall, and one can see lots of bubbles in the water, is that due to cavitation? Why, or why not?

5.107 When gage A indicates a pressure of 130 kPa gage, then cavitation just starts to occur in the venturi meter. If $D = 50$ cm and $d = 10$ cm, what is the water discharge in the system for this condition of incipient cavitation? The atmospheric pressure is 100 kPa gage, and the water temperature is 10°C. Neglect gravitational effects.



PROBLEM 5.107

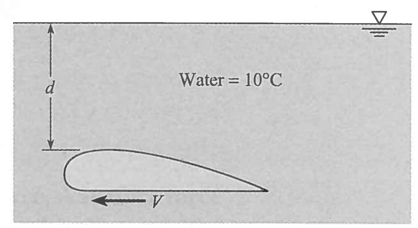
5.108 A sphere 30 cm in diameter is moving horizontally at a depth of 3.6 m below a water surface where the water temperature is 10°C. $V_{max} = 1.5\ V_o$, where V_o is the free stream velocity and occurs at the maximum sphere width. At what speed in still water will cavitation first occur?

5.109 When the hydrofoil shown was tested, the minimum pressure on the surface of the foil was found to be 70 kPa absolute when the foil was submerged 1.80 m and towed at a speed of 8 m/s. At the same depth, at what speed will cavitation first occur? Assume irrotational flow for both cases and $T = 10$°C.

5.110 For the hydrofoil of Prob. 5.109, at what speed will cavitation begin if the depth is increased to 3 m?

5.111 When the hydrofoil shown was tested, the minimum pressure on the surface of the foil was found to be 17 kPa vacuum when the foil was submerged 1.2 m and towed at a speed of 7.5 m/s. At the same depth, at what speed will cavitation first occur? Assume irrotational flow for both cases and $T = 10$°C.

5.112 For the conditions of Prob. 5.111 , at what speed will cavitation begin if the depth is increased to 3 m?



PROBLEMS 5.109, 5.110, 5.111, 5.112

5.113 A sphere is moving in water at a depth where the absolute pressure is 124 kPa abs. The maximum velocity on a sphere occurs 90° from the forward stagnation point and is 1.5 times the free-stream velocity. The density of water is 1000 kg/m³. Calculate the speed of the sphere at which cavitation will occur. $T = 10$°C.

5.114 The minimum pressure on a cylinder moving horizontally in water ($T = 10$°C) at 5 m/s at a depth of 1 m is 80 kPa absolute. At what velocity will cavitation begin? Atmospheric pressure is 100 kPa absolute.