Solutions Manual to accompany

Fundamentals of Fluid Mechanics, 8th Edition, ISV

Chapter 1

1.1 Determine the dimensions, in both the *FLT* system and the *MLT* system, for **(a)** the product of mass times velocity, **(b)** the product of force times volume, and **(c)** kinetic energy divided by area.

(a) $\text{mass} \times \text{velocity} \doteq (M)(LT^{-1}) \doteq \underline{\underline{MLT^{-1}}}$

Since $F \doteq MLT^{-2}$

$\text{mass} \times \text{velocity} \doteq (FL^{-1}T^{2})(LT^{-1}) \doteq \underline{\underline{FT}}$

(b) $\text{force} \times \text{volume} \doteq \underline{\underline{FL^3}}$

$\doteq (MLT^{-2})(L^3) \doteq \underline{\underline{ML^4T^{-2}}}$

(c) $\dfrac{\text{kinetic energy}}{\text{area}} \doteq \dfrac{FL}{L^2} \doteq \underline{\underline{FL^{-1}}}$

$\doteq \dfrac{(MLT^{-2})L}{L^2} \doteq \underline{\underline{MT^{-2}}}$

1.2 Determine the dimensions, in both the *FLT* system and the *MLT* system, for **(a)** the product of force times acceleration, **(b)** the product of force times velocity divided by area, and **(c)** momentum divided by volume.

(a) $\text{force} \times \text{acceleration} \doteq (F)(LT^{-2}) \doteq \underline{\underline{FLT^{-2}}}$

Since $F \doteq MLT^{-2}$,

$\text{force} \times \text{acceleration} \doteq (MLT^{-2})(LT^{-2}) \doteq \underline{\underline{ML^2T^{-4}}}$

(b) $$\frac{\text{force} \times \text{velocity}}{\text{area}} \doteq \frac{(F)(LT^{-1})}{L^2} \doteq \underline{\underline{FL^{-1}T^{-1}}}$$

$$\doteq \frac{(MLT^{-2})(LT^{-1})}{L^2} \doteq \underline{\underline{MT^{-3}}}$$

(c) $$\frac{\text{momentum}}{\text{volume}} = \frac{\text{mass} \times \text{velocity}}{\text{volume}}$$

$$\doteq \frac{(FT^2L^{-1})(LT^{-1})}{L^3} \doteq \underline{\underline{FL^{-3}T}}$$

$$\doteq \frac{(M)(LT^{-1})}{L^3} \doteq \underline{\underline{ML^{-2}T^{-1}}}$$

1.3 If V is a velocity, determine the dimensions of Z, α, and G, which appear in the dimensionally homogeneous equation

$$V = Z(\alpha - 1) + G$$

$$V = Z(\alpha - 1) + G$$

$$[LT^{-1}] \doteq [Z][\alpha - 1] + [G]$$

Since each term in the equation must have the same dimensions, it follows that

$$Z \doteq \underline{\underline{LT^{-1}}}$$

$$\alpha \doteq \underline{\underline{F^0L^0T^0}} \text{ (dimensionless since combined with a number)}$$

$$G \doteq \underline{\underline{LT^{-1}}}$$

1.4 According to information found in an old hydraulics book, the energy loss per unit weight of fluid flowing through a nozzle connected to a hose can be estimated by the formula

$$h = (0.04 \text{ to } 0.09)(D/d)^4V^2/2g$$

where h is the energy loss per unit weight, D the hose diameter, d the nozzle tip diameter, V the fluid velocity in the hose, and g the acceleration of gravity. Do you think this equation is valid in any system of units? Explain.

$$h = (0.04 \text{ to } 0.09)\left(\frac{D}{d}\right)^4 \frac{V^2}{2g}$$

$$\left[\frac{FL}{F}\right] \doteq [0.04 \text{ to } 0.09]\left[\frac{L^4}{L^4}\right]\left[\frac{1}{2}\right]\left[\frac{L^2}{T^2}\right]\left[\frac{T^2}{L}\right]$$

$$[L] \doteq [0.04 \text{ to } 0.09][L]$$

Since each term in the equation must have the same dimensions, the constant term (0.04 to 0.09) must be dimensionless. Thus, the equation is a general homogeneous equation that is valid in any system of units. <u>Yes</u>.

1.5 The force, P, that is exerted on a spherical particle moving slowly through a liquid is given by the equation

$$P = 3\pi\mu DV$$

where μ is a fluid property (viscosity) having dimensions of $FL^{-2}T$, D is the particle diameter, and V is the particle velocity. What are the dimensions of the constant, 3π? Would you classify this equation as a general homogeneous equation?

$$P = 3\pi\mu DV$$

$$[F] \doteq [3\pi][FL^{-2}T][L][LT^{-1}]$$

$$[F] \doteq [3\pi][F]$$

$\therefore$ 3π is dimensionless, and the equation is a general homogeneous equation. Yes.

1.6 For Table 1.3 verify the conversion relationships for: **(a)** area, **(b)** density, **(c)** velocity, and **(d)** specific weight. Use the basic conversion relationships: 1 ft = 0.3048 m; 1 lb = 4.4482 N; and 1 slug = 14.594 kg.

(a) $$1\ ft^2 = (1\ ft^2)\left[(0.3048)^2 \frac{m^2}{ft^2}\right] = 0.09290\ m^2$$

Thus, multiply ft^2 by 9.290 E−2 to convert to m^2.

(b) $$1\ \frac{slug}{ft^3} = \left(1\ \frac{slug}{ft^3}\right)\left(14.594\ \frac{kg}{slug}\right)\left[\frac{1\ ft^3}{(0.3048)^3 m^3}\right]$$

$$= 515.4\ \frac{kg}{m^3}$$

Thus, multiply $slugs/ft^3$ by 5.154 E+2 to convert to kg/m^3.

(c) $1\ \frac{ft}{s} = \left(1\ \frac{ft}{s}\right)\left(0.3048\ \frac{m}{ft}\right) = 0.3048\ \frac{m}{s}$

Thus, multiply ft/s by $\underline{\underline{3.048\ E-1}}$ to convert to m/s.

(d) $1\ \frac{lb}{ft^3} = \left(1\ \frac{lb}{ft^3}\right)\left(4.4482\ \frac{N}{lb}\right)\left[\frac{1\ ft^3}{(0.3048)^3 m^3}\right]$

$$= 157.1\ \frac{N}{m^3}$$

Thus, multiply lb/ft^3 by $\underline{\underline{1.571\ E+2}}$ to convert to N/m^3.

1.7 For Table 1.4 verify the conversion relationships for: **(a)** acceleration, **(b)** density, **(c)** pressure, and **(d)** volume flowrate. Use the basic conversion relationships: 1 m = 3.2808 ft; 1N = 0.22481lb; and 1 kg = 0.068521 slug.

(a) $1\ \frac{m}{s^2} = \left(1\ \frac{m}{s^2}\right)\left(3.2808\ \frac{ft}{m}\right) = 3.281\ \frac{ft}{s^2}$

Thus, multiply m/s^2 by $\underline{\underline{3.281}}$ to convert to ft/s^2.

(b) $1\ \frac{kg}{m^3} = \left(1\ \frac{kg}{m^3}\right)\left(0.068521\ \frac{slugs}{kg}\right)\left[\frac{1\ m^3}{(3.2808)^3 ft^3}\right]$

$$= 1.940 \times 10^{-3}\ \frac{slugs}{ft^3}$$

Thus, multiply kg/m^3 by $\underline{\underline{1.940\ E-3}}$ to convert to $slugs/ft^3$.

(c) $1\ \frac{N}{m^2} = \left(1\ \frac{N}{m^2}\right)\left(0.22481\ \frac{lb}{N}\right)\left[\frac{1\ m^2}{(3.2808)^2\ ft^2}\right]$

$= 2.089 \times 10^{-2}\ \frac{lb}{ft^2}$

Thus, multiply N/m^2 by $\underline{\underline{2.089\ E{-2}}}$ to convert to lb/ft^2.

(d) $1\ \frac{m^3}{s} = \left(1\ \frac{m^3}{s}\right)\left[(3.2808)^3\ \frac{ft^3}{m^3}\right] = 35.31\ \frac{ft^3}{s}$

Thus, multiply m^3/s by $\underline{\underline{3.531\ E{+1}}}$ to convert to ft^3/s.

1.8 A tank contains 375 kg of a liquid whose specific gravity is 3.5. Determine the volume of the liquid in the tank.

The volume is related to the mass and fluid density by

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

density of the liquid is related to the density of liquid water at 4 C by

$$\rho = SG \cdot \rho_{H20}$$

Where the density of water at 4 C is 1000 kg/m^3. The volume of the tank is then determined by

$$V = \frac{m}{\rho} = \frac{375kg}{3.5 \cdot 1000\frac{kg}{m^3}} = 0.107\ m^3$$

1.9 A tank of oil has a mass of 47 slugs. **(a)** Determine its weight in pounds and in newtons at the Earth's surface. **(b)** What would be its mass in slugs and its weight in pounds if it were located on the moon's surface where the gravitational attraction is approximately one-sixth that at the Earth's surface?

The relation between mass and weight is given by Newton's Second Law

$$W = m\,g$$

(a) At the Earth's surface the gravitational attraction is 32.2 ft/s^2. With the mass in slugs, the weight in pounds is

$$W = 47\,slugs \cdot 32.2\frac{ft}{s^2} \cdot 1\frac{lb\,s^2}{slug\,ft} = 1513\,lb$$

Using the conversion factor in Table 1.3 on the inside of the text cover, the weight in newtons is

$$W = 1513\,lb \cdot \frac{4.448\,N}{lb} = 6730\,N$$

(b) The mass of an object is independent of gravity, so at the moon's surface the mass would still be 47 slugs. The gravitational attraction at the Moon's surface is approximately 5.4 ft/s^2 so the weight on the moon would be

$$W = 47\,slugs \cdot 5.4\,\frac{ft}{s^2} \cdot 1\frac{lb\,s^2}{slug\,ft} = 254\,lb$$

1.10 A certain object weighs 450 N at the Earth's surface. Determine the mass of the object in kilograms and its weight in newtons when located on a planet with an acceleration of gravity equal to 23.0 ft/s^2

The relation between mass and weight is given by Newton's Second Law

$$W = m\,g$$

At the Earth's surface the gravitational attraction is 9.81m/s^2. The mass at the Earth's surface is then

$$m = \frac{W}{g} = \frac{450\,N}{9.81\frac{m}{s^2}} = 45.9\,kg$$

The mass on the planet is the same as that on Earth since the mass is independent of gravitational attraction. The acceleration of gravity of 23.0 ft/s^2 is converted to m/s^2 using the conversion factor of 0.3048 m/ft found in the table on the inside cover of the text. The acceleration of gravity is then 7.01 m/s^2 . The weight on the planet is then

$$W = 45.9\,kg \cdot 7.01\frac{m}{s^2} = 322\,N$$

1.11 A mountain climber's oxygen tank contains 1.8 lb of oxygen when it is filled at sea level where the acceleration of gravity is 32.174 ft/s^2. What would be the weight of the oxygen in the tank at the top of Mt. Everest where the acceleration of gravity is 32.082 ft/s^2?

The mass of oxygen in the tank is the same both at sea level and the top of Mt Everest. The relation between mass and weight in the EE system is given by Newton's Second Law

$$W = m\,\frac{g}{g_c}$$

Where g is the sea level value of acceleration due to gravity and g_c is a conversion factor. At the top of Mt Everest, the weight in pounds is determined using Newtons

$$W = m\,\frac{g_{Mt\ Everet}}{g_c} = m\frac{g}{g_c}\,\frac{g_{Mt\ Everet}}{g_{sea\ level}} = W_{sea\ level}\frac{g_{Mt\ Everet}}{g_{sea\ level}}$$

or

$$W = 1.8\,lb\,\frac{32.082\frac{ft}{s^2}}{32.174\frac{ft}{s^2}} = 1.793\,lb$$

1.12 The specific weight of a certain liquid is 85.3 lb/ft^3. Determine its density and specific gravity.

$$\rho = \frac{\gamma}{g} = \frac{85.3\ \frac{lb}{ft^3}}{32.2\ \frac{ft}{s^2}} = \underline{\underline{2.65\ \frac{slugs}{ft^3}}}$$

$$SG = \frac{\rho}{\rho_{H_2O}\ @\ 4°C} = \frac{2.65\ \frac{slugs}{ft^3}}{1.94\ \frac{slugs}{ft^3}} = \underline{\underline{1.37}}$$

1.13 A liquid when poured into a graduated cylinder is found to weigh 8 N when occupying a volume of 500 ml (milliliters). Determine its specific weight, density, and specific gravity.

$$\gamma = \frac{\text{weight}}{\text{volume}} = \frac{8\ N}{(0.500\ \ell)\left(10^{-3}\ \frac{m^3}{\ell}\right)} = \underline{\underline{16.0\ \frac{kN}{m^3}}}$$

$$\rho = \frac{\gamma}{g} = \frac{16 \times 10^3\ \frac{N}{m^3}}{9.81\ \frac{m}{s^2}} = \underline{\underline{1.63 \times 10^3\ \frac{kg}{m^3}}}$$

$$SG = \frac{\rho}{\rho_{H_2O}\ @\ 4°C} = \frac{1.63 \times 10^3\ \frac{kg}{m^3}}{10^3\ \frac{kg}{m^3}} = \underline{\underline{1.63}}$$

1.14 The density of a jet fuel is 685 kg/m^3. What is its specific gravity and specific weight?

The specific gravity is defined by Eq. 1.7

$$SG = \frac{\rho}{\rho_{H2O\ 4C}}$$

Where the density of water at 4 C is 1000 kg/m^3. For jet fuel, the specific gravity is

$$SG = \frac{\rho}{\rho_{H2O\ 4C}} = \frac{685\ \frac{kg}{m^3}}{1000\ \frac{kg}{m^3}} = 0.685$$

The specific weight is related to the density through Newton's Law and given by

$$\gamma = \rho g$$

Where g is the gravitational attraction, 9.8 m/s2. The specific weight of jet fuel is then

$$\gamma = 685\ \frac{kg}{m^3} \cdot 9.8 \frac{m}{s^2} \cdot 1 \frac{N\ s^2}{kg\ m} = 6710 \frac{N}{m^3}$$

1.15 Determine the mass of air in a 2m³ tank if the air is at room temperature, 20 °C, and the absolute pressure within the tank is 200 kPa (abs).

$m = \rho V$ where $V = 2\,m^3$ and

$\rho = p/RT$ with $T = 20°C = (20+273)\,K = 293\,K$

and $p = 200\,kPa = 200 \times 10^3 \frac{N}{m^2}$

Thus,

$$\rho = \left(200 \times 10^3 \frac{N}{m^2}\right) \Big/ \left[\left(2.869 \times 10^2 \frac{N \cdot m}{kg \cdot K}\right)(293\,K)\right]$$

$$= 2.38 \frac{kg}{m^3}$$

Hence,

$$m = \rho V = 2.38 \frac{kg}{m^3}(2\,m^3) = \underline{\underline{4.76\,kg}}$$

1.16 A tire having a volume of 3 ft³ contains air at a gage pressure of 26 psi and a temperature of 70 °F. Determine the density of the air and the weight of the air contained in the tire.

$$\rho = \frac{p}{RT} = \frac{\left(26 \frac{lb}{in.^2} + 14.7 \frac{lb}{in.^2}\right)\left(144 \frac{in.^2}{ft^2}\right)}{\left(1716 \frac{ft \cdot lb}{slug \cdot °R}\right)\left[(70°F + 460)°R\right]} = \underline{\underline{6.44 \times 10^{-3} \frac{slugs}{ft^3}}}$$

$$\text{weight} = \rho g \times \text{volume} = \left(6.44 \times 10^{-3} \frac{slugs}{ft^3}\right)\left(32.2 \frac{ft}{s^2}\right)\left(3\,ft^3\right)$$

$$= \underline{\underline{0.622\,lb}}$$

1.17 Make use of the data in Appendix B to determine the dynamic viscosity of mercury at 75 °F. Express your answer in BG units.

$$T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(75\,°F - 32) = 23.9\,°C$$

From Fig. B.1 in Appendix B:

$$\mu\,(\text{mercury at } 75\,°F\,(23.9\,°C)) \approx 1.5 \times 10^{-3}\,\frac{N\cdot s}{m^2}$$

$$\mu \approx \left(1.5\times 10^{-3}\,\frac{N\cdot s}{m^2}\right)\left(2.089\times 10^{-2}\,\frac{\frac{lb\cdot s}{ft^2}}{\frac{N\cdot s}{m^2}}\right) \approx \underline{\underline{3.1\times 10^{-5}\,\frac{lb\cdot s}{ft^2}}}$$

1.18 Carbon dioxide is compressed to a density of 6.5 kg/m^3 under an absolute pressure of 400 kPa. Determine the temperature in degrees Celsius.

The density is related to the pressure and temperature through the ideal gas law

$$\rho = \frac{p}{RT}$$

Where R is the gas constant for the particular gas. The gas constant for carbon dioxide is 188.9 J/kg-K (Table 1.6). The temperature is then

$$T = \frac{p}{R\rho} = \frac{400\cdot 10^3 Pa}{188.9\frac{J}{kg\,K}\cdot 6.5\,\frac{kg}{m^3}} = 325.8K = 52.6C$$

1.19 A tank having a volume of 7 ft^3 is filled with 1 lb of a gas. A pressure gage attached to the tank reads 18 psi when the gas temperature is 65 F. No one knows whether the gas in the tank is carbon dioxide, oxygen or nitrogen. Which do you think it is? Explain how you arrived at your answer.

The approach will be to use the ideal gas relation to solve for the gas constant, and then see whether the constant is near the tabulated values for one of these substances. The ideal gas relation is

$$\rho = \frac{p}{RT}$$

The density is determined from the volume and mass

$$\rho = \frac{m}{V} = \frac{1\ lbm}{7ft^3} = 0.1429\frac{lb}{ft^3} \cdot 1\frac{slug}{32.2\ lbm} = 0.00444\frac{slug}{ft^3}$$

Or, solving for R and using the known temperature and pressure

$$R = \frac{p}{\rho T} = \frac{18psi \cdot 144\frac{ft^2}{in^2}}{0.00444\frac{slug}{ft^3} \cdot 424.7R} = 1113\frac{ft\ lb}{slug\ R}$$

From Table 1.7, the gas constant closest to this value is carbon dioxide. The tank probably contains carbon dioxide and the value of R isn't exact as the pressure and temperature gages are not all that accurate.

1.20 A rigid tank contains air at a pressure of 90 psia and a temperature of 60 F. By how much will the pressure increase as the temperature is increased to 110 F?

The ideal gas law will be used to determine the pressure increase. The relation is

$$\rho = \frac{p}{RT}$$

Because the tank is rigid, the volume and mass, and thus the density, are constant. The pressure and temperature at the two conditions can be related as

$$\rho = \frac{p_1}{RT_1} = \frac{p_2}{RT_2}$$

Or

$$p_2 = p_1\frac{T_2}{T_1} = 90psia\frac{(110 + 459.6)R}{(65 + 459.6)R} = 97.7psia$$

1.21 Oxygen at 30 °C and 300 kPa absolute pressure expands isothermally to an absolute pressure of 120 kPa. Determine the final density of the gas.

For isothermal expansion, $\frac{p}{\rho}$ = constant so that

$$\frac{p_i}{\rho_i} = \frac{p_f}{\rho_f}$$ where $i \sim$ initial state and $f \sim$ final state.

Thus,

$$\rho_f = \frac{p_f}{p_i}\rho_i$$

Also,

$$\rho_i = \frac{p_i}{RT_i} = \frac{300 \times 10^3 \frac{N}{m^2}}{\left(259.8 \frac{J}{kg \cdot K}\right)\left[(30°C + 273)K\right]} = 3.81 \frac{kg}{m^3}$$

so that

$$\rho_f = \left(\frac{120 \text{ kPa}}{300 \text{ kPa}}\right)\left(3.81 \frac{kg}{m^3}\right) = \underline{\underline{1.52 \frac{kg}{m^3}}}$$

1.22 Determine the ratio of the dynamic viscosity of water to air at a temperature of 60 °C. Compare this value with the corresponding ratio of kinematic viscosities. Assume the air is at standard atmospheric pressure.

From Table B.2 in Appendix B:

(for water at 60°C) $\mu = 4.665 \times 10^{-4} \frac{N \cdot s}{m^2}$; $\nu = 4.745 \times 10^{-7} \frac{m^2}{s}$

From Table B.4 in Appendix B:

(for air at 60°C) $\mu = 1.97 \times 10^{-5} \frac{N \cdot s}{m^2}$; $\nu = 1.86 \times 10^{-5} \frac{m^2}{s}$

Thus,

$$\frac{\mu_{H_2O}}{\mu_{air}} = \frac{4.665 \times 10^{-4}}{1.97 \times 10^{-5}} = \underline{\underline{23.7}}$$

$$\frac{\nu_{H_2O}}{\nu_{air}} = \frac{4.745 \times 10^{-7}}{1.86 \times 10^{-5}} = \underline{\underline{2.55 \times 10^{-2}}}$$

1.23 A thin layer of glycerin flows down an inclined, wide plate with the velocity distribution shown in Fig. P1.23. For $h = 0.3$ in. and, $\alpha = 20°$ determine the surface velocity, U. Note that for equilibrium, the component of weight acting parallel to the plate surface must be balanced by the shearing force developed along the plate surface. In your analysis assume a unit plate width.

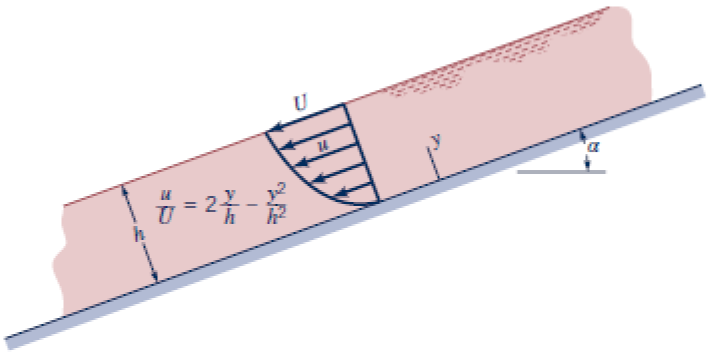
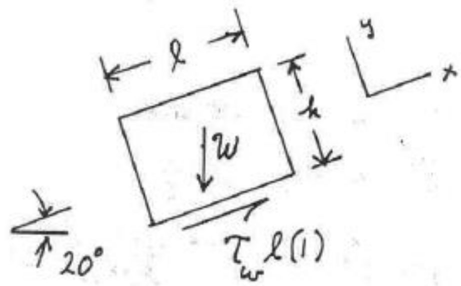


Figure P1.23



$$\Sigma F_x = 0$$

Thus,

$$\mathcal{W} \sin 20° = \tau_w \, \ell \, (1)$$

and with $\quad \mathcal{W} = \gamma \ell h (1)$

$$\gamma \ell h (1) \sin 20° = \tau_w \, \ell (1)$$

or

$$\gamma h \sin 20° = \tau_w \qquad (1)$$

At the plate

$$\tau_w = \mu \left(\frac{du}{dy} \right)_{y=0}$$

Since
$$\frac{du}{dy} = \frac{2U}{h} - \frac{2Uy}{h^2}$$
$$\left(\frac{du}{dy}\right)_{y=0} = \frac{2U}{h}$$

Thus, from Eq. (1)
$$\gamma h \sin 20° = \mu \frac{2U}{h}$$

and
$$U = \frac{\gamma h^2 \sin 20°}{2\mu}$$
$$= \frac{\left(78.6\ \frac{lb}{ft^3}\right)\left(\frac{0.3}{12}\ ft\right)^2 \sin 20°}{2\left(3.13 \times 10^{-2}\ \frac{lb \cdot s}{ft^2}\right)} = \underline{\underline{0.268\ \frac{ft}{s}}}$$

1.24 One type of rotating cylinder viscometer, called a *Stormer* viscometer, uses a falling weight, $\mathcal{W}$, to cause the cylinder to rotate with an angular velocity, ω, as illustrated in Fig. P1.24. For this device the viscosity, μ, of the liquid is related to $\mathcal{W}$ and ω through the equation $\mathcal{W} = K\mu\omega$, where K is a constant that depends only on the geometry (including the liquid depth) of the viscometer. The value of K is usually determined by using a calibration liquid (a liquid of known viscosity).

(a) Some data for a particular Stormer viscometer, obtained using glycerin at 20 °C as a calibration liquid, are given below. Plot values of the weight as ordinates and values of the angular velocity as abscissae. Draw the best curve through the plotted points and determine K for the viscometer.

$\mathcal{W}$(lb)	0.22	0.66	1.10	1.54	2.20
ω(rev/s)	0.53	1.59	2.79	3.83	5.49

(b) A liquid of unknown viscosity is placed in the same viscometer used in part (a), and the data given below are obtained. Determine the viscosity of this liquid.

$\mathcal{W}$(lb)	0.04	0.11	0.22	0.33	0.44
ω(rev/s)	0.72	1.89	3.73	5.44	7.42

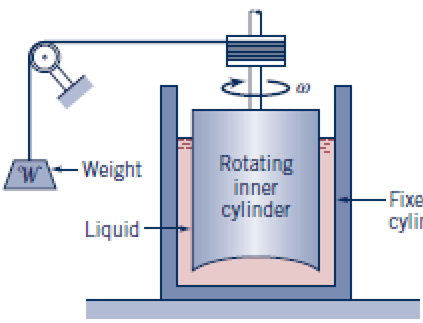


Figure P1.24

(a) Since $\mathcal{W} = K\mu\omega$ the slope of the $\mathcal{W}$ vs. ω curve is

$$slope = K\mu = \frac{\mathcal{W}\,(lb)}{\omega\,\left(\frac{rev}{s}\right)}$$

so that

$$K = \frac{slope\,\left(\frac{lb\cdot s}{rev}\right)}{\mu\,\left(\frac{lb\cdot s}{ft^2}\right)} \qquad (1)$$

For the glycerin data (see plot on next page) the slope (based on a least squares fit of the data) is

$$slope\,(glycerin) = 0.398\ \frac{lb\cdot s}{rev}$$

Since $\mu\,(glycerin) = 3.13 \times 10^{-2}\ \frac{lb\cdot s}{ft^2}$ then

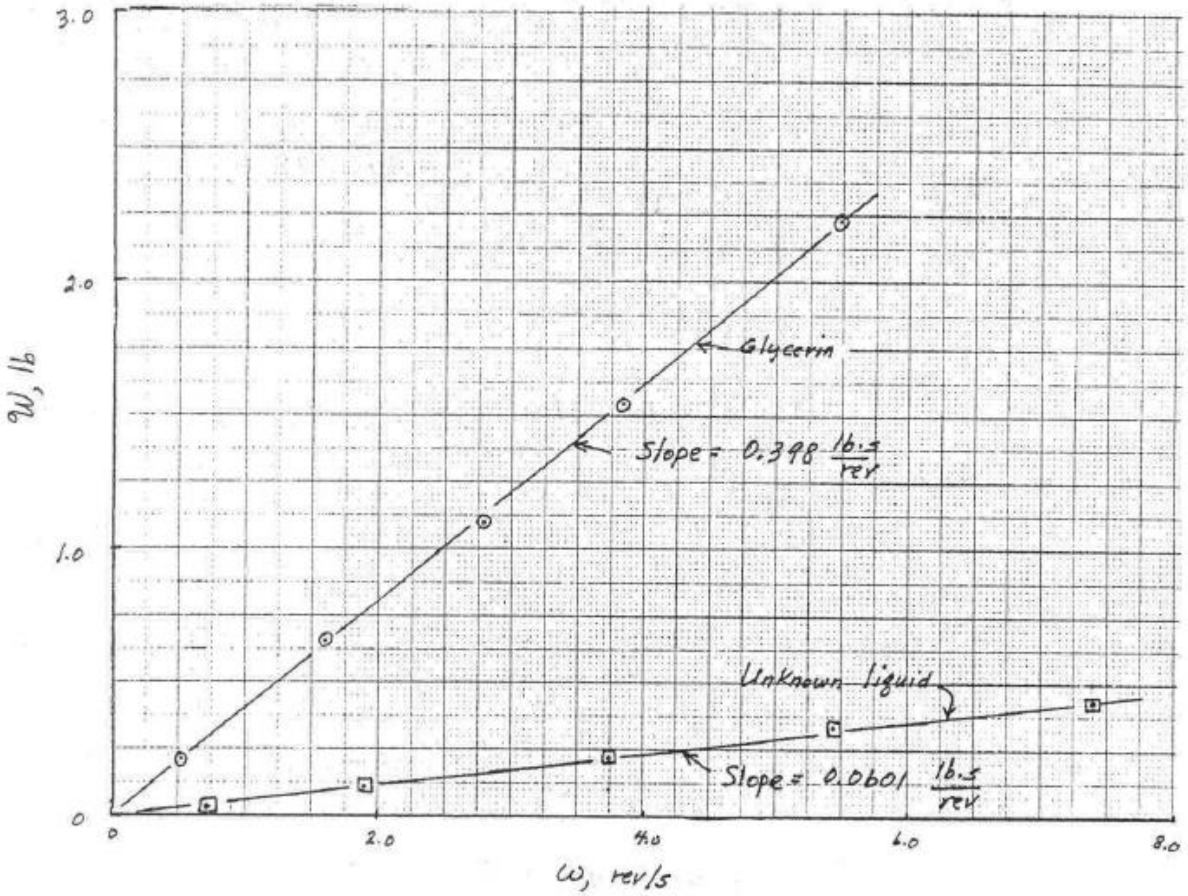
$$K = \frac{0.398\ \frac{lb\cdot s}{rev}}{3.13\times10^{-2}\ \frac{lb\cdot s}{ft^2}} = \underline{\underline{12.7\ \frac{ft^2}{rev}}}$$

(b) For the unknown fluid data (see plot on next page) the slope (based on a least squares fit of the data) is

$$slope\,(unknown\ fluid) = 0.0601\ \frac{lb\cdot s}{rev}$$

Thus, from Eq.(1)

$$\mu\,(unknown\ fluid) = \frac{slope}{K} = \frac{0.0601\ \frac{lb\cdot s}{rev}}{12.7\ \frac{ft^2}{rev}} = \underline{\underline{4.73\times10^{-3}\ \frac{lb\cdot s}{ft^2}}}$$



1.25 In a test to determine the bulk modulus of a liquid it was found that as the absolute pressure was changed from 15 to 3000 psi the volume decreased from 10.240 to 10.138 in.^{3} Determine the bulk modulus for this liquid.

$$E_v = -\frac{dp}{d\mathcal{V}/\mathcal{V}} \qquad \text{(Eq. 1.12)}$$

Since

$$dp \approx \Delta p = 3000 - 15 = 2985 \text{ psi}$$

and

$$d\mathcal{V} \approx \Delta\mathcal{V} = 10.240 - 10.138 = 0.102 \text{ in.}^3$$

$$E_v \approx -\frac{2985 \ \frac{\text{lb}}{\text{in.}^2}}{\left(\frac{0.102 \text{ in.}^3}{10.240 \text{ in.}^3}\right)} = \underline{\underline{3.00 \times 10^5 \text{ psi}}}$$

1.26 The kinematic viscosity and specific gravity of a liquid are 7 10^{-3} m^2/s and 1.4, respectively. What is the dynamic viscosity of the liquid in SI units?

The relation between the dynamic viscosity and the kinematic viscosity is

$$\nu = \frac{\mu}{\rho}$$

The density is determined from the specific gravity and the density of water at 4 C as

$$\rho = SG \cdot \rho_{H2O\,4C} = 1.4 \cdot 1000\frac{kg}{m^3} = 1400\frac{kg}{m^3}$$

The dynamic viscosity is then

$$\mu = \nu\rho = 7 \cdot 10^{-3}\frac{m^2}{s} \cdot 1400\frac{kg}{m^3} = 9.8\frac{kg}{m\,s} = 9.8\frac{N\,s}{m^2}$$

1.27 Calculate the Reynolds numbers for the flow of water and for air through a 9-mm-diameter tube for conditions of a mean velocity of 1.5 m/s, a temperature is of 20 C, and atmospheric pressure. (see Example 1.4).

The Reynolds number is defined as

$$Re = \frac{\rho VD}{\mu}$$

For water at 20 C, the density is 998.2 kg/m^3 and the dynamic viscosity is 0.001002 N s/m^2. The Reynolds number is then

$$Re = \frac{\rho VD}{\mu} = \frac{998.2\frac{kg}{m^3} \cdot 1.5\frac{m}{s} \cdot 0.009m}{0.001002\frac{N\,s}{m^2}} = 13{,}300$$

For air at 20 C, the density is 1.204 kg/m^3 and the dynamic viscosity is 1.82x10^{-5} N s/m^2. The Reynolds number is then

$$Re = \frac{\rho VD}{\mu} = \frac{1.204\frac{kg}{m^3} \cdot 1.5\frac{m}{s} \cdot 0.009m}{1.82 \cdot 10^{-5}\frac{N\,s}{m^2}} = 893$$

1.28 SAE 30 oil at 95 F flows through a 1.2-in.-diameter pipe with a mean velocity of 6 ft/s. Determine the value of the Reynolds number (see Example 1.4).

The Reynolds number is defined in terms of either the dynamic or kinematic viscosity as

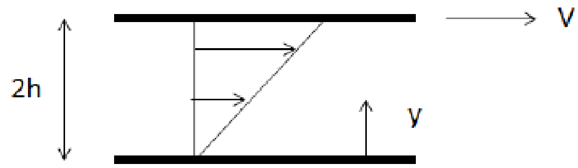
$$Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$$

For SAE oil at 95 F (35 C), the kinematic viscosity is about 2.5x10^{-4} m^2/s (Figure B.2), which corresponds to 0.0027 ft^2/s. The Reynolds number is then

$$Re = \frac{VD}{\nu} = \frac{6\frac{ft}{s} \cdot \frac{2}{12} ft}{0.0027\frac{ft^2}{s}} = 220$$

1.29 For a parallel plate arrangement of the type shown in Fig. 1.5, when the distance between plates is 3 mm, a shearing stress of 275 Pa develops at the upper plate when it is pulled at a velocity of 1.2 m/s. Determine the viscosity of the fluid between the plates. Express your answer in SI units.

The velocity profile for a parallel plate arrangement in which the top plate is moving and the bottom plate is stationary is linear, as shown in the sketch,



The shear stress is given by

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

For the linear velocity profile, the velocity gradient is constant and the shear stress is given then by

$$\tau = \mu \frac{du}{dy} = \mu \frac{\Delta u}{\Delta y} = \mu \frac{V}{2h}$$

The viscosity is then

$$\mu = \tau \frac{2h}{V} = 275 Pa \cdot \frac{0.003 m}{1.2\frac{m}{s}} = 0.688 \frac{N\, s}{m^2}$$

1.30 A 50-mm-diameter shaft is pulled through a cylindrical bearing as shown in Fig. P1.30. Oil with a kinematic viscosity of 2×10^{-4} m^2/s and a specific gravity of 0.72 fills the 0.25-mm gap between the shaft and bearing. Determine the force *P* required to pull the shaft at a velocity of 2.5 m/s. Assume the velocity distribution in the gap is linear.

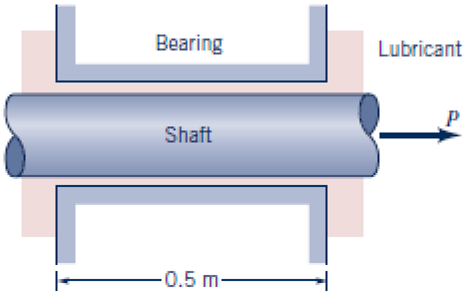
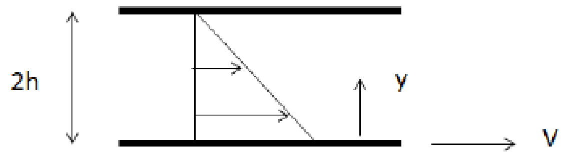


Figure P1.30

Assuming that the velocity profile in the gap is linear, the velocity distribution across the gap is as shown in the sketch,



The shear stress is given by

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

For the linear velocity profile, the velocity gradient is constant and the shear stress is given then by

$$\tau = \mu \frac{du}{dy} = \mu \frac{\Delta u}{\Delta y} = \mu \frac{V}{2h}$$

The force is the area times the shear stress and is then

$$F = \tau A = \mu \frac{V}{2h} \cdot \pi D L$$

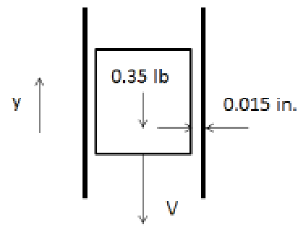
The dynamic viscosity is the product of the kinematic viscosity and density, and the density is the specific gravity times the density of water at 4C

$$\mu = \rho \nu = SG\ \rho_{H2O}\ \nu = 0.72 \cdot 1000 \frac{kg}{m^3} \cdot 2 \cdot 10^{-4} \frac{m^2}{s} = 0.144 \frac{N\,s}{m^2}$$

The force is then

$$F = \mu \frac{V}{2h} \cdot \pi D L = 0.144 \frac{N\,s}{m^2} \cdot \frac{2.5 \frac{m}{s}}{0.025m} \cdot \pi \cdot 0.050m \cdot 0.5m = 1.13\ N$$

1.31 A piston having a diameter of 4.3 in. and a length of 6.7 in. slides downward with a velocity V through a vertical pipe. The downward motion is resisted by an oil film between the piston and the pipe wall. The film thickness is 0.0015 in., and the cylinder weighs 0.35 lb. Estimate V if the oil viscosity is 0.0075 lbf s/ft^2. Assume the velocity distribution in the gap is linear.



The forces acting on the piston for steady motion are the weight and the shear force in the oil. The force balance in the positive y-direction is

$$F_{shear} - W = 0$$

Where the shear force is the product of the shear stress and the piston surface area

$$F_{shear} = \tau A = \tau \pi D L$$

The shear stress is the product of the viscosity and the velocity gradient at the wall. Assuming that the velocity distribution in the gap is linear, the velocity gradient is the difference in the piston and wall velocity (which is zero) divided by the film thickness t.

$$\tau = \mu \frac{du}{dy} = \mu \frac{\Delta u}{t} = \mu \frac{V - 0}{t} = \mu \frac{V}{t}$$

The force balance becomes

$$F_{shear} - W = \mu \frac{V}{t} \pi D L - W = 0$$

The velocity is then

$$V = \frac{Wt}{\mu \pi D L} = 0.00928 \frac{ft}{s} = 0.114 \frac{in}{s}$$

1.32 A layer of water at 25 C flows down an inclined fixed surface with the velocity profile shown in Fig. P1.81. Determine the magnitude and direction of the shearing stress that the water exerts on the fixed surface for $U = 1.8$ m/s and $h = 0.08$ m.

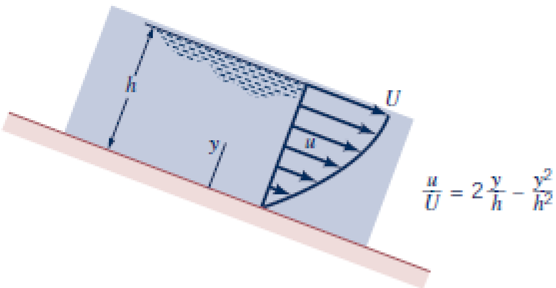


Figure P1.32

The shear stress at the surface is given by

$$\tau_s = \left[\mu \frac{du}{dy}\right]_{y=0}$$

The velocity gradient at the wall is

$$\left[\frac{du}{dy}\right]_{y=0} = \left[\frac{d}{dy} U\left(2\frac{y}{h} - \frac{y^2}{h^2}\right)\right]_{y=0} = \left[U\left(\frac{2}{h} - \frac{2y}{h^2}\right)\right]_{y=0} = U\frac{2}{h}$$

The viscosity of water at 25 C from Table B.2 is $9.00\text{x}10^{-4}$ N s/m^2. The shear stress is then

$$\tau_s = \mu U \frac{2}{h} = 9.00 \cdot 10^{-4} \frac{N\,s}{m^2} \cdot 1.8 \frac{m}{s} \cdot \frac{2}{0.08m} = 0.0405 \ \frac{N}{m^2}$$

1.33 Calculate the speed of sound in m/s for **(a)** gasoline, **(b)** mercury, and **(c)** seawater.

$$c = \sqrt{\frac{E_v}{\rho}} \qquad (Eq. 1.19)$$

(a) For gasoline: $c = \sqrt{\dfrac{1.3 \times 10^9 \frac{N}{m^2}}{680 \frac{kg}{m^3}}} = \underline{\underline{1.38 \frac{km}{s}}}$

(b) For mercury: $c = \sqrt{\dfrac{2.85 \times 10^{10} \frac{N}{m^2}}{1.36 \times 10^4 \frac{kg}{m^3}}} = \underline{\underline{1.45 \frac{km}{s}}}$

(c) For seawater: $c = \sqrt{\dfrac{2.34 \times 10^9 \frac{N}{m^2}}{1.03 \times 10^3 \frac{kg}{m^3}}} = \underline{\underline{1.51 \frac{km}{s}}}$

1.34 Compare the isentropic bulk modulus of air at 101 kPa (abs) with that of water at the same pressure.

For air (Eq. 1.17),

$$E_v = kp = (1.40)(101 \times 10^3 Pa) = 1.41 \times 10^5 Pa$$

For water (Table 1.6)

$$E_v = 2.15 \times 10^9 Pa$$

Thus,

$$\frac{E_v\,(water)}{E_v\,(air)} = \frac{2.15 \times 10^9 Pa}{1.41 \times 10^5 Pa} = \underline{\underline{1.52 \times 10^4}}$$

1.35 Jet airliners typically fly at altitudes between approximately 0 to 40,000 ft. Make use of the data in Appendix C to show on a graph how the speed of sound varies over this range.

$$c = \sqrt{kRT} \qquad \text{(Eq. 1.20)}$$

For $k = 1.40$ and $R = 1716 \frac{\text{ft}\cdot\text{lb}}{\text{slug}\cdot{}^\circ\text{R}}$

$$c = 49.0\sqrt{T(^\circ\text{R})}$$

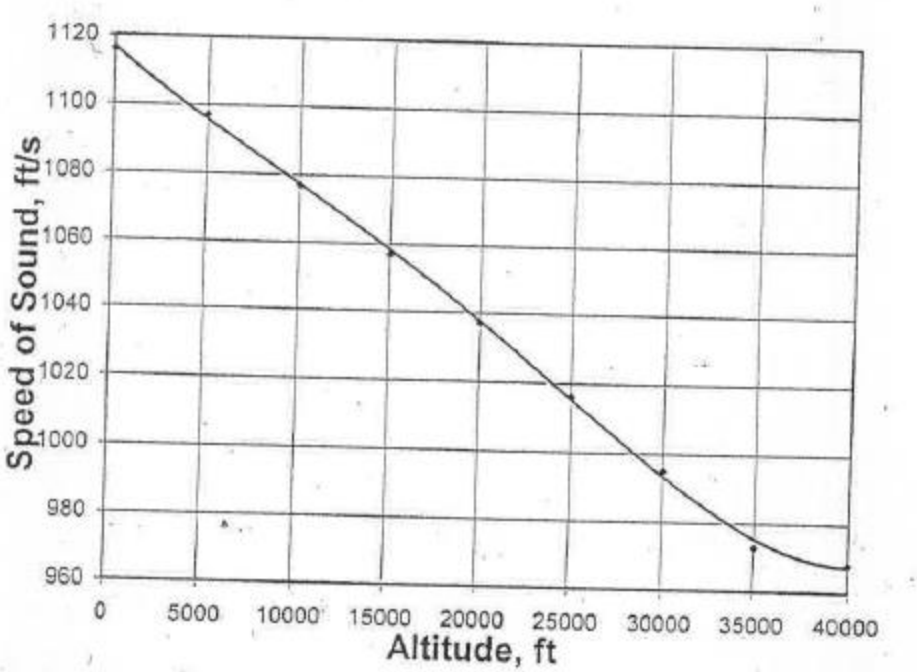
From Table C.1 in Appendix C at an altitude of 0 ft

$T = 59.00 + 460 = 519\,^\circ\text{R}$ so that

$$c = 49.0\sqrt{519\,^\circ\text{R}} = 1116\ \frac{\text{ft}}{\text{s}}$$

Similar calculations can be made for other altitudes and the resulting graph is shown below.

Altitude, ft	Temp.,° F	Temp.,° R	c, ft/s
0	59	519	1116
5000	41.17	501.17	1097
10000	23.36	483.36	1077
15000	5.55	465.55	1057
20000	-12.26	447.74	1037
25000	-30.05	429.95	1016
30000	-47.83	412.17	995
35000	-65.61	394.39	973
40000	-69.7	390.3	968



1.36 When a fluid flows through a sharp bend, low pressures may develop in localized regions of the bend. Estimate the minimum absolute pressure (in psia) that can develop without causing cavitation if the fluid is water at 140 F. Will the pressure be lower or higher if the temperature is less?

The minimum absolute pressure that can develop without causing cavitation is the vapor pressure of water at 140 F. From Table B.1, the vapor pressure is

$$p_v = 2.88\ psia$$

If the temperature is less, the vapor pressure will be less.

1.37 A partially filled closed tank contains carbon tetrachloride at 100 F. If the air above the alcohol is evacuated, what is the minimum absolute pressure that develops in the evacuated space? Will the pressure be lower or higher if the temperature is less?

The minimum absolute pressure that can develop without causing cavitation is the vapor pressure of carbon tetrachloride at 100 F. From sources on the web, the vapor pressure at 100 F(278 K) is 0.248 atm, or

$$p_v = 3.64\ psia$$

If the temperature is less, the vapor pressure will be less.

1.38 Estimate the minimum absolute pressure (in pascal and atmospheres) that can be developed at the inlet of a pump to avoid cavitation if the fluid is ethyl alcohol at 30 C.

The minimum absolute pressure that can develop without causing cavitation is the vapor pressure of water at 30 C. From Table B.2, the vapor pressure is

$$p_v = 4243 \frac{N}{m^2}$$

A pascal equals 1 N/m^2, so the pressure is also

$$p_v = 4243\ pascal$$

An atmosphere equals $1.013 x 10^5 N/m^2$, so the pressure in atmospheres is

$$p_v = \frac{4243 \frac{N}{m^2}}{1.013 \cdot 10^5 \frac{N}{m^2}} = 0.0418\ atm$$

1.39 When water at 45 C flows through a converging section of pipe, the pressure decreases in the direction of flow. Estimate the minimum absolute pressure that can develop without causing cavitation. Express your answer in both BG and SI units.

The minimum absolute pressure that can develop without causing cavitation is the vapor pressure of water at 45 C. From Table B.2, the vapor pressure is

$$p_v = 9850 \frac{N}{m^2}$$

The temperature of 45 C corresponds to 113 F. Converting from N/m^2 to psia yields

$$p_v = 1.43 psia$$

The temperature of 45 C corresponds to 113 F. Using Table B.1 also yields

$$p_v = 1.43 psia$$

1.40 An open 2-mm-diameter tube is inserted into a pan of ethyl alcohol, and a similar 4-mm-diameter tube is inserted into a pan of water. In which tube will the height of the rise of the fluid column due to capillary action be the greatest? Assume the angle of contact is the same for both tubes.

$$h = \frac{2\sigma \cos\theta}{\gamma R} \qquad \text{(Eq. 1.22)}$$

Thus,

$$\frac{h\,(\text{alcohol})}{h\,(\text{water})} = \frac{\sigma\,(\text{alcohol})\,\gamma\,(\text{water})}{\sigma\,(\text{water})\,\gamma\,(\text{alcohol})}\left(\frac{4\text{ mm}}{2\text{ mm}}\right)$$

$$= \frac{\left(2.28\times 10^{-2}\,\frac{N}{m}\right)\left(9.80\times 10^{3}\,\frac{N}{m^3}\right)(4\text{ mm})}{\left(7.34\times 10^{-2}\,\frac{N}{m}\right)\left(7.74\times 10^{3}\,\frac{N}{m^3}\right)(2\text{ mm})}$$

$$= 0.787$$

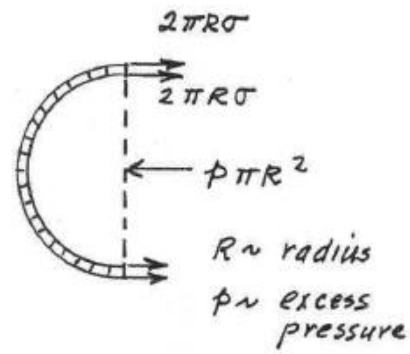
Height of rise of $\underline{\underline{\text{water column}}}$ is greatest.

1.41 Estimate the excess pressure inside a raindrop having a diameter of 3 mm.

$$p = \frac{2\sigma}{R} \qquad \text{(Eq. 1.21)}$$

$$= \frac{2\left(7.34\times 10^{-2}\,\frac{N}{m}\right)}{0.0015\text{ m}} = \underline{\underline{97.9\text{ Pa}}}$$

1.42 What is the difference between the pressure inside a soap bubble and atmospheric pressure for a 3-in.-diameter bubble? Assume the surface tension of the soap film to be 70% of that of water at 70 °F.



For equilibrium,

$$2\,(2\pi R\sigma) = p\,\pi R^2$$

or

$$p = \frac{4\sigma}{R}$$

(Note: There are two surfaces for bubble.)

σ (water at 70°F) $= 4.97 \times 10^{-3}\ \frac{lb}{ft}$ (Table B.1 in Appendix B)

Thus,

$$p = \frac{4\,(0.7)(4.97 \times 10^{-3}\ \frac{lb}{ft})}{\frac{1.5}{12}\ ft} = \underline{\underline{0.111\ \frac{lb}{ft^2}}}$$

1.43 To measure the water depth in a large open tank with opaque walls, an open vertical glass tube is attached to the side of the tank. The height of the water column in the tube is then used as a measure of the depth of water in the tank. **(a)** For a true water depth in the tank of 3 ft, make use of Eq. 1.22 (with $\theta \simeq 0°$) to determine the percent error due to *capillarity as the diameter of the glass tube is changed*. Assume a water temperature of 80 °F. Show your results on a graph of percent error versus tube diameter, D, in the range 0.1 in. < D < 1.0 in. **(b)** If you want the error to be less than 1%, what is the smallest tube diameter allowed?

(a) The excess height, h, caused be the surface tension is

$$h = \frac{2\sigma\cos\theta}{\gamma R} \qquad \text{(Eq. 1.22)}$$

For $\theta \cong 0°$ with $D = 2R$

$$h = \frac{4\sigma}{\gamma D} \qquad (1)$$

From Table B.1 in Appendix B for water at 80°F
$\sigma = 4.91 \times 10^{-3}$ lb/ft and $\gamma = 62.22$ lb/ft³.
Thus, from Eq. (1)

$$h\,(ft) = \frac{4\,(4.91 \times 10^{-3}\ \frac{lb}{ft})}{(62.22\ \frac{lb}{ft^3})\ \frac{D\,(in.)}{12\ in./ft}} = \frac{3.79 \times 10^{-3}}{D\,(in.)} \qquad (2)$$

Since

$$\%\ error = \frac{h\,(ft)}{3\ ft} \times 100 \qquad \text{(with the true depth} = 3\ ft)$$

it follows from Eq. (2) that

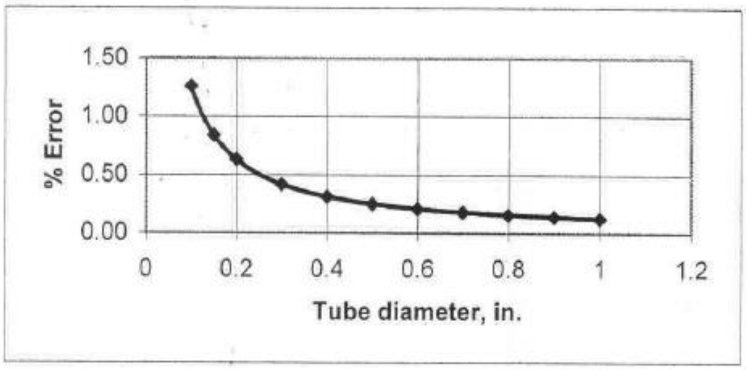
$$\% \text{ error} = \frac{3.79 \times 10^{-3}}{3\, D(\text{in.})} \times 100$$

$$= \frac{0.126}{D(\text{in.})} \qquad (3)$$

A plot of % error versus tube diameter is shown on the next page.

Diameter of tube, in.	% Error
0.1	1.26
0.15	0.84
0.2	0.63
0.3	0.42
0.4	0.32
0.5	0.25
0.6	0.21
0.7	0.18
0.8	0.16
0.9	0.14
1	0.13

Values obtained from Eq. (3)



(b) For 1% error from Eq. (3)

$$1 = \frac{0.126}{D(\text{in.})}$$

$$D = \underline{\underline{0.126 \text{ in.}}}$$