

2.13 What is the change in the viscosity and density of water between 10°C and 70°C? What is the change in the viscosity and density of air between 10°C and 70°C? Assume standard atmospheric pressure ($p = 101 \text{ kN/m}^2$ absolute).

2.14 What is the change in the kinematic viscosity of air between 10°C and 60°C? Assume standard atmospheric pressure.

2.15 Find the dynamic and kinematic viscosities of kerosene, SAE 10W-30 motor oil, and water at a temperature of 38°C (100°F).

2.16 What is the ratio of the dynamic viscosity of air to that of water at standard pressure and a temperature of 20°C? What is the ratio of the kinematic viscosity of air to that of water for the same conditions?

2.17 Write a computer program to calculate the dynamic and kinematic viscosities of air using Sutherland's equation. Using Sutherland's constants from Table A.2, compare several calculated values with the data provided in Fig. A.3.

2.18 Using Sutherland's equation and the ideal gas law, develop an expression for the kinematic viscosity ratio ν/ν_0 in terms of pressures p and p_0 and temperatures T and T_0 , where the subscript 0 refers to a reference condition.

2.19 The dynamic viscosity of air at 15°C is $1.78 \times 10^{-5} \text{ N} \cdot \text{s/m}^2$. Using Sutherland's equation, find the viscosity at 200°C.

FLUID SOLUTIONS

2.20 The kinematic viscosity of methane at 15°C and atmospheric pressure is $1.59 \times 10^{-5} \text{ m}^2/\text{s}$. Using Sutherland's equation and the ideal gas law, find the kinematic viscosity at 200°C and 2 atmospheres.

2.21 The dynamic viscosity of nitrogen at 59°F is $3.59 \times 10^{-7} \text{ lbf} \cdot \text{s/ft}^2$. Using Sutherland's equation, find the dynamic viscosity at 200°F.

2.22 The kinematic viscosity of helium at 59°F and 1 atmosphere is $1.22 \times 10^{-3} \text{ ft}^2/\text{s}$. Using Sutherland's equation and the ideal gas law, find the kinematic viscosity at 30°F and a pressure of 1.5 atmospheres.

2.23 The absolute viscosity of propane at 100°C is $1.00 \times 10^{-5} \text{ N} \cdot \text{s/m}^2$ and at 400°C is $1.72 \times 10^{-5} \text{ N} \cdot \text{s/m}^2$. Find Sutherland's constant for propane.

2.24 The absolute viscosity of ammonia at 68°F is $2.07 \times 10^{-7} \text{ lbf} \cdot \text{s/ft}^2$ and at 392°F is $3.46 \times 10^{-7} \text{ lbf} \cdot \text{s/ft}^2$. Using these two data points, find Sutherland's constant for ammonia.

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2.25 The viscosity of SAE 10W-30 motor oil at 38°C is $0.067 \text{ N} \cdot \text{s/m}^2$ and at 99°C is $0.011 \text{ N} \cdot \text{s/m}^2$. Using Eq. (2.8) for interpolation, find the viscosity at 60°C. Compare this value with that obtained by linear interpolation.

2.26 The viscosity of grade 100 aviation oil at 100°F is $4.43 \times 10^{-3} \text{ lbf} \cdot \text{s/ft}^2$ and at 210°F is $3.9 \times 10^{-4} \text{ lbf} \cdot \text{s/ft}^2$. Using Eq. (2.8), find the viscosity at 150°F.

2.27 Develop a program that gives the Sutherland constant in terms of μ/μ_0 and T/T_0 , where the subscript represents the

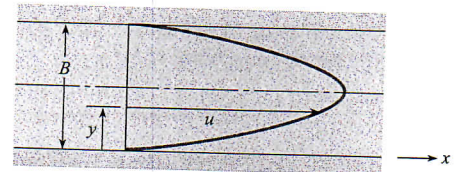
reference value. Enter the following data for carbon monoxide and find the Sutherland constant for each data point, and take the average to find the best value. Using this value for Sutherland's constant, calculate the viscosity ratio using Sutherland's equation. Find the percentage error at each data point and make a statement about the adequacy of Sutherland's equation in this application. The reference temperature is 273 K.

μ/μ_0	0.9605	0.9906	1.020
T (K)	260	270	280
μ/μ_0	1.049	1.078	1.213
T (K)	290	300	350
μ/μ_0	1.574	2.519	3.285
T (K)	500	1000	1500

2.28 Two plates are separated by a 1/8-in. space. The lower plate is stationary; the upper plate moves at a velocity of 25 ft/s. Oil (SAE 10W-30, 150°F), which fills the space between the plates, has the same velocity as the plates at the surface of contact. The variation in velocity of the oil is linear. What is the shear stress in the oil?

2.29 Find the kinematic and dynamic viscosities of air and water at a temperature of 40°C (104°F) and an absolute pressure of 170 kPa (25 psia).

2.30 The velocity distribution for water (20°C) near a wall is given by $u = a(y/b)^{1/6}$, where $a = 10 \text{ m/s}$, $b = 2 \text{ mm}$, and y is the distance from the wall in mm. Determine the shear stress in the water at $y = 1 \text{ mm}$.



PROBLEMS 2.31, 2.32, 2.33

2.31 The velocity distribution for the flow of crude oil at 100°C ($\mu = 8 \times 10^{-5} \text{ lbf} \cdot \text{s/ft}^2$) between two walls is given by $u = 100y(0.1 - y) \text{ ft/s}$, where y is measured in feet and the space between the walls is 0.1 ft. Plot the velocity distribution and determine the shear stress at the walls.

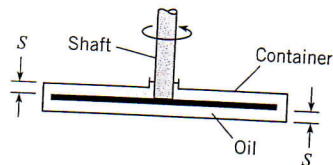
2.32 A liquid flows between parallel boundaries as shown above. The velocity distribution near the lower wall is given by the following table.

y in mm	V in m/s
1.0	1.00
2.0	1.99
3.0	2.98

2.42 What torque is required to rotate the disk of Prob. 2.41 at a rate of 5 rad/s, with $D = 10$ cm and with the same viscosity and spacing as in part (c)?

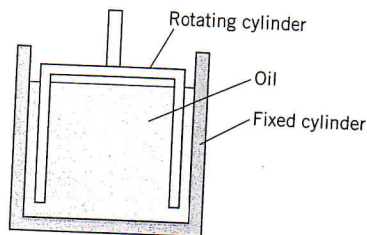
FLUID SOLUTIONS

2.43 Some instruments having angular motion are damped by means of a disk connected to the shaft. The disk, in turn, is immersed in a container of oil, as shown. Derive a formula for the damping torque as a function of the disk diameter D , spacing S , rate of rotation ω , and oil viscosity μ .



PROBLEM 2.43

2.44 One type of viscometer involves the use of a rotating cylinder inside a fixed cylinder. The gap between the cylinders must be very small to achieve a linear velocity distribution in the liquid. (Assume the maximum spacing for proper operation is 0.05 in.). Design a viscometer that will be used to measure the viscosity of motor oil from 50°F to 200°F.



PROBLEM 2.44

2.45 A pressure of 2×10^6 N/m² is applied to a mass of water that initially filled a 1000-cm volume. Estimate its volume after the pressure is applied.

FLUID SOLUTIONS

2.46 What pressure increase must be applied to water to reduce its volume by 1%?

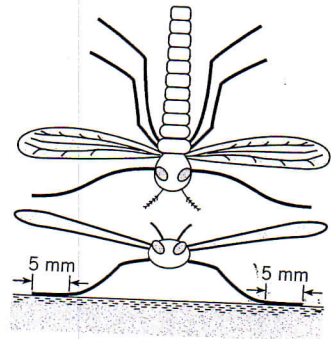
FLUID SOLUTIONS

2.47 Which of the following is the formula for the gage pressure within a very small spherical droplet of water?

(a) $p = \sigma/d$, (b) $p = 4\sigma/d$, (c) $p = 8\sigma/d$.

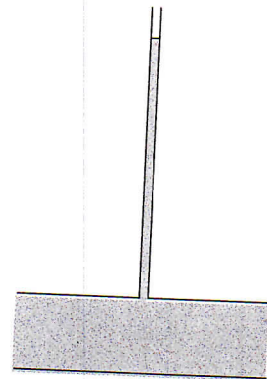
2.48 A spherical soap bubble has an inside radius R , a film thickness t , and a surface tension σ . Derive a formula for the pressure within the bubble relative to the outside atmospheric pressure. What is the pressure difference for a bubble with a 4-mm radius? Assume σ is the same as for pure water.

2.49 A water bug is suspended on the surface of a pond by surface tension (water does not wet the legs). The bug has six legs, and each leg is in contact with the water over a length of 5 mm. What is



PROBLEM 2.49

2.50 A water column in a glass tube is used to measure the pressure in a pipe. The tube is 1/4 in. (6.35 mm) in diameter. How much of the water column is due to surface-tension effects? What would be the surface-tension effects if the tube were 1/8 (3.2 mm) or 1/32 in. (0.8 mm) in diameter?



PROBLEM 2.50

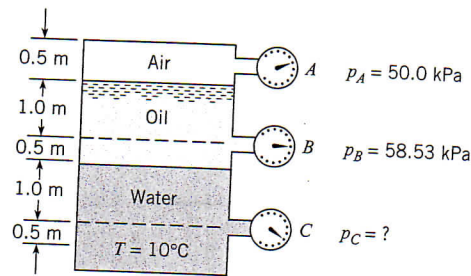
2.51 Calculate the maximum capillary rise of water between two vertical glass plates spaced 1 mm apart.

2.52 What is the pressure within a 1-mm spherical droplet of water relative to the atmospheric pressure outside?

2.53 By measuring the capillary rise in a tube, one can calculate the surface tension. The surface tension of water varies linearly with temperature from 0.0756 N/m at 0°C to 0.0589 N/m at 100°C. Size a tube (specify diameter and length) that uses capillary rise of water to measure temperature in the range from 0°C to 100°C. Is this concept a good idea?

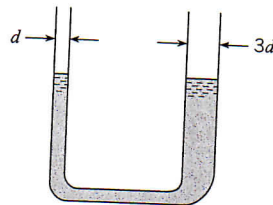
2.54 Mercury does not adhere to a glass surface, so when a glass tube is immersed in a pool of mercury, the meniscus is depressed, as shown in the figure. The surface tension of mercury is 0.514 N/m and the angle of contact is 40°. Find the depression distance in a 1-mm glass tube.

- FLUID SOLUTIONS** 3.7 For the closed tank with Bourdon-tube gages tapped into it, what is the specific gravity of the oil and the pressure reading on gage *C*?



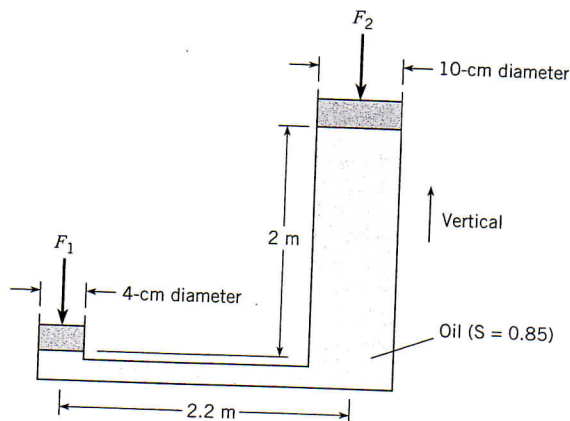
PROBLEM 3.7

- 3.8 This manometer contains water at room temperature. The glass tube on the left has an inside diameter of 1 mm ($d = 1.0$ mm). The glass tube on the right is three times as large. For these conditions, the water surface level in the left tube will be (a) higher than the water surface level in the right tube, (b) equal to the water surface level in the right tube, (c) less than the water surface level in the right tube. State your main reason or assumption for making your choice.



PROBLEM 3.8

- FLUID SOLUTIONS** 3.9 If a 200-N force F_1 is applied to the piston with the 4-cm diameter, what is the magnitude of the force F_2 that can be resisted by the piston with the 10-cm diameter? Neglect the weights of the pistons.

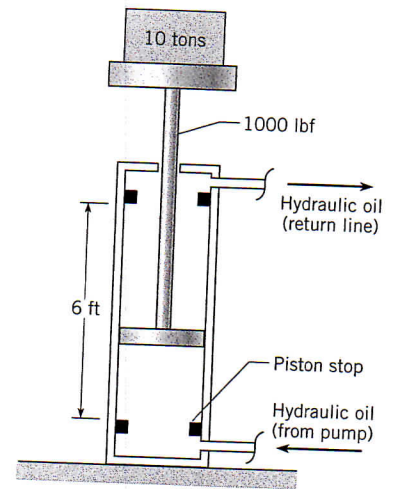


PROBLEM 3.9

- 3.10 Some skin divers go as deep as 50 m. What is the pressure at this depth in fresh water, and what is the ratio of absolute pressure at this depth to normal atmospheric pressure. Assume $T = 20^\circ\text{C}$.

- 3.11 Water occupies the bottom 1.0 m of a cylindrical tank. The top of the water is 0.5 m of kerosene, which is open to the atmosphere. If the temperature is 20°C , what is the gage pressure at the bottom of the tank?

- 3.12 An engineer is designing a hydraulic lift with a capacity of 10 tons. The moving parts of this lift weigh 1000 lbf. This weight should be raised to a height of 6 ft in 20 seconds. This weight can be accomplished with a hydraulic pump that delivers fluid to a cylinder. Hydraulic cylinders with a stroke of 72 inches are available with bore sizes from 2 to 8 inches. Hydraulic piston pumps with an operating pressure range from 200 to 3000 psig are available with pumping capacities of 5, 10, and 15 gallons per minute. Select a hydraulic pump size and a hydraulic cylinder size that can be used for this application.

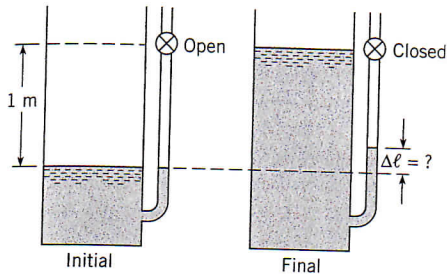


PROBLEM 3.12

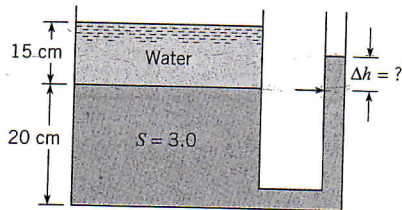
- 3.13 The gage pressure at a depth of 5 m in an open tank of liquid is 75 kPa. What are the specific weight and the specific gravity of the liquid?

- 3.14 A tank with an attached manometer contains water at 20°C . The atmospheric pressure is 100 kPa. There is a stopcock located 1 m from the surface of the water in the manometer. The stopcock is closed, trapping the air in the manometer, and water is added to the tank to the level of the stopcock. Find the increase in elevation of the water in the manometer assuming the air in the manometer is compressed isothermally.

- 3.15 A tank is fitted with a manometer on the side, as shown. The liquid in the bottom of the tank and in the manometer has a specific gravity (*S*) of 3.0. The depth of this bottom liquid is 20 cm. A 15-cm layer of water lies on top of the bottom liquid. Find the position of the liquid surface in the manometer.



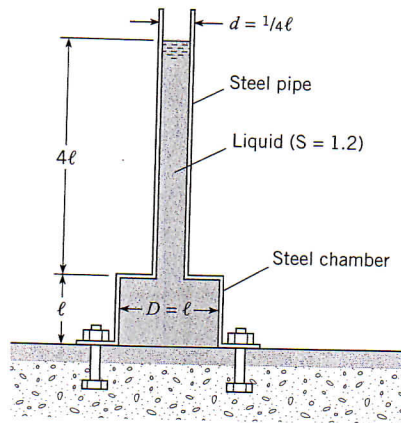
PROBLEM 3.14



PROBLEM 3.15

3.18 The steel pipe and steel chamber together weigh 600 lbf. What force will have to be exerted on the chamber by all the bolts to hold it in place? The dimension ℓ is equal to 2.5 ft. *Note:* There is no bottom on the chamber—only a flange bolted to the floor.

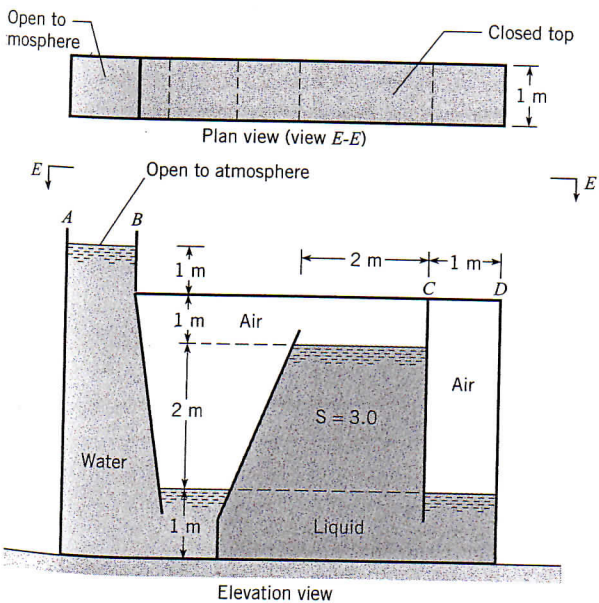
FLUID SOLUTIONS



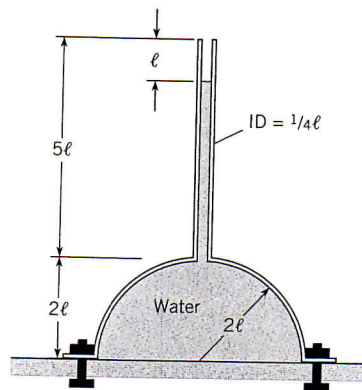
PROBLEM 3.18

16 What is the maximum gage pressure in the odd tank shown in the figure? Where will the maximum pressure occur? What is the hydrostatic force acting on the top (CD) of the last chamber in the right-hand side of the tank? Assume $T = 10^\circ\text{C}$.

3.19 What force must be exerted through the bolts to hold the dome in place? The metal dome and pipe weigh 1300 lbf. The dome has no bottom. Here $\ell = 3.0$ ft.



PROBLEM 3.16



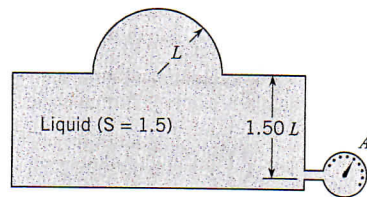
PROBLEMS 3.19, 3.20

3.20 What force must be exerted through the bolts to hold the dome in place? The metal dome and pipe weigh 6 kN. The dome has no bottom. Here $\ell = 80$ cm.

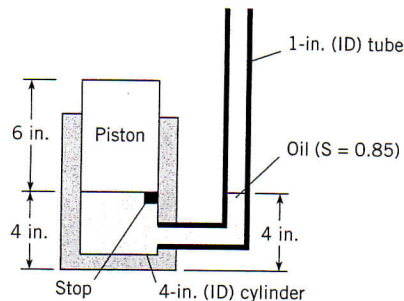
3.21 Find the vertical component of force in the metal at the base of the spherical dome shown when gage A reads 5 psig. Indicate whether the metal is in compression or tension. The specific gravity of the enclosed fluid is 1.5. The dimension L is 2 ft. Assume the dome weighs 1000 lbf.

3.22 The piston shown weighs 10 lbf. In its initial position, the piston is restrained from moving to the bottom of the cylinder by means of the metal stop. Assuming there is neither friction nor leakage between piston and cylinder, what volume of oil ($S = 0.85$) would have to be added to the 1-in. tube to cause the piston to rise 1 in. from its initial position?

7 Usually water is assumed to be incompressible for hydrostatic computations; however, extreme pressures may cause significant changes in density. Estimate the percentage difference in density of water between the surface and a point 6 km deep. Assume a constant temperature of 10°C and a bulk modulus of elasticity of 2.2 GPa.



PROBLEM 3.21



PROBLEM 3.22

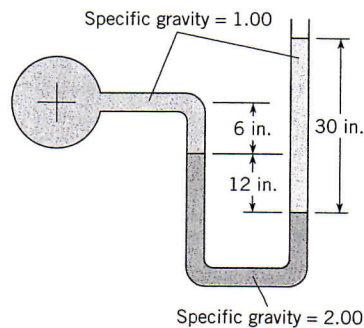
FLUID SOLUTIONS 3.23 Consider an air bubble rising from the bottom of a lake. Neglecting surface tension, determine approximately what the ratio of the density of the air in the bubble will be at a depth of 34 ft to its density at a depth of 8 ft.

3.24 A liquid has the peculiar property that its mass density increases linearly with depth according to the expression $\rho = \rho_{\text{water}}(1 + 0.01d)$, where d is the depth below the liquid surface in meters. At a depth of 10 m, what is the gage pressure?

3.25 Consider the conditions given for Problem 3.24. The gage pressure at a particular point in the liquid is found by measurement to be 60 kPa. At what depth is that point?

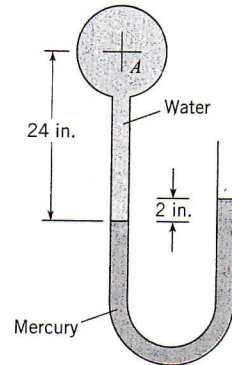
3.26 The specific weight of a liquid increases with depth as follows: $\gamma = 50 + 0.1d$, where d = depth in feet below the surface and γ is given in lb/ft^3 . What is the pressure at a depth of 20 ft?

3.27 The gage pressure at the center of the pipe has a value that is (a) negative, (b) zero, (c) positive. (Neglect surface tension effects.)



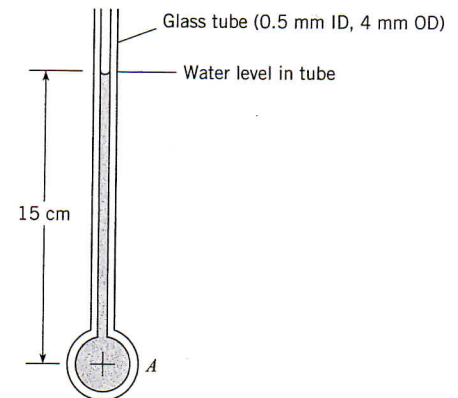
PROBLEM 3.27

3.28 Determine the gage pressure at the center of pipe A in pounds per square inch when the temperature is 70°F.



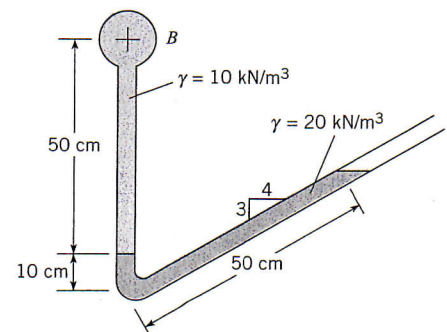
PROBLEM 3.28

3.29 Considering the effects of surface tension, estimate the gage pressure at the center of pipe A. $T = 20^\circ\text{C}$.



PROBLEM 3.29

3.30 What is the pressure at the center of pipe B?



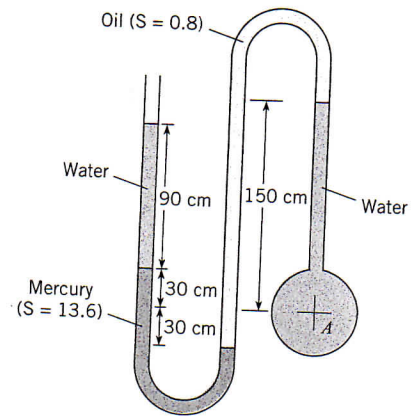
PROBLEM 3.30

3.37 A U-tube manometer is needed that will measure the difference in pressure between two points 100 m apart in a horizontal 6 cm pipe. The pipe carries water, and the maximum pressure difference is expected to be 60 kPa. Design the manometer and predict the probable degree of accuracy of measurement of Δp for your design.

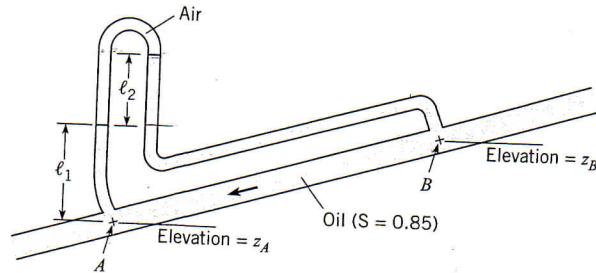
3.38 It is necessary to measure the specific weight of several different liquids. The specific weights of these liquids may range from 50 lbf/ft³ to 100 lbf/ft³. Design an apparatus using the manometer principle to measure the specific weights of these liquids. Also estimate the expected degree of error of measurement using your equipment.

3.39 Find the pressure at the center of pipe A. Assume $T = 10^\circ\text{C}$.

3.40 Determine (a) the difference in pressure and (b) the difference in piezometric head between points A and B. The elevations z_A and z_B are 10 m and 11 m, respectively, $\ell_1 = 1$ m, and the manometer deflection ℓ_2 is 50 cm.

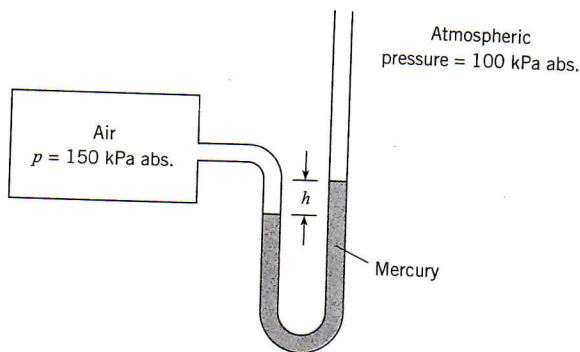


PROBLEMS 3.39

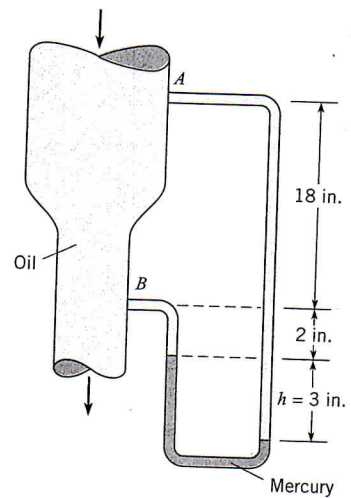


PROBLEM 3.40

3.41 The deflection on the manometer is h meters when the pressure in the tank is 150 kPa absolute. If the absolute pressure in the tank is doubled, what will the deflection on the manometer be?



PROBLEM 3.41



PROBLEM 3.42

3.42 A vertical conduit is carrying oil ($S = 0.95$). A differential mercury manometer is tapped into the conduit at points A and B. Determine the difference in pressure between A and B when $h = 3$ in. What is the difference in piezometric head between A and B?

3.43 Two water manometers are connected to a tank of air. One leg of the manometer is open to 100 kPa pressure (absolute) while the other leg is subjected to 90 kPa. Find the difference in deflection between both manometers, $\Delta h_a - \Delta h_b$.