1–1. Represent each of the following quantities with combinations of units in the correct SI form, using an appropriate prefix: (a) $\text{mm} \cdot \text{MN}$, (b) Mg/mm, (c) km/ms, (d) kN/(mm)^2.

SOLUTION

a) $\text{mm} \cdot \text{MN} = (10^{-3}\ \text{m})(10^{6}\ \text{N}) = 10^{3}\ \text{N} \cdot \text{m} = \text{kN} \cdot \text{m}$ **Ans.**

b) $\text{Mg/mm} = (10^{6}\ \text{g})/(10^{-3}\ \text{m}) = 10^{9}\ \text{g/m} = \text{Gg/m}$ **Ans.**

c) $\text{km/ms} = (10^{3}\ \text{m})/(10^{-3}\ \text{s}) = 10^{6}\ \text{m/s} = \text{Mm/s}$ **Ans.**

d) $\text{kN/(mm)}^2 = (10^{3}\ \text{N})/(10^{-3}\ \text{m})^2 = 10^{9}\ \text{N/m}^2 = \text{GN/m}^2$ **Ans.**

Ans:
a) $\text{kN} \cdot \text{m}$
b) Gg/m
c) Mm/s
d) GN/m^2

1–2. Evaluate each of the following to three significant figures, and express each answer in SI units using an appropriate prefix: (a) $[4.86(10^6)]^2$ mm, (b) $(348\ \text{mm})^3$, (c) $(83\,700\ \text{mN})^2$.

SOLUTION

a) $[4.86(10^6)]^2\,\text{mm} = [4.86(10^6)]^2(10^{-3}\,\text{m}) = 23.62(10^9)\ \text{m} = 23.6\ \text{Gm}$ **Ans.**

b) $(348\ \text{mm})^3 = [348(10^{-3})\ \text{m}]^3 = 42.14(10^{-3})\ \text{m}^3 = 42.1(10^{-3})\ \text{m}^3$ **Ans.**

c) $(83{,}700\ \text{mN})^2 = [83{,}700(10^{-3})\ \text{N}]^2 = 7.006(10^3)\ \text{N}^2 = 7.01(10^3)\ \text{N}^2$ **Ans.**

Ans:
a) 23.6 Gm
b) $42.1(10^{-3})\ \text{m}^3$
c) $7.01(10^3)\ \text{N}^2$

1–3. Evaluate each of the following to three significant figures, and express each answer in SI units using an appropriate prefix: (a) 749 μm/63 ms, (b) (34 mm)(0.0763 Ms)/263 mg, (c) (4.78 mm)(263 Mg).

SOLUTION

a) $749\ \mu\text{m}/63\ \text{ms} = 749(10^{-6})\ \text{m}/63(10^{-3})\ \text{s} = 11.88(10^{-3})\ \text{m/s}$

$= 11.9\ \text{mm/s}$ **Ans.**

b) $(34\ \text{mm})(0.0763\ \text{Ms})/263\ \text{mg} = [34(10^{-3})\ \text{m}][0.0763(10^{6})\text{s}]/[263(10^{-6})(10^{3})\ \text{g}]$

$= 9.86(10^{6})\ \text{m}\cdot\text{s/kg} = 9.86\ \text{Mm}\cdot\text{s/kg}$ **Ans.**

c) $(4.78\ \text{mm})(263\ \text{Mg}) = [4.78(10^{-3})\ \text{m}][263(10^{6})\ \text{g}]$

$= 1.257(10^{6})\ \text{g}\cdot\text{m} = 1.26\ \text{Mg}\cdot\text{m}$ **Ans.**

Ans:
a) 11.9 mm/s
b) 9.86 Mm·s/kg
c) 1.26 Mg·m

***1–4.** Convert the following temperatures: (a) 250 K to degrees Celsius, (b) 322°F to degrees Rankine, (c) 230°F to degrees Celsius, (d) 40°C to degrees Fahrenheit.

SOLUTION

a) $T_K = T_C + 273; \quad 250 \text{ K} = T_C + 273 \quad T_C = -23.0°\text{C}$ **Ans.**

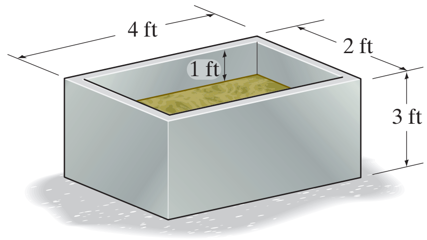
b) $T_R = T_F + 460 = 322°\text{F} + 460 = 782°\text{R}$ **Ans.**

c) $T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(230°\text{F} - 32) = 110°\text{C}$ **Ans.**

d) $T_C = \frac{5}{9}(T_F - 32); \quad 40°\text{C} = \frac{5}{9}(T_F - 32) \quad T_F = 104°\text{F}$ **Ans.**

Ans:
a) −23.0°C
b) 782°R
c) 110°C
d) 104°F

1–5. The tank contains a liquid having a density of $1.22\ \text{slug/ft}^3$. Determine the weight of the liquid when it is at the level shown.



SOLUTION

The specific weight of the liquid and the volume of the liquid are

$$\gamma = \rho g = \left(1.22\ \text{slug/ft}^3\right)\left(32.2\ \text{ft/s}^2\right) = 39.284\ \text{lb/ft}^3$$

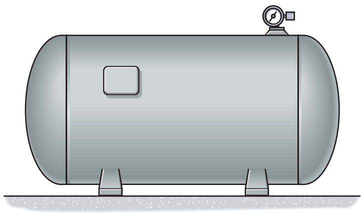
$$\mathcal{V} = (4\ \text{ft})(2\ \text{ft})(2\ \text{ft}) = 16\ \text{ft}^3$$

Then the weight of the liquid is

$$W = \gamma\mathcal{V} = \left(39.284\ \text{lb/ft}^3\right)\left(16\ \text{ft}^3\right) = 628.54\ \text{lb} = 629\ \text{lb}$$ **Ans.**

Ans:
$W = 629\ \text{lb}$

1–6. If air within the tank is at an absolute pressure of 680 kPa and a temperature of 70°C, determine the weight of the air inside the tank. The tank has an interior volume of 1.35 m^3.



SOLUTION

From the table in Appendix A, the gas constant for air is $R = 286.9\ \text{J/kg}\cdot\text{K}$.

$$p = \rho RT$$

$$680\left(10^3\right)\ \text{N/m}^2 = \rho(286.9\ \text{J/kg}\cdot\text{K})(70^\circ + 273)\ \text{K}$$

$$\rho = 6.910\ \text{kg/m}^3$$

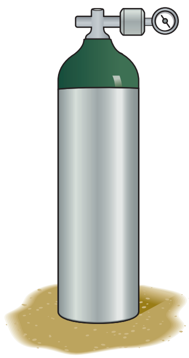
The weight of the air in the tank is

$$W = \rho g V = \left(6.910\ \text{kg/m}^3\right)\left(9.81\ \text{m/s}^2\right)\left(1.35\ \text{m}^3\right)$$

$$= 91.5\ \text{N} \qquad \textbf{Ans.}$$

Ans:
$W = 91.5\ \text{N}$

1–7. The bottle tank has a volume of $0.35\ \text{m}^3$ and contains 40 kg of nitrogen at a temperature of 40°C. Determine the absolute pressure in the tank.



SOLUTION

The density of nitrogen in the tank is

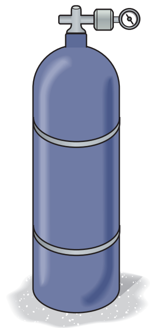
$$\rho = \frac{m}{V} = \frac{40\ \text{kg}}{0.35\ \text{m}^3} = 114.29\ \text{kg/m}^3$$

From the table in Appendix A, the gas constant for nitrogen is $R = 296.8\ \text{J/kg}\cdot\text{K}$. Applying the ideal gas law,

$$p = \rho R T$$
$$p = (114.29\ \text{kg/m}^3)(296.8\ \text{J/kg}\cdot\text{K})(40°\text{C} + 273)\ \text{K}$$
$$= 10.62(10^6)\ \text{Pa}$$
$$= 10.6\ \text{MPa} \qquad \textbf{Ans.}$$

Ans:
$p = 10.6\ \text{MPa}$

***1–8.** The bottle tank contains nitrogen having a temperature of 60°C. Plot the variation of the pressure in the tank (vertical axis) versus the density for $0 \leq \rho \leq 5\ \text{kg/m}^3$. Report values in increments of $\Delta p = 50$ kPa.



SOLUTION

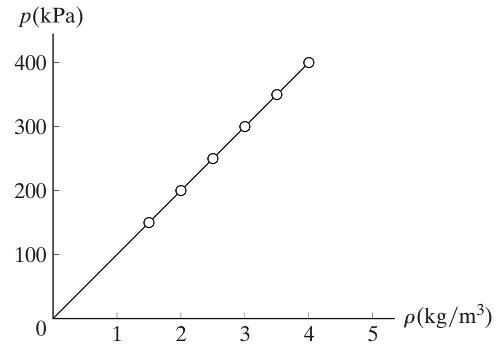
From the table in Appendix A, the gas constant for nitrogen is $R = 296.8\ \text{J/kg}\cdot\text{K}$. The constant temperature is $T = (60°\text{C} + 273)\ \text{K} = 333\ \text{K}$. Applying the ideal gas law,

$$p = \rho R T$$
$$p = \rho(296.8\ \text{J/kg}\cdot\text{K})(333\ \text{K})$$
$$p = (98{,}834\rho)\ \text{Pa}$$
$$= (98.8\rho)\ \text{kPa}$$

Ans.

p (kPa)	150	200	250	300	350	400
ρ (kg/m^3)	1.52	2.02	2.53	3.04	3.54	4.05

The plot of p vs ρ is shown in Fig. *a*.



(a)

Ans:
$p = (98.8\rho)$ kPa

1–9. Determine the specific weight of hydrogen when the temperature is 85°C and the absolute pressure is 4 MPa.

SOLUTION

From the table in Appendix A, the gas constant for hydrogen is $R = 4124\ \text{J/kg}\cdot\text{K}$. Applying the ideal gas law,

$$p = \rho RT$$
$$4\left(10^6\right)\ \text{N/m}^2 = \rho(4124\ \text{J/kg}\cdot\text{K})(85°\text{C} + 273)\ \text{K}$$
$$\rho = 2.7093\ \text{kg/m}^3$$

Then the specific weight of hydrogen is

$$\gamma = \rho g = \left(2.7093\ \text{kg/m}^3\right)\left(9.81\ \text{m/s}^2\right)$$
$$= 26.58\ \text{N/m}^3$$
$$= 26.6\ \text{N/m}^3 \qquad \textbf{Ans.}$$

Ans:
$\gamma = 26.6\ \text{N/m}^3$

1–10. Dry air at 25°C has a density of 1.23 kg/m^3. But if it has 100% humidity at the same pressure, its density is 0.65% less. At what temperature would dry air produce this same smaller density?

SOLUTION

For both cases, the pressures are the same. Applying the ideal gas law with $\rho_1 = 1.23\ \text{kg/m}^3$, $\rho_2 = (1.23\ \text{kg/m}^3)(1 - 0.0065) = 1.222005\ \text{kg/m}^3$ and $T_1 = (25°\text{C} + 273) = 298\ \text{K}$,

$$p = \rho_1 R T_1 = (1.23\ \text{kg/m}^3)\, R\,(298\ \text{K}) = 366.54\ \text{R}$$

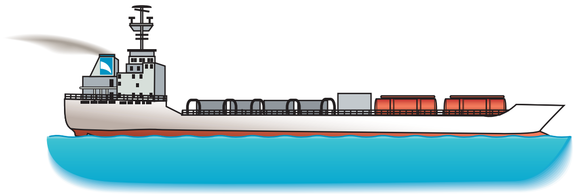
Then

$$p = \rho_2 R T_2; \quad 366.54\, R = (1.222005\ \text{kg/m}^3) R (T_C + 273)$$

$$T_C = 26.9°\text{C}$$ **Ans.**

Ans:
$T_C = 26.9°\text{C}$

1–11. The tanker carries $900(10^3)$ barrels of crude oil in its hold. Determine the weight of the oil if its specific gravity is 0.940. Each barrel contains 42 gallons, and there are $7.48\ \text{gal/ft}^3$.



SOLUTION

The specific weight of the crude oil is

$$\gamma_o = S_o\gamma_w = 0.940\left(62.4\ \text{lb/ft}^3\right) = 58.656\ \text{lb/ft}^3$$

The volume of the crude oil is

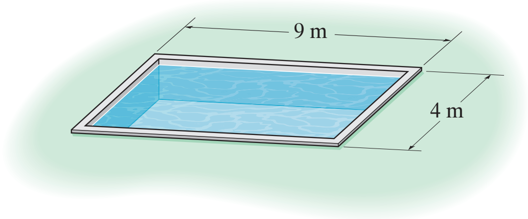
$$\mathcal{V}_o = \left[900(10^3)\ \text{bl}\right]\left(\frac{42\ \text{gal}}{1\ \text{bl}}\right)\left(\frac{1\ \text{ft}^3}{7.48\ \text{gal}}\right) = 5.0535(10^6)\ \text{ft}^3$$

Then, the weight of the crude oil is

$$\begin{aligned} W_o &= \gamma_o\mathcal{V}_o = \left(58.656\ \text{lb/ft}^3\right)\left[5.0535\left(10^6\right)\ \text{ft}^3\right] \\ &= 296.41\left(10^6\right)\ \text{lb} \\ &= 296\left(10^6\right)\ \text{lb} \end{aligned}$$ **Ans.**

Ans:
$W_o = 296\left(10^6\right)$ lb

***1–12.** Water in the swimming pool has a measured depth of 3.03 m when the temperature is 5°C. Determine its approximate depth when the temperature becomes 35°C. Neglect losses due to evaporation.



SOLUTION

From Appendix A, at $T_1 = 5°\text{C}$, $(\rho_w)_1 = 1000.0\ \text{kg/m}^3$. The volume of the water is $\forall = Ah$. Thus, $\forall_1 = (9\ \text{m})(4\ \text{m})(3.03\ \text{m})$. Then

$$(\rho_w)_1 = \frac{m}{\forall_1}; \qquad 1000.0\ \text{kg/m}^3 = \frac{m}{36\ \text{m}^2(3.03\ \text{m})}$$

$$m = 109.08(10^3)\ \text{kg}$$

At $T_2 = 35°\text{C}$, $(\rho_w)_2 = 994.0\ \text{kg/m}^3$. Then

$$(\rho_w)_2 = \frac{m}{\forall_2}; \qquad 994.0\ \text{kg/m}^3 = \frac{109.08(10^3)}{(36\ \text{m}^2)h}$$

$$h = 3.048\ \text{m} = 3.05\ \text{m} \qquad \textbf{Ans.}$$

Ans:
$h = 3.05\ \text{m}$

1–13. Determine the weight of carbon tetrachloride that should be mixed with 15 lb of glycerin so that the combined mixture has a density of 2.85 slug/ft^3.

SOLUTION

From the table in Appendix A, the densities of glycerin and carbon tetrachloride at s.t.p. are $\rho_g = 2.44\ \text{slug/ft}^3$ and $\rho_{ct} = 3.09\ \text{slug/ft}^3$, respectively. Thus, their volumes are given by

$$\rho_g = \frac{m_g}{V_g}; \quad 2.44\ \text{slug/ft}^3 = \frac{(15\ \text{lb})/(32.2\ \text{ft/s}^2)}{V_g} \qquad V_g = 0.1909\ \text{ft}^3$$

$$\rho_{ct} = \frac{m_{ct}}{V_{ct}}; \quad 3.09\ \text{slug/ft}^3 = \frac{W_{ct}/(32.2\ \text{ft/s}^2)}{V_{ct}} \qquad V_{ct} = (0.01005W_{ct})\ \text{ft}^3$$

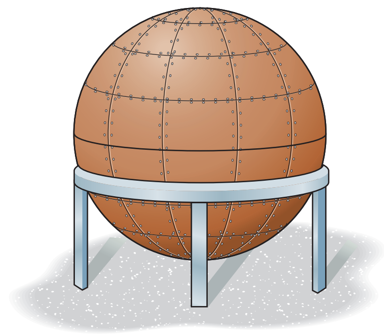
The density of the mixture is

$$\rho_m = \frac{m_m}{V_m}; \quad 2.85\ \text{slug/ft}^3 = \frac{W_{ct}/(32.2\ \text{ft/s}^2) + (15\ \text{lb})/(32.2\ \text{ft/s}^2)}{0.1909\ \text{ft}^3 + 0.01005W_{ct}}$$

$$W_{ct} = 32.5\ \text{lb} \qquad \textbf{Ans.}$$

Ans:
$W_{ct} = 32.5$ lb

1–14. The tank contains air at a temperature of 18°C and an absolute pressure of 160 kPa. If the volume of the tank is 3.48 m^3 and the temperature rises to 42°C, determine the mass of air that must be removed from the tank to maintain the same pressure.



SOLUTION

For $T_1 = (18°\text{C} + 273)\text{ K} = 291\text{ K}$ and $R = 286.9\text{ J/kg}\cdot\text{K}$ for air (Appendix A), the ideal gas law gives

$$p_1 = \rho_1 R T_1; \qquad 160(10^3)\text{ N/m}^2 = \rho_1(286.9\text{ J/kg}\cdot\text{K})(291\text{ K})$$
$$\rho_1 = 1.9164\text{ kg/m}^3$$

Thus, the mass of the air at T_1 is

$$m_1 = \rho_1 V = (1.9164\text{ kg/m}^3)(3.48\text{ m}^3) = 6.6692\text{ kg}$$

For $T_2 = (42°\text{C} + 273)\text{ K} = 315\text{ K}$, and $R = 286.9\text{ J/kg}\cdot\text{K}$,

$$p_2 = \rho_2 R T_2; \qquad 160(10^3)\text{ N/m}^2 = \rho_2(286.9\text{ J/kg}\cdot\text{K})(315\text{ K})$$
$$\rho_2 = 1.7704\text{ kg/m}^3$$

Thus, the mass of air at T_2 is

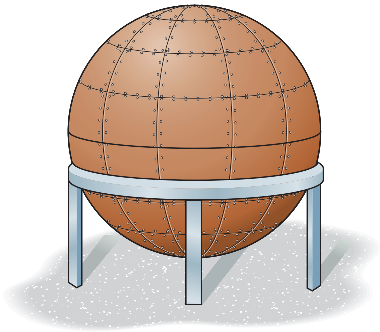
$$m_2 = \rho_2 V = (1.7704\text{ kg/m}^3)(3.48\text{ m}^3) = 6.1611\text{ kg}$$

Finally, the mass of air that must be removed is

$$\Delta m = m_1 - m_2 = 6.6692\text{ kg} - 6.1611\text{ kg} = 0.508\text{ kg} \qquad \textbf{Ans.}$$

Ans:
$\Delta m = 0.508\text{ kg}$

1–15. The tank contains 4 kg of air at an absolute pressure of 350 kPa and a temperature of 18°C. If 0.8 kg of air is added to the tank and the temperature rises to 38°C, determine the resulting pressure in the tank.



SOLUTION

For $T_1 = (18°\text{C} + 273)\text{ K} = 291\text{ K}$, $p_1 = 350\text{ kPa}$ and $R = 286.9\text{ J/kg}\cdot\text{K}$ for air (Appendix A), the ideal gas law gives

$$p_1 = \rho_1 R T_1; \quad 350(10^3)\text{ N/m}^2 = \rho_1(286.9\text{ J/kg}\cdot\text{K})(291\text{ K})$$
$$\rho_1 = 4.1922\text{ kg/m}^3$$

Since the volume is constant,

$$\forall = \frac{m_1}{\rho_1} = \frac{m_2}{\rho_2}; \quad \rho_2 = \frac{m_2}{m_1}\rho_1$$

Here, $m_1 = 4\text{ kg}$ and $m_2 = (4 + 0.8)\text{ kg} = 4.8\text{ kg}$

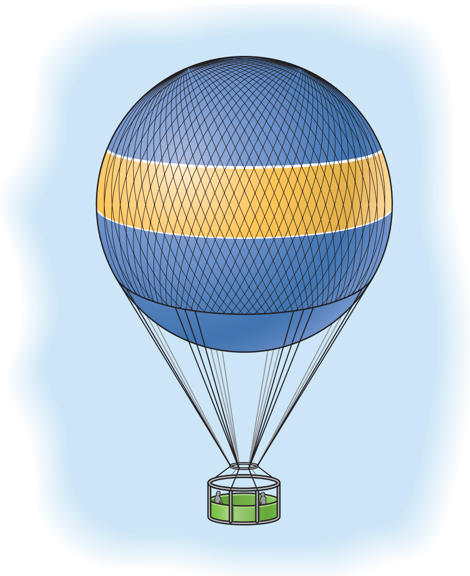
$$\rho_2 = \left(\frac{4.8\text{ kg}}{4\text{ kg}}\right)(4.1922\text{ kg/m}^3) = 5.0307\text{ kg/m}^3$$

Again, applying the ideal gas law with $T_2 = (38°\text{C} + 273)\text{ K} = 311\text{ K}$,

$$p_2 = \rho_2 R T_2; = (5.0307\text{ kg/m}^3)(286.9\text{ J/kg}\cdot\text{K})(311\text{ K})$$
$$= 448.86(10^3)\text{ Pa}$$
$$= 449\text{ kPa} \qquad \textbf{Ans.}$$

Ans:
$p_2 = 449\text{ kPa}$

***1–16.** The 8-m-diameter spherical balloon is filled with helium that is at a temperature of 28°C and an absolute pressure of 106 kPa. Determine the weight of the helium contained in the balloon. The volume of a sphere is $V = \frac{4}{3}\pi r^3$.



SOLUTION

For helium, the gas constant is $R = 2077\ \text{J/kg}\cdot\text{K}$. Applying the ideal gas law at $T = (28 + 273)\ \text{K} = 301\ \text{K}$,

$$p = \rho RT; \qquad 106(10^3)\ \text{N/m}^2 = \rho(2077\ \text{J/kg}\cdot\text{K})(301\ \text{K})$$
$$\rho = 0.1696\ \text{kg/m}^3$$

Here,

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(4\ \text{m})^3 = \frac{256}{3}\pi\ \text{m}^3$$

Then, the mass of the helium is

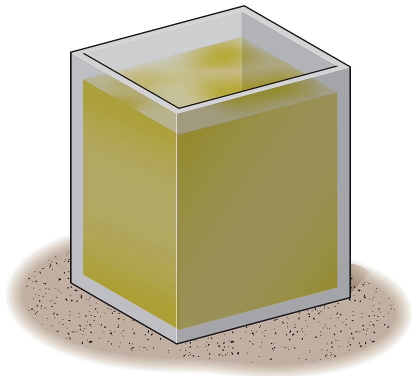
$$M = \rho V = \left(0.1696\ \text{kg/m}^3\right)\left(\frac{256}{3}\pi\ \text{m}^3\right) = 45.45\ \text{kg}$$

Thus,

$$W = mg = \left(45.45\ \text{kg}\right)\left(9.81\ \text{m/s}^2\right) = 445.90\ \text{N} = 446\ \text{N}$$ **Ans.**

Ans:
$W = 446\ \text{N}$

1–17. Gasoline is mixed with 8 ft^3 of kerosene so that the volume of the mixture in the tank becomes 12 ft^3. Determine the specific weight and the specific gravity of the mixture at standard temperature and pressure.



SOLUTION

From the table in Appendix A, the densities of gasoline and kerosene at s.t.p. are $\rho_g = 1.41\ \text{slug/ft}^3$ and $\rho_k = 1.58\ \text{slug/ft}^3$, respectively. The volume of gasoline is

$$V_g = 12\ \text{ft}^3 - 8\ \text{ft}^3 = 4\ \text{ft}^3$$

Then the total weight of the mixture is therefore

$$W_m = \rho_g g V_g + \rho_k g V_k$$
$$= (1.41\ \text{slug/ft}^3)(32.2\ \text{ft/s}^2)(4\ \text{ft}^2) + (1.58\ \text{slug/ft}^3)(32.2\ \text{ft/s}^2)(8\ \text{ft}^3)$$
$$= 588.62\ \text{lb}$$

Thus, the specific weight and specific gravity of the mixture are

$$\gamma_m = \frac{W_m}{V_m} = \frac{588.62\ \text{lb}}{12\ \text{ft}^3} = 49.05\ \text{lb/ft}^3 = 49.1\ \text{lb/ft}^3 \qquad \textbf{Ans.}$$

$$S_m = \frac{\gamma_m}{\gamma_w} = \frac{49.05\ \text{lb/ft}^3}{62.4\ \ \text{lb/ft}^3} = 0.786 \qquad \textbf{Ans.}$$

Ans:
$\gamma_m = 49.1\ \text{lb/ft}^3$
$S_m = 0.786$

1–18. Determine the change in the density of oxygen when the absolute pressure changes from 345 kPa to 286 kPa, while the temperature *remains constant* at 25°C. This is called an *isothermal process*.

SOLUTION

Applying the ideal gas law with $T_1 = (25°\text{C} + 273)\text{ K} = 298\text{ K}$, $p_1 = 345\text{ kPa}$ and $R = 259.8\text{ J/kg}\cdot\text{K}$ for oxygen (table in Appendix A),

$$p_1 = \rho_1 R T_1; \qquad 345\left(10^3\right)\text{ N/m}^2 = \rho_1(259.8\text{ J/kg}\cdot\text{K})(298\text{ K})$$
$$\rho_1 = 4.4562\text{ kg/m}^3$$

For $p_2 = 286\text{ kPa}$ and $T_2 = T_1 = 298\text{ K}$,

$$p_2 = \rho_2 R T_2; \qquad 286\left(10^3\right)\text{ N/m}^2 = \rho_2(259.8\text{ J/kg}\cdot\text{K})(298\text{ K})$$
$$\rho_2 = 3.6941\text{ kg/m}^3$$

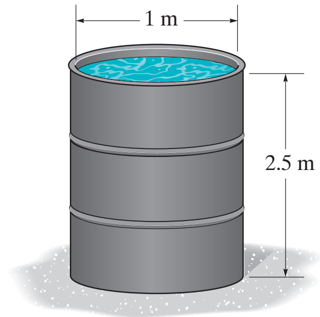
Thus, the change in density is

$$\Delta\rho = \rho_2 - \rho_1 = 3.6941\text{ kg/m}^3 - 4.4562\text{ kg/m}^3$$
$$= -0.7621\text{ kg/m}^3 = -0.762\text{ kg/m}^3 \qquad \textbf{Ans.}$$

The negative sign indicates a decrease in density.

Ans:
$\Delta\rho = -0.762\text{ kg/m}^3$

1–19. The container is filled with water at a temperature of 25°C and a depth of 2.5 m. If the container has a mass of 30 kg, determine the combined weight of the container and the water.



SOLUTION

From Appendix A, $\rho_w = 997.1\ \text{kg/m}^3$ at $T = 25°\text{C}$. Here, the volume of water is

$$\forall = \pi r^2 h = \pi(0.5\ \text{m})^2(2.5\ \text{m}) = 0.625\pi\ \text{m}^3$$

Thus, the mass of water is

$$M_w = \rho_w \forall = 997.1\ \text{kg/m}^3\left(0.625\pi\ \text{m}^3\right) = 1957.80\ \text{kg}$$

The total mass is

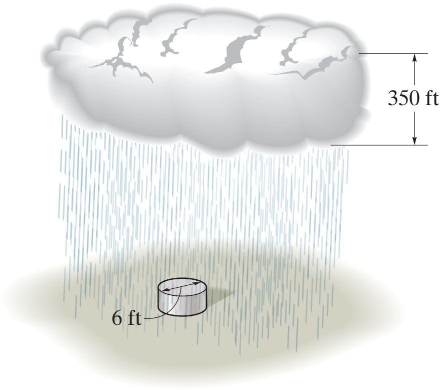
$$M_T = M_w + M_c = (1957.80 + 30)\ \text{kg} = 1987.80\ \text{kg}$$

Then the total weight is

$$W = M_T g = (1987.80\ \text{kg})\left(9.81\ \text{m/s}^2\right) = 19\,500\ \text{N} = 19.5\ \text{kN} \qquad \textbf{Ans.}$$

Ans:
$W = 19.5\ \text{kN}$

***1–20.** The rain cloud has an approximate volume of 6.50 mile^3 and an average height, top to bottom, of 350 ft. If a cylindrical container 6 ft in diameter collects 2 in. of water after the rain falls out of the cloud, estimate the total weight of rain that fell from the cloud. 1 mile = 5280 ft.



SOLUTION

The volume of rain water collected is $V_w = \pi(3\text{ ft})^2\left(\frac{2}{12}\text{ ft}\right) = 1.5\pi\text{ ft}^3$. Then, the weight of the rain water is $W_w = \gamma_w V_w = \left(62.4\text{ lb/ft}^3\right)\left(1.5\pi\text{ ft}^3\right) = 93.6\pi\text{ lb}$. Here, the volume of the overhead cloud that produced this amount of rain is

$$V_c' = \pi(3\text{ ft})^2(350\text{ ft}) = 3150\pi\text{ ft}^3$$

Thus,

$$\gamma_c = \frac{W}{V_c'} = \frac{93.6\pi\text{ lb}}{3150\pi\text{ ft}^3} = 0.02971\text{ lb/ft}^3$$

Then

$$W_c = \gamma_c V_c = \left(0.02971\frac{\text{lb}}{\text{ft}^3}\right)\left[(6.50)\left(\frac{5280^3\text{ ft}^3}{1}\right)\right]$$
$$= 28.4\left(10^9\right)\text{ lb}$$ **Ans.**

Ans:
$W_c = 28.4\left(10^9\right)\text{ lb}$

1–21. A volume of 8 m^3 of oxygen initially at 80 kPa of absolute pressure and 15°C is subjected to an absolute pressure of 25 kPa while the temperature remains constant. Determine the new density and volume of the oxygen.

SOLUTION

From the table in Appendix A, the gas constant for oxygen is $R = 259.8\ \text{J/kg}\cdot\text{K}$. Applying the ideal gas law,

$$p_1 = \rho_1 R T_1; \quad 80\left(10^3\right)\ \text{N/m}^3 = \rho_1(259.8\ \text{J/kg}\cdot\text{K})(15°\text{C} + 273)\ \text{K}$$

$$\rho_1 = 1.0692\ \text{kg/m}^3$$

For $T_2 = T_1$ and $p_2 = 25\ \text{kPa}$,

$$\frac{p_1}{p_2} = \frac{\rho_1 R T_1}{\rho_2 R T_2}; \quad \frac{p_1}{p_2} = \frac{\rho_1}{\rho_2}$$

$$\frac{80\ \text{kPa}}{25\ \text{kPa}} = \frac{1.0692\ \text{kg/m}^3}{\rho_2}$$

$$\rho_2 = 0.3341\ \text{kg/m}^3 = 0.334\ \text{kg/m}^3 \qquad \textbf{Ans.}$$

The mass of the oxygen is

$$m = \rho_1 \forall_1 = \left(1.0692\ \text{kg/m}^3\right)\left(8\ \text{m}^3\right) = 8.5536\ \text{kg}$$

Since the mass of the oxygen is constant regardless of the temperature and pressure,

$$m = \rho_2 \forall_2;\ 8.5536\ \text{kg} = \left(0.3341\ \text{kg/m}^3\right)$$

$$\forall_2 = 25.6\ \text{m}^3 \qquad \textbf{Ans.}$$

Ans:
$\rho_2 = 0.334\ \text{kg/m}^3$
$\forall_2 = 25.6\ \text{m}^3$

1–22. When a pressure of 650 psi is applied to a solid, its specific weight increases from 310 lb/ft^3 to 312 lb/ft^3. Determine the approximate bulk modulus.

SOLUTION

Differentiating $\forall = \dfrac{W}{\gamma}$ with respect to γ, we obtain

$$d\forall = -\frac{W}{\gamma^2}\,d\gamma$$

Then

$$E_\forall = -\frac{dp}{d\forall/\forall} = -\frac{dp}{\left[-\dfrac{W}{\gamma^2}d\gamma\Big/(W/\gamma)\right]} = \frac{dp}{d\gamma/\gamma}$$

Therefore,

$$E_\forall = \frac{650\text{ lb/in}^2}{\left(\dfrac{(312\text{ lb/ft}^3 - 310\text{ lb/ft}^3)}{310\text{ lb/ft}^3}\right)} = 100.75(10^3)\text{ psi} = 101(10^3)\text{ psi} \quad \textbf{Ans.}$$

The more precise answer can be obtained from

$$E_\forall = \frac{\displaystyle\int_{p_i}^{p} dp}{\displaystyle\int_{\gamma_i}^{\gamma}\frac{d\gamma}{\gamma}} = \frac{p - p_i}{\ln\left(\dfrac{\gamma}{\gamma_i}\right)} = \frac{650\text{ lb/in}^2}{\ln\left(\dfrac{312\text{ lb/ft}^3}{310\text{ lb/ft}^3}\right)} = 101.07(10^3)\text{ psi} = 101(10^3)\text{ psi} \quad \textbf{Ans.}$$

Ans:
$E_\forall = 101(10^3)$ psi

1–23. Water at 20°C is subjected to a pressure increase of 44 MPa. Determine the percent increase in its density. Take $E_V = 2.20$ GPa.

SOLUTION

$$\frac{\Delta\rho}{\rho_1} = \frac{m/V_2 - m/V_1}{m/V_1} = \frac{V_1}{V_2} - 1$$

To find V_1/V_2, use $E_V = -d_p/(dV/V)$.

$$\frac{dV}{V} = -\frac{dp}{E_V}$$

$$\int_{V_1}^{V_2}\frac{dV}{V} = -\frac{1}{E_V}\int_{p_1}^{p_2} dp$$

$$\ln\left(\frac{V_1}{V_2}\right) = \frac{1}{E_V}\Delta p$$

$$\frac{V_1}{V_2} = e^{\Delta p/E_V}$$

So, since the bulk modulus of water at 20°C is $E_V = 2.20$ GPa,

$$\frac{\Delta\rho}{\rho_1} = e^{\Delta p/E_V} - 1$$

$$= e^{(44\text{ MPa})/2.20\text{ GPa})} - 1$$

$$= 0.0202 = 2.02\%$$ **Ans.**

Ans:
$\frac{\Delta\rho}{\rho_1} = 2.02\%$

***1–24.** If the bulk modulus for water at 70°F is 319 kip/in^2, determine the change in pressure required to reduce its volume by 0.3%.

SOLUTION

Use $E_V = -dp/(dV/V)$.

$$dp = -E_V \frac{dV}{V}$$

$$\Delta p = \int_{p_i}^{p_f} dp = -E_V \int_{V_i}^{V_f} \frac{dV}{V}$$

$$= -(319 \text{ kip/in}^2)\ln\left(\frac{V - 0.03V}{V}\right)$$

$$= 0.958 \text{ kip/in}^2 \text{ (ksi)}$$ **Ans.**

Ans:
$\Delta p = 0.958 \text{ kip/in}^2$ (ksi)

1–25. At a point deep in the ocean, the specific weight of seawater is $64.2\ \text{lb/ft}^3$. Determine the absolute pressure in lb/in^2 at this point if at the surface the specific weight is $\gamma = 63.6\ \text{lb/ft}^3$ and the absolute pressure is $p_a = 14.7\ \text{lb/in}^2$. Take $E_V = 48.7(10^6)\ \text{lb/ft}^2$.

SOLUTION

Differentiating $V = \dfrac{W}{\gamma}$ with respect to γ, we obtain

$$dV = -\frac{W}{\gamma^2}\,d\gamma$$

Then

$$E_V = -\frac{dp}{dV/V} = -\frac{dp}{\left(-\dfrac{W}{\gamma^2}d\gamma\right)\Big/(W/\gamma)} = \frac{dp}{d\gamma/\gamma}$$

$$dp = E_V\frac{d\gamma}{\gamma}$$

Integrate this equation with the initial condition at $p = p_a$, $\gamma = \gamma_0$, then

$$\int_{p_a}^{p} dp = E_V\int_{\gamma_0}^{\gamma}\frac{d\gamma}{\gamma}$$

$$p - p_a = E_V \ln\frac{\gamma}{\gamma_0}$$

$$p = p_a + E_V \ln\frac{\gamma}{\gamma_0}$$

Substitute $p_a = 14.7\ \text{lb/in}^2$, $E_V = \left[48.7(10^6)\ \dfrac{\text{lb}}{\text{ft}^2}\right]\left(\dfrac{1\ \text{ft}}{12\ \text{in}}\right)^2 = 338.19(10^3)\ \text{lb/in}^2$

$\gamma_0 = 63.6\ \text{lb/ft}^3$ and $\gamma = 64.2\ \text{lb/ft}^3$ into this equation,

$$p = 14.7\ \text{lb/in}^2 + [338.19(10^3)\ \text{lb/in}^2]\left[\ln\left(\frac{64.2\ \text{lb/ft}^3}{63.6\ \text{lb/ft}^3}\right)\right]$$

$$= 3.190(10^3)\ \text{psi}$$

$$= 3.19(10^3)\ \text{psi} \qquad \textbf{Ans.}$$

Ans:
$p = 3.19(10^3)$ psi

1–26. A 2-kg mass of oxygen is held at a constant temperature of 50°C and an absolute pressure of 220 kPa. Determine its bulk modulus.

SOLUTION

$$E_V = -\frac{dp}{dV/V} = -\frac{dpV}{dV}$$

$$p = \rho RT$$

$$dp = d\rho RT$$

$$E_V = -\frac{d\rho RTV}{dV} = -\frac{d\rho pV}{\rho dV}$$

$$\rho = \frac{m}{V}$$

$$d\rho = -\frac{mdV}{V^2}$$

$$E_V = \frac{mdVpV}{V^2(m/V)dV} = P = 220\text{ kPa} \qquad \textbf{Ans.}$$

Note: This illustrates a general point. For an ideal gas, the isothermal (constant-temperature) bulk modulus equals the absolute pressure.

Ans:
$E_V = 220\text{ kPa}$

1–27. The viscosity of SAE 10 W30 oil is $\mu = 0.100\ \text{N}\cdot\text{s/m}^2$. Determine its kinematic viscosity. The specific gravity is $S_o = 0.92$. Express the answer in SI and FPS units.

SOLUTION

The density of the oil can be determined from

$$\rho_o = S_o\rho_w = 0.92\left(1000\ \text{kg/m}^3\right) = 920\ \text{kg/m}^3$$

Then,

$$\nu_o = \frac{\mu_o}{\rho_o} = \frac{0.100\ \text{N}\cdot\text{s/m}^2}{920\ \text{kg/m}^3} = 108.70\left(10^{-6}\right)\text{m}^2/\text{s} = 109\left(10^{-6}\right)\text{m}^2/\text{s} \qquad \textbf{Ans.}$$

In FPS units,

$$\nu_o = \left[108.70\left(10^{-6}\right)\frac{\text{m}^2}{\text{s}}\right]\left(\frac{1\ \text{ft}}{0.3048\ \text{m}}\right)^2$$

$$= 1.170\left(10^{-3}\right)\text{ft}^2/\text{s} = 1.17\left(10^{-3}\right)\text{ft}^2/\text{s} \qquad \textbf{Ans.}$$

Ans:
$\nu_o = 109\left(10^{-6}\right)\text{m}^2/\text{s}$
$= 1.17\left(10^{-3}\right)\text{ft}^2/\text{s}$

***1–28.** If the kinematic viscosity of glycerin is $\nu = 1.15(10^{-3})\ \mathrm{m^2/s}$, determine its viscosity in FPS units. At the temperature considered, glycerin has a specific gravity of $S_g = 1.26$.

SOLUTION

The density of glycerin is

$$\rho_g = S_g \rho_w = 1.26\left(1000\ \mathrm{kg/m^3}\right) = 1260\ \mathrm{kg/m^3}$$

Then,

$$\nu_g = \frac{\mu_y}{\rho_g};\quad 1.15(10^{-3})\ \mathrm{m^2/s} = \frac{\mu_g}{1260\ \mathrm{kg/m^3}}$$

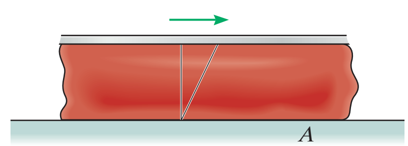
$$\mu_g = \left(1.449\ \frac{\mathrm{N\cdot s}}{\mathrm{m^2}}\right)\left(\frac{1\ \mathrm{lb}}{4.448\ \mathrm{N}}\right)\left(\frac{0.3048\ \mathrm{m}}{1\ \mathrm{ft}}\right)^2$$

$$= 0.03026\ \mathrm{lb\cdot s/ft^2}$$

$$= 0.0303\ \mathrm{lb\cdot s/ft^2}$$ **Ans.**

Ans:
$\mu_g = 0.0303\ \mathrm{lb\cdot s/ft^2}$

1–29. An experimental test using human blood at $T = 30°\text{C}$ indicates that it exerts a shear stress of $\tau = 0.15\ \text{N/m}^2$ on surface A, where the measured velocity gradient is $16.8\ \text{s}^{-1}$. Since blood is a non-Newtonian fluid, determine its *apparent viscosity* at A.



SOLUTION

Here, $\frac{du}{dy} = 16.8\ \text{s}^{-1}$ and $\tau = 0.15\ \text{N/m}^2$. Thus,

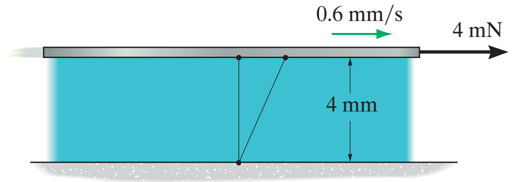
$$\tau = \mu_a \frac{du}{dy}; \qquad 0.15\ \text{N/m}^2 = \mu_a\left(16.8\ \text{s}^{-1}\right)$$

$$\mu_a = 8.93\left(10^{-3}\right)\ \text{N}\cdot\text{s/m}^2 \qquad \textbf{Ans.}$$

Realize that blood is a non-Newtonian fluid. For this reason, we are calculating the *apparent* viscosity.

Ans:
$\mu_a = 8.93(10^{-3})\ \text{N}\cdot\text{s/m}^2$

1–30. The plate is moving at 0.6 mm/s when the force applied to the plate is 4 mN. If the surface area of the plate in contact with the liquid is 0.5 m^2, determine the approximate viscosity of the liquid, assuming that the velocity distribution is linear.



SOLUTION

The shear stress acting on the fluid contact surface is

$$\tau = \frac{F}{A} = \frac{4(10^{-3})\text{ N}}{0.5\text{ m}^2} = 8.00(10^{-3})\text{ N/m}^2$$

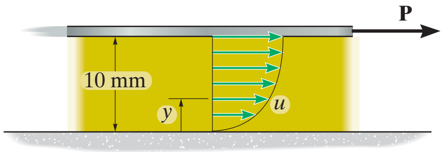
Since the velocity distribution is assumed to be linear, the velocity gradient is a constant.

$$\tau = \mu\frac{du}{dy}; \qquad 8.00\,(10^{-3})\text{ N/m}^2 = \mu\left[\frac{0.6(10^{-3})\text{m/s}}{4(10^{-3})\text{m}}\right]$$

$$\mu = 0.0533\text{ N}\cdot\text{s/m}^2 \qquad \textbf{Ans.}$$

Ans:
$\mu = 0.0533\text{ N}\cdot\text{s/m}^2$

1–31. When the force **P** is applied to the plate, the velocity profile for a Newtonian fluid that is confined under the plate is approximated by $u = (4.23y^{1/3})$ mm/s, where y is in mm. Determine the shear stress within the fluid at $y = 5$ mm. Take $\mu = 0.630(10^{-3})\ \text{N}\cdot\text{s/m}^2$.



SOLUTION

Since the velocity distribution is not linear, the velocity gradient varies with y.

$$u = (4.23y^{1/3})\ \text{mm/s}$$

$$\frac{du}{dy} = \left[\frac{1}{3}(4.23)y^{-2/3}\right]\text{s}^{-1}$$

$$= \left(\frac{1.41}{y^{2/3}}\right)\text{s}^{-1}$$

At $y = 5$ mm,

$$\frac{du}{dy} = \left(\frac{1.41}{5^{2/3}}\right)\text{s}^{-1} = 0.4822\ \text{s}^{-1}$$

The shear stress is

$$\tau = \mu\frac{du}{dy} = [0.630(10^{-3})\text{N}\cdot\text{s/m}^2](0.4822\ \text{s}^{-1})$$

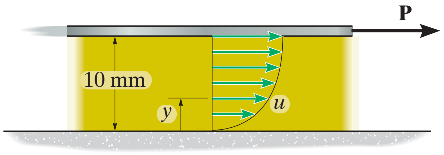
$$= 0.3038(10^{-3})\ \text{N/m}^2$$

$$= 0.304\ \text{mPa}$$ **Ans.**

Note: When $y = 0$, $\frac{du}{dy} \rightarrow \infty$ and so $\tau \rightarrow \infty$. Hence, the equation cannot be applied at this point.

Ans:
$\tau = 0.304$ mPa

***1–32.** When the force **P** is applied to the plate, the velocity profile for a Newtonian fluid that is confined under the plate is approximated by $u = (4.23y^{1/3})$ mm/s, where y is in mm. Determine the minimum shear stress within the fluid. Take $\mu = 0.630(10^{-3})\ \text{N}\cdot\text{s/m}^2$.



SOLUTION

Since the velocity distribution is not linear, the velocity gradient varies with y.

$$u = (4.23y^{1/3})\ \text{mm/s}$$

$$\frac{du}{dy} = \left[\frac{1}{3}(4.23)y^{-2/3}\right]\text{s}^{-1}$$

$$= \left(\frac{1.41}{y^{2/3}}\right)\text{s}^{-1}$$

The velocity gradient is smallest when $y = 10$ mm and this minimum value is

$$\left(\frac{du}{dy}\right)_{\text{min}} = \left(\frac{1.41}{10^{2/3}}\right)\text{s}^{-1} = 0.3038\ \text{s}^{-1}$$

The minimum shear stress is

$$\tau_{\text{min}} = \mu\left(\frac{du}{dy}\right)_{\text{min}} = \left[0.630(10^{-3})\ \text{N}\cdot\text{s/m}^2\right](0.3038\ \text{s}^{-1})$$

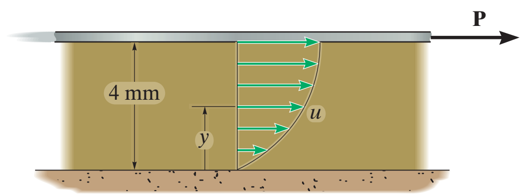
$$= 0.1914(10^{-3})\ \text{N/m}^2$$

$$= 0.191\ \text{MPa}$$ **Ans.**

Note: When $y = 0$, $\frac{du}{dy} \rightarrow \infty$ and so $\tau \rightarrow \infty$. Hence, the equation can not be applied at this point.

Ans:
$\tau_{\text{min}} = 0.191$ MPa

1–33. The Newtonian fluid is confined between a plate and a fixed surface. If its velocity profile is defined by $u = (8y - 0.3y^2)$ mm/s, where y is in mm, determine the shear stress that the fluid exerts on the plate and on the fixed surface. Take $\mu = 0.482\ \text{N}\cdot\text{s/m}^2$.



SOLUTION

Since the velocity distribution is not linear, the velocity gradient varies with y.

$$u = (8y - 0.3y^2)\ \text{mm/s}$$

$$\frac{du}{dy} = (8 - 0.6y)\ \text{s}^{-1}$$

At the plate and the fixed surface, $y = 4$ mm and $y = 0$, respectively. Thus,

$$\left(\frac{du}{dy}\right)_p = [8 - 0.6(4)]\ \text{s}^{-1} = 5.60\ \text{s}^{-1}$$

$$\left(\frac{du}{dy}\right)_{fs} = [8 - 0.6(0)]\ \text{s}^{-1} = 8.00\ \text{s}^{-1}$$

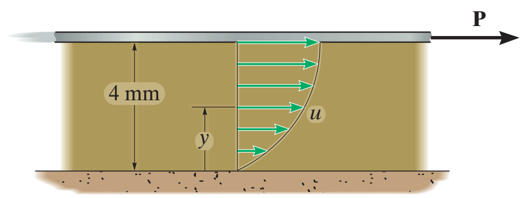
The shear stresses are

$$\tau_p = \mu\left(\frac{du}{dy}\right)_p = (0.482\ \text{N}\cdot\text{s/m}^2)(5.60\ \text{s}^{-1}) = 2.699\ \text{N/m}^2 = 2.70\ \text{Pa}$$

$$\tau_{fs} = \mu\left(\frac{du}{dy}\right)_{fs} = (0.482\ \text{N}\cdot\text{s/m}^2)(8.00\ \text{s}^{-1}) = 3.856\ \text{N/m}^2 = 3.86\ \text{Pa} \quad \textbf{Ans.}$$

Ans:
$\tau_p = 2.70$ Pa
$\tau_{fs} = 3.86$ Pa

1–34. The Newtonian fluid is confined between the plate and a fixed surface. If its velocity profile is defined by $u = (8y - 0.3y^2)$ mm/s, where y is in mm, determine the force **P** that must be applied to the plate to cause this motion. The plate has a surface area of $15(10^3)$ mm^2 in contact with the fluid. Take $\mu = 0.482$ N·s/m^2.



SOLUTION

Since the velocity distribution is not linear, the velocity gradient varies with y given by

$$u = (8y - 0.3y^2) \text{ mm/s}$$

$$\frac{du}{dy} = (8 - 0.6y) \text{ s}^{-1}$$

At the plate, $y = 4$ mm. Thus,

$$\left(\frac{du}{dy}\right)_p = [8 - 0.6(4)] \text{ s}^{-1} = 5.60 \text{ s}^{-1}$$

The shear stress is

$$\tau_p = \mu\left(\frac{du}{dy}\right)_p = (0.482 \text{ N}\cdot\text{s/m}^2)(5.60 \text{ s}^{-1}) = 2.6992 \text{ N/m}^2$$

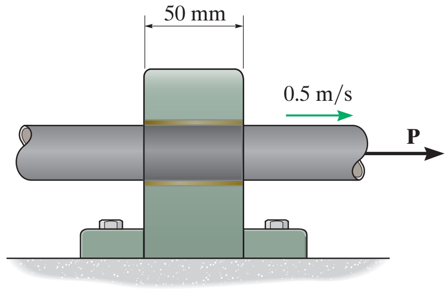
Thus, the force P applied to the plate is

$$P = \tau_p A = (2.6992 \text{ N/m}^2)\left[15(10^3) \text{ mm}^2\right]\left(\frac{1 \text{ m}}{1000 \text{ mm}}\right)^2$$

$$= 0.04049 \text{ N} = 0.0405 \text{ N}$$ **Ans.**

Ans:
$P = 0.0405$ N

1–35. If a force of $P = 2$ N causes the 30-mm-diameter shaft to slide along the lubricated bearing with a constant speed of 0.5 m/s, determine the viscosity of the lubricant and the constant speed of the shaft when $P = 8$ N. Assume the lubricant is a Newtonian fluid and the velocity profile between the shaft and the bearing is linear. The gap between the bearing and the shaft is 1 mm.



SOLUTION

Since the velocity distribution is linear, the velocity gradient will be constant.

$$\tau = \mu \frac{du}{dy}$$

$$\frac{2\text{ N}}{[2\pi(0.015\text{ m})](0.05\text{ m})} = \mu\left(\frac{0.5\text{ m/s}}{0.001\text{ m}}\right)$$

$$\mu = 0.8498\text{ N}\cdot\text{s/m}^2 \qquad \textbf{Ans.}$$

Thus,

$$\frac{8\text{ N}}{[2\pi(0.015\text{ m})](0.05\text{ m})} = (0.8488\text{ N}\cdot\text{s/m}^2)\left(\frac{v}{0.001\text{ m}}\right)$$

$$v = 2.00\text{ m/s} \qquad \textbf{Ans.}$$

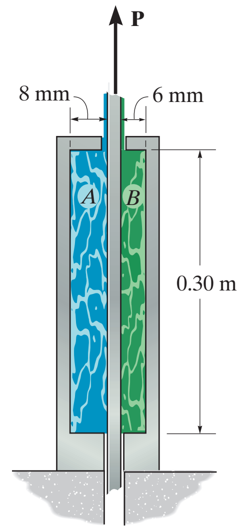
Also, by proportion,

$$\frac{\left(\frac{2\text{ N}}{A}\right)}{\left(\frac{8\text{ N}}{A}\right)} = \frac{\mu\left(\frac{0.5\text{ m/s}}{t}\right)}{\mu\left(\frac{v}{t}\right)}$$

$$v = \frac{4}{2}\text{ m/s} = 2.00\text{ m/s} \qquad \textbf{Ans.}$$

Ans:
$\mu = 0.849\text{ N}\cdot\text{s/m}^2$
$v = 2.00\text{ m/s}$

***1–36.** A plastic strip having a width of 0.2 m and a mass of 150 g passes between two layers A and B of paint having a viscosity of $5.24\ \text{N}\cdot\text{s/m}^2$. Determine the force **P** required to overcome the viscous friction on each side if the strip moves upwards at a constant speed of 4 mm/s. Neglect any friction at the top and bottom openings, and assume the velocity profile through each layer is linear.



SOLUTION

Since the velocity distribution is assumed to be linear, the velocity gradient will be constant. For layers A and B,

$$\left(\frac{du}{dy}\right)_A = \frac{4\ \text{mm/s}}{8\ \text{mm}} = 0.5\ \text{s}^{-1}\quad \left(\frac{du}{dy}\right)_B = \frac{4\ \text{mm/s}}{6\ \text{mm}} = 0.66675\ \text{s}^{-1}$$

The shear stresses acting on the surfaces in contact with layers A and B are

$$\tau_A = \mu\left(\frac{du}{dy}\right)_A = (5.24\ \text{N}\cdot\text{s/m}^2)(0.5\ \text{s}^{-1}) = 2.62\ \text{N/m}^2$$

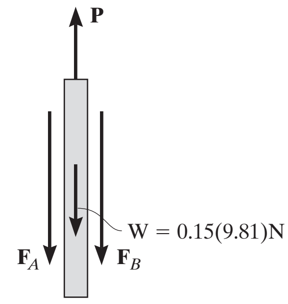
$$\tau_B = \mu\left(\frac{du}{dy}\right)_B = (5.24\ \text{N}\cdot\text{s/m}^2)(0.6667\ \text{s}^{-1}) = 3.4933\ \text{N/m}^2$$

Thus, the shear forces acting on the contact surfaces are

$$F_A = \tau_A A = (2.62\ \text{N/m}^2)[(0.2\ \text{m})(0.3\ \text{m})] = 0.1572\ \text{N}$$

$$F_B = \tau_B A = (3.4933\ \text{N/m}^2)[(0.2\ \text{m})(0.3\ \text{m})] = 0.2096\ \text{N}$$

Consider the force equilibrium along y axis for the FBD of the strip, Fig. a.



(a)

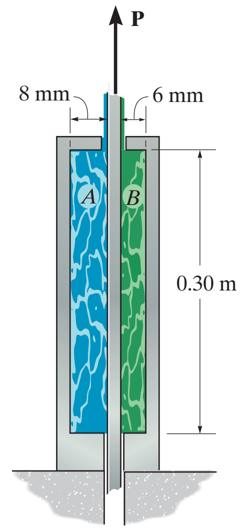
$$+\uparrow\Sigma F_y = 0;\qquad P - 0.15(9.81)\ \text{N} - 0.1572\ \text{N} - 0.2096\ \text{N} = 0$$

$$P = 1.8383\ \text{N} = 1.84\ \text{N}\qquad \textbf{Ans.}$$

Ans:
$P = 1.84\ \text{N}$

M01_HIBB9290_01_SE_C01_ANS.indd 36 22/02/17 4:51 PM

1–37. A plastic strip having a width of 0.2 m and a mass of 150 g passes between two layers A and B of paint. If force $P = 2\text{ N}$ is applied to the strip, causing it to move at a constant speed of 6 mm/s, determine the viscosity of the paint. Neglect any friction at the top and bottom openings, and assume the velocity profile through each layer is linear.



SOLUTION

Since the velocity distribution is assumed to be linear, the velocity gradient will be constant. For layers A and B,

$$\left(\frac{du}{dy}\right)_A = \frac{6\text{ mm/s}}{8\text{ mm}} = 0.75\text{ s}^{-1} \qquad \left(\frac{du}{dy}\right)_B = \frac{6\text{ mm/s}}{6\text{ mm}} = 1.00\text{ s}^{-1}$$

The shear stresses acting on the surfaces of the strip in contact with layers A and B are

$$\tau_A = \mu\left(\frac{du}{dy}\right)_A = \mu(0.75\text{ s}^{-1}) = (0.75\mu)\text{ N/m}^2$$

$$\tau_B = \mu\left(\frac{du}{dy}\right)_B = \mu(1.00\text{ s}^{-1}) = (1.00\mu)\text{ N/m}^2$$

Thus, the shear forces acting on these contact surfaces are

$$F_A = \tau_A A = (0.75\mu\text{ N/m}^2)[(0.2\text{ m})(0.3\text{ m})] = (0.045\mu)\text{ N}$$

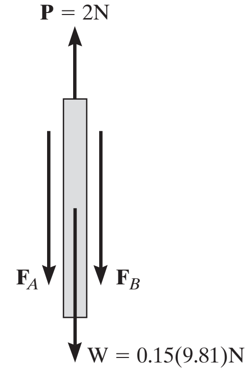
$$F_B = \tau_B A = (1.00\mu\text{ N/m}^2)[(0.2\text{ m})(0.3\text{ m})] = (0.06\mu)\text{ N}$$

Consider the force equilibrium along the y axis for the FBD of the strip, Fig. *a*.

$$+\uparrow\Sigma F_y = 0; \qquad 2\text{ N} - 0.045\mu\text{ N} - 0.06\mu\text{ N} - 0.15(9.81)\text{ N} = 0$$

$$\mu = 5.0333\text{ N}\cdot\text{s/m}^2$$

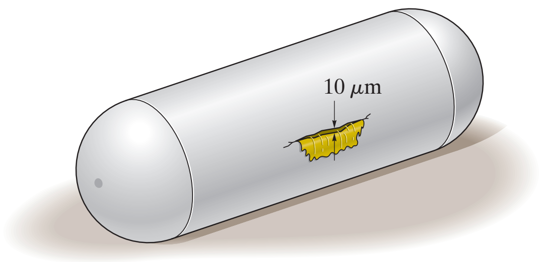
$$= 5.03\text{ N}\cdot\text{s/m}^2 \qquad \textbf{Ans.}$$



(a)

Ans:
$\mu = 5.03\text{ N}\cdot\text{s/m}^2$

1–38. The tank containing gasoline has a long crack on its side that has an average opening of 10 μm. The velocity through the crack is approximated by the equation $u = 10(10^9)[10(10^{-6})y - y^2]$ m/s, where y is in meters, measured upward from the bottom of the crack. Find the shear stress at the bottom, $y = 0$, and the location y within the crack where the shear stress in the gasoline is zero. Take $\mu_g = 0.317(10^{-3})\ \mathrm{N \cdot s/m^2}$.



SOLUTION

Gasoline is a Newtonian fluid.

The rate of change of shear strain as a function of y is

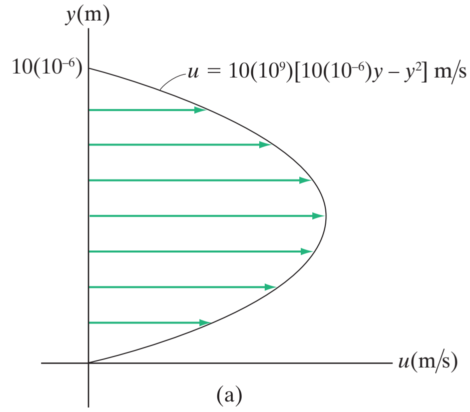
$$\frac{du}{dy} = 10(10^9)\left[10(10^{-6}) - 2y\right]\ \mathrm{s}^{-1}$$

At the surface of crack, $y = 0$ and $y = 10(10^{-6})$ m. Then

$$\left.\frac{du}{dy}\right|_{y=0} = 10(10^9)\left[10(10^{-6}) - 2(0)\right] = 100(10^3)\ \mathrm{s}^{-1}$$

or

$$\left.\frac{du}{dy}\right|_{y=10(10^{-6})\,m} = 10(10^9)\left\{10(10^{-6}) - 2\left[10(10^{-6})\right]\right\} = -100(10^3)\ \mathrm{s}^{-1}$$



(a)

Applying Newton's law of viscosity,

$$\tau_{y=0} = \mu_g \left.\frac{du}{dy}\right|_{y=0} = \left[0.317(10^{-3})\ \mathrm{N \cdot s/m^2}\right]\left[100(10^3)\ \mathrm{s}^{-1}\right] = 31.7\ \mathrm{N/m^2} \qquad \textbf{Ans.}$$

$\tau = 0$ when $\frac{du}{dy} = 0$. Thus,

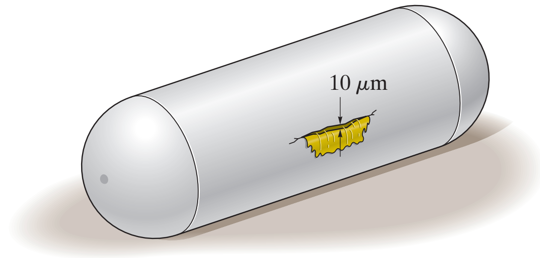
$$\frac{du}{dy} = 10(10^9)\left[10(10^{-6}) - 2y\right] = 0$$

$$10(10^{-6}) - 2y = 0$$

$$y = 5(10^{-6})\ \mathrm{m} = 5\ \mu\mathrm{m} \qquad \textbf{Ans.}$$

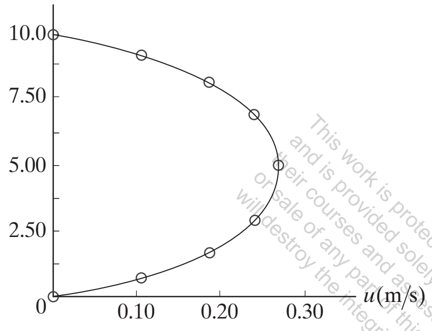
Ans:
$\tau_{y=0} = 31.7\ \mathrm{N/m^2}$
$\tau = 0$ when $y = 5\ \mu\mathrm{m}$

1–39. The tank containing gasoline has a long crack on its side that has an average opening of 10 μm. If the velocity profile through the crack is approximated by the equation $u = 10(10^9)[10(10^{-6})y - y^2]$ m/s, where y is in meters, plot both the velocity profile and the shear stress distribution for the gasoline as it flows through the crack. Take $\mu_g = 0.317(10^{-3})\ \text{N}\cdot\text{s/m}^2$.



SOLUTION

$y(10^{-6}\text{ m})$	0	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.0
$u(\text{m/s})$	0	0.1094	0.1875	0.2344	0.250	0.2344	0.1875	0.1094	0



(a)

Gasoline is a Newtonian fluid. The rate of change of shear strain as a function of y is

$$\frac{du}{dy} = 10(10^9)[10(10^{-6}) - 2y]\ \text{s}^{-1}$$

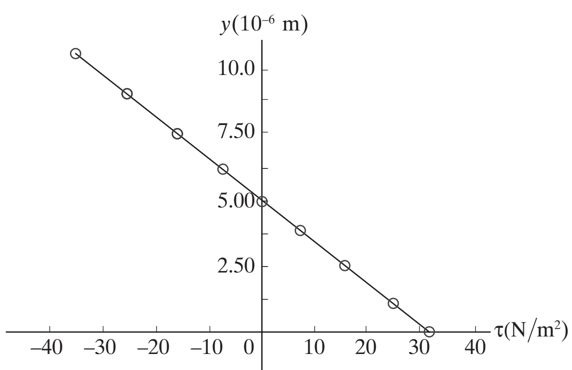
Applying Newton's law of viscoscity,

$$\tau = \mu\frac{du}{dy} = [0.317(10^{-3})\ \text{N}\cdot\text{s/m}^2]\{10(10^9)[10(10^{-6}) - 2y]\ \text{s}^{-1}\}$$

$$\tau = 3.17(10^6)[10(10^{-6}) - 2y]\ \text{N/m}^2$$

The plots of the velocity profile and the shear stress distribution are shown in Figs. *a* and *b*, respectively.

$y(10^{-6}\text{ m})$	0	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.0
$\tau(\text{N/m}^2)$	31.70	23.78	15.85	7.925	0	−7.925	−15.85	−23.78	−31.70



(b)

***1–40.** Determine the constants B and C in Andrade's equation for water if it has been experimentally determined that $\mu = 1.00(10^{-3})\ \text{N}\cdot\text{s/m}^2$ at a temperature of 20°C and that $\mu = 0.554(10^{-3})\ \text{N}\cdot\text{s/m}^2$ at 50°C.

SOLUTION

The Andrade's equation is

$$\mu = Be^{C/T}$$

At $T = (20 + 273)\ \text{K} = 293\ \text{K}$, $\mu = 1.00\left(10^{-3}\right)\ \text{N}\cdot\text{s/m}^2$. Thus,

$$1.00\left(10^{-3}\right)\ \text{N}\cdot\text{s/m}^2 = Be^{C/293\ \text{K}}$$

$$\ln\left[1.00\left(10^{-3}\right)\right] = \ln\left(Be^{C/293}\right)$$

$$-6.9078 = \ln B + \ln e^{C/293}$$

$$-6.9078 = \ln B + C/293$$

$$\ln B = -6.9078 - C/293 \qquad \textbf{(1)}$$

At $T = (50 + 273)\ \text{K} = 323\ \text{K}$, $\mu = 0.554\left(10^{-3}\right)\ \text{N}\cdot\text{s/m}^2$. Thus,

$$0.554\left(10^{-3}\right)\ \text{N}\cdot\text{s/m}^2 = Be^{C/323}$$

$$\ln\left[0.554\left(10^{-3}\right)\right] = \ln\left(Be^{C/323}\right)$$

$$-7.4983 = \ln B + \ln e^{C/323}$$

$$-7.4983 = \ln B + \frac{C}{323}$$

$$\ln B = -7.4983 - \frac{C}{323} \qquad \textbf{(2)}$$

Equating Eqs. (1) and (2),

$$-6.9078 - \frac{C}{293} = -7.4983 - \frac{C}{323}$$

$$0.5906 = 0.31699\left(10^{-3}\right) C$$

$$C = 1863.10 = 1863\ \text{K} \qquad \textbf{Ans.}$$

Substitute this result into Eq. (1).

$$B = 1.7316\left(10^{-6}\right)\ \text{N}\cdot\text{s/m}^2$$

$$= 1.73\left(10^{-6}\right)\ \text{N}\cdot\text{s/m}^2 \qquad \textbf{Ans.}$$

Ans:
$C = 1863\ \text{K}$
$B = 1.73\left(10^{-6}\right)\ \text{N}\cdot\text{s/m}^2$