CHAPTER 1

1.1   Use the Appendix tables to find the conversion factor between gallons per minute (gpm) to cubic feet per second (cfs or ft^3/s).

$$\frac{gallons}{minute} \cdot \frac{3.785411784 \times 10^{-3}}{2.8316846592 \times 10^{-2}} \cdot \frac{1 \text{ minute}}{60 \text{ s}}$$

$$\boxed{gpm \cdot 2.228 \times 10^{-3} = ft^3/s}$$

1.2   What is the conversion factor between BTU/hr and horsepower? Use the conversion factors from Appendix Table A.2 to determine the answer.

$$\frac{BTU}{hr} \cdot \frac{1 \text{ hr}}{3600 \text{ s}} \cdot \frac{1054}{745.7} = \boxed{3.926 \times 10^{-4} \frac{HP}{(BTU/hr)}}$$

1.3   An object has a mass of 46 kg and weighs 450 N on a spring scale. Determine the acceleration due to gravity at this location.

$$m = 46 \text{ kg, } W = 450 \text{ N, } g = \frac{W}{m} = \frac{450}{46} = \boxed{9.78 \text{ m}/s^2}$$

1.4   A plastic milk container is labeled as containing 3.78 liters. If the specific gravity of milk is 1.03, determine the mass of the milk in the container and express it in kilograms.

$$3.78 \text{ l} \cdot 1 \times 10^{-3} = 3.78 \times 10^{-3} \text{ m}^3$$

$$\frac{m}{\cancel{V}} = \rho; \; m = \rho\cancel{V} = (1\,030 \text{ kg}/m^3)(3.78 \times 10^{-3} \text{ m}^3)$$

$$\boxed{m = 3.9 \text{ kg}}$$

1.5   The density of Ocean Breeze Shampoo was determined by weighing an object of known volume in air, and again by weighing it while submerged in the liquid. If the object was a 4 cm diameter sphere made of aluminum (specific gravity = 2.7), what is the expected weight of the object while submerged in the shampoo?

$D = 4$ cm $\cancel{V} = \dfrac{\pi D^3}{6} = \dfrac{\pi(0.04)^3}{6} = 3.35 \times 10^{-5} \text{ m}^3$

$s = 2.7$ for the al $\rho_{liq} = 1\,121 \text{ kg}/m^3$ from the example

$(s\rho_w)_{object} = 2.7(1\,000) = 2\,700 \text{ kg}/m^3$

$\rho_{Liq} = (s\rho_w)_{object} - \dfrac{W_2}{\cancel{V}g}$

Rearranging, $\dfrac{W_2}{\cancel{V}g} = (s\rho_w)_{object} - \rho_{Liq}$

and $W_2 = \cancel{V}g\left[(s\rho_w)_{object} - \rho_{Liq}\right]$

Substituting,

$$W_2 = 3.35 \times 10^{-5}(9.81)(2\,700 - 1\,121)$$

$$\boxed{W_2 = 0.519 \text{ N}}$$

1.6   The density of Golden Apple Shampoo is to be determined by weighing an object of known volume in air, and again by weighing it while submerged in the liquid. A stainless steel cylinder of diameter 1 inch and length 2 inches is submerged in the shampoo. The measured weight while submerged is 0.39 lbf. What is the density of the shampoo?

$V_{\text{cul}} = \pi R^2 L = \pi(0.0417)^2(0.1667) = 9.09 \times 10^{-4} \text{ ft}^3$
By definition, the specific gravity of the cylinder is
$$s = \frac{\rho}{\rho_w}$$
With the density of water as 1.94 slug/ft³, the density of the steel is
$$\rho_{\text{cyl}} = s\,\rho_w = 8(1.94) = 15.52 \text{ slug/ft}^3$$

The weight of the cylinder in air is calculated to be

$$W_1 = (\rho V)_{\text{cyl}}g = (15.52)(9.09 \times 10^{-4})(32.2)$$

$W_1 = 0.45$ lbf
The weight of the cylinder while submerged was measured as $W_2 = 0.39$ lbf. The buoyant force is the difference between these two weights:

$$B = W_1 - W_2 = 0.45 - 0.39 = 0.06 \text{ lbf}$$

The specific weight of the liquid is:

$$SW = \rho g = \frac{B}{V} = \frac{0.06}{9.09 \times 10^{-4}} = 71 \text{ lbf/ft}^3$$

The density is finally determined as:

$$\rho = \frac{71}{32.2}$$
$$\underline{\rho_{\text{liq}} = 2.20 \text{ slug/ft}^3}$$

1.7   The density of Strawberry Breeze Shampoo is to be determined by weighing an object of known volume in air, and again by weighing it while submerged in the liquid. The object is a 4 cm diameter sphere made of brass (density = 8.4 g/cm³), and the weight while submerged is 2.36 N. What is the density of the shampoo?

$V_{\text{cul}} = \pi D/6 = \pi(0.04)^3/6 = 3.351 \times 10^{-5} \text{ m}^3$
By definition, the specific gravity of the cylinder is
$$s = \frac{\rho}{\rho_w}$$
With the density of water as 1 000 kg/m³, the density of the steel is

$$\rho_{cyl} = s\,\rho_w = 8.4(1\ 000\ \text{kg/m}^3) = 8\ 400\ \text{kg/m}^3$$

The weight of the cylinder in air is calculated to be

$$W_1 = (\rho V)_{cyl}g = (8\ 400\ \text{kg/m}^3)(3.351 \times 10^{-5}\ \text{m}^3)(9.81\ \text{m/s}^2)$$

$$W_1 = 2.76\ \text{N}$$

The weight of the cylinder while submerged was measured as $W_2 = 2.36$ N. The buoyant force is the difference between these two weights:

$$B = W_1 - W_2 = 2.76\ \text{N} - 2.36\ \text{N} = 0.4\ \text{N}$$

The specific weight of the liquid is:

$$SW = \rho g = \frac{B}{V} = \frac{0.4\ \text{N}}{3.351 \times 10^{-5}\ \text{m}^3} = 12\ 968\ \text{N/m}^3$$

The density is finally determined as:

$$\rho = \frac{12\ 968\ \text{N/m}^3}{9.81\ \text{m/s}^2}$$

$$\underline{\rho_{liq} = 1\ 220\ \text{kg/m}^3}$$

1.8   Water has a density of 1 000 kg/m^3. What is its density in lbm/ft^3, slug/ft^3, and g/cm^3?

$\rho = 1\ 000\ \text{kg/m}^3$ (SI); $\rho = \dfrac{1\ 000}{16.01} = \boxed{62.5\ \text{lbm/ft}^3}$

$\rho = \dfrac{1\ 000}{16.01(32.2)} = \boxed{1.94\ \text{slug/ft}^3}$ $\rho = \dfrac{1\ 000}{1\ 000} = \boxed{1\ \text{g/cm}^3}$

1.9   The earth may be considered as a sphere whose diameter is 8000 miles and whose density is roughly approximated to be 6 560 kg/m^3. What is the mass of the earth in lbm and in kg?

Sphere $D = 8000\ \text{miles} \cdot 5280\ \text{ft/mile} = 4.224 \times 10^7\ \text{ft}$

$V = \dfrac{\pi D^3}{6} = \dfrac{\pi(4.224 \times 10^7)^3}{6} = 5.92 \times 10^{22}\ \text{ft}^3$ $\rho = 6\ 560\ \text{kg/m}^3 = 410\ \text{lbm/ft}^3$

$m = \rho V = 410(5.92 \times 10^{22}) = \boxed{2.43 \times 10^{25}\ \text{lbm}}$

$m = 2.43 \times 10^{25} \cdot 4.535 \times 10^{-1} = \boxed{1.1 \times 10^{25}\ \text{kg} = m}$

1.10   It is commonly known that there are 16 ounces in one pound. However, Appendix Table A.2 lists the ounce as a unit of volume for liquids. A 1/2 lbf glass weighs 1 lbf when filled with 8 ounces of liquid. Determine the liquid density and the specific weight in SI units.

Liquid weighs $1 - 1/2 = 1/2$ lbf; $\rho g = \dfrac{0.5 \text{ lbf}}{8 \text{ ounces}}$; using conversions,

$\rho g = \dfrac{0.5 \text{ lbf}}{8 \text{ oz}} \cdot \dfrac{4.448}{2.957 \times 10^{-5}} = \boxed{9.4 \times 10^3 \text{ N/m}^3 = SW}$

$\rho = \dfrac{9\ 400}{9.81} = \boxed{958 \text{ kg/m}^3 = \rho}$ $\rho = \dfrac{958}{515.379} = \boxed{1.86 \text{ slug/ft}^3 = \rho}$

$\rho g = 1.86(32.2) = \boxed{59.9 \text{ lbf/ft}^3 = SW}$

1.11   What is the weight in N of 1 ft^3 of kerosene?

$V = 1$ ft^3; kerosene Appendix Table A-5, $\rho = 0.823(1.94)$ slug/ft^3;

$W = mg = \rho V g = 0.823(1.94)(1)(32.2) = 5.14$ lbf; $W = 5.14(4.448)$ or

$\boxed{W = 22.9 \text{ N}}$

1.12   What is the mass in kg of 5 ft^3 of acetone?

$V = 5$ ft^3, acetone Appendix Table A-5, $\rho = 0.787(1.94$ slug/ft$^3)$;

$m = \rho V = 0.787(1.94)(5) = 7.63$ slug; $m = 7.63(14.59)$ or

$\boxed{m = 111 \text{ kg}}$

1.13   What is the density of ethylene glycol lbm/ft^3? What is the mass of 1 ft^3 of ethylene glycol in slugs?

$\boxed{\rho = 1.1(62.4) = 68.64 \text{ lbm/ft}^3}$ $V = 1$ ft^3; $W = 68.6$ lbf

$W = mg$; $m = \dfrac{W}{g} = \dfrac{68.6}{32.2}$

$\boxed{m = 1.94 \text{ slug}}$

1.14   Graph the density of air as a function of temperature.


Density of air vs temperature
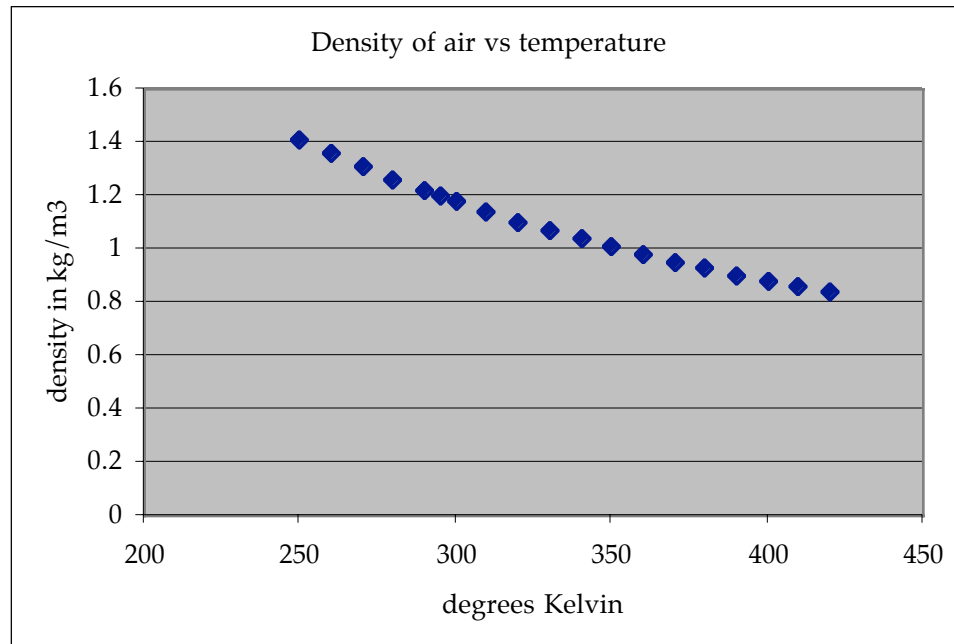
1.15   In the petroleum industry, the specific gravity of a substance (usually an oil) is expressed in terms of degrees API; or °API (American Petroleum Institute). The specific gravity and the °API are related by
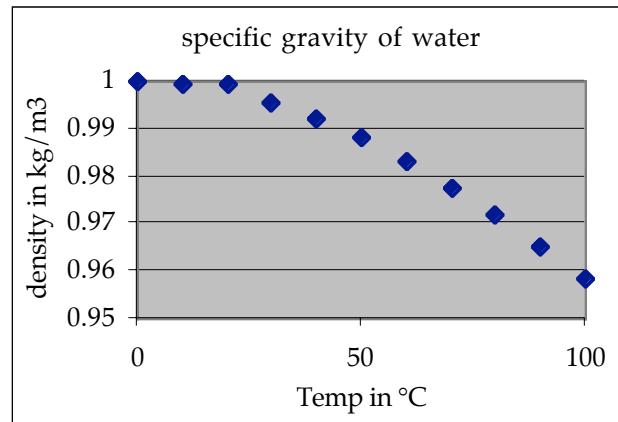
$$°\text{API} = \frac{141.5}{\text{specific gravity}} - 131.5$$

Graph °API (vertical axis) versus specific gravity ranging from 0.8 to 0.9 (typical for many oils).

$$°\text{API} = \frac{141.5}{\text{specific gravity}} - 131.5$$

°API equation
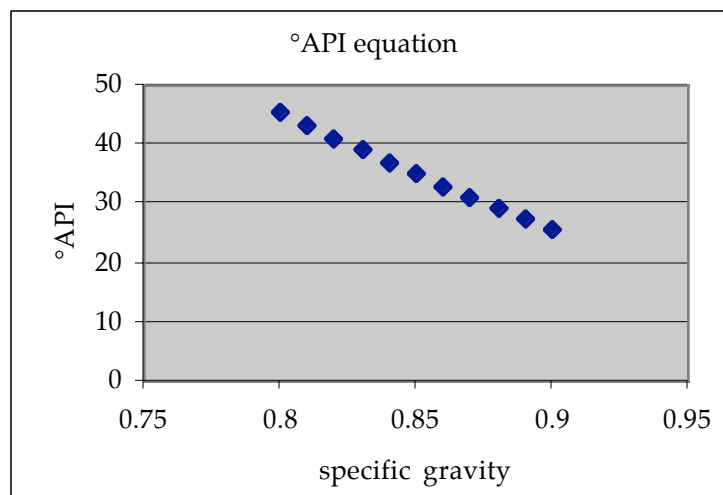
1.16   Prepare a plot of specific gravity of water as a function of temperature. Let temperature vary in 10° increments.

1.17   In Example 1.4b, what is the minimum mass required to move the upper plate if the fluid has an initial yield stress of $4 \, N/m^2$?

minimum shear required is τ_o; movement impending when $\tau = \tau_o$

$$\tau_o = 4 \, N/m^2 = \frac{force}{area} = \frac{mg}{A} \; ;$$

$$so \; m = \frac{A\tau_o}{g} = \frac{0.5 \, m^2 \, (4 \, N/m^2)}{9.81 \, m/s^2} = 0.204 \, N{\cdot}s^2/m = 0.204 \, kg$$

$\boxed{so \; for \; movement \; to \; begin, \; m > 0.204 \, kg}$

1.18   If the mass in example 1.4b is 0.025 kg, and the fluid is castor oil, determine the plate velocity.

$$\frac{F}{A} = \mu \, \frac{\Delta V}{\Delta y} \; ; \; F = 0.025 \, kg(9.81 \, m/s^2) = 0.245 \, N$$

$\Delta y = 0.01 \, m$; castor oil, $\mu = 650 \times 10^{-3} \, N{\cdot}s/m^2$; $A = 0.75 \, m^2$

$$\Delta V = \frac{0.245(0.01)}{0.75(650 \times 10^{-3})} = 5.03 \times 10^{-3} \, m/s$$

so $\boxed{V = 5.03 \, mm/s}$

1.19   Referring to Figure 1.7, assume that the fluid in the space is castor oil. What weight is required to move the plate at 5 cm/s?

$$\tau = \mu \, \frac{\Delta V}{\Delta y} \; ; \; \tau = \frac{W}{A} = \frac{W}{0.5 \, m^2}$$

Table A-5 for castor oil, $\mu = 650 \times 10^{-3} \, N{\cdot}s/m^2$

$\Delta V = 0.05 \, m/s$;   By substitution, $\frac{W}{0.5} = 650 \times 10^{-3} \, \frac{0.05}{0.005}$

$\boxed{W = 3.25 \, N}$

1.20 A weightless plate is moving upward in a space as shown in Figure P1.20. The plate has a constant velocity of 2.5 mm/s, and kerosene is placed on both sides. The contact area for either side is 2.5 m^2. The plate is equidistant from the outer boundaries with $\Delta y = 1.2$ cm. Find the force F.
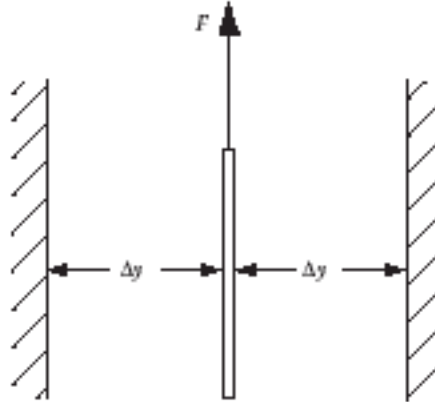

FIGURE P1.20

$$\frac{F}{A} = \mu \frac{\Delta V}{\Delta y} \; ; A = 2 \text{ sides} \cdot \frac{2.5 \text{ m}^2}{\text{side}} = 5 \text{ m}^2; \Delta V = 0.002\ 5 \text{ m/s}; \Delta y = 0.012 \text{ m}$$

Table A-5 $\quad \mu = 1.64 \times 10^{-3} \text{ N·s/m}^2$

so $\quad F = \dfrac{5(1.64 \times 10^{-3})(0.002\ 5)}{0.012} \quad$ or

$\boxed{F = 1.708 \times 10^{-3} \text{ N}}$

1.21 What is the kinematic viscosity of the Ocean Breeze Shampoo in Example 1.6? Express the results in m^2/s and in centistokes (cs).

$$\nu = \frac{\mu}{\rho} = \frac{9.11}{1\ 121} = \boxed{8.13 \times 10^{-3} \text{ m}^2/\text{s} = 8\ 130 \text{ cs}}$$

1.22 A falling sphere viscometer is used to measure the viscosity of shampoo whose density is 1 008 kg/m^3. A sphere of diameter 0.792 cm is dropped into the shampoo, and measurements indicate that the sphere travels 0.183 m in 7.35 seconds. The density of the sphere is 7 940 kg/m^3. Calculate the absolute and kinematic viscosity of the shampoo.

The viscosity is found with the equations derived previously:

$$\mu = \frac{\rho g D^2}{18V}\left(\frac{\rho_s}{\rho} - 1\right)$$

where

$\rho = 1\ 008 \text{ kg/m}^3$
$\rho_s = 7\ 940 \text{ kg/m}^3$
$D = 0.007\ 92 \text{ m}$
$g = 9.81 \text{ m/s}^2$
$V = 18.3 \text{ cm}/7.35 \text{ s} = 2.49 \text{ cm/s} = 0.024\ 9 \text{ m/s}$

Substituting,

$$\mu = \frac{(1\ 008\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.007\ 92\ \text{m})^2}{18(0.024\ 9\ \text{m/s})}\left(\frac{7\ 940}{1\ 008} - 1\right)$$

$$\underline{\mu = 9.52\ \text{N·s/m}^2 = 9.52\ \text{Pa·s}}$$

As a check on the validity of using the equation for the drag force, we calculate:

$$\frac{\rho VD}{\mu} = \frac{1\ 008(0.024\ 9)(0.007\ 92)}{9.52} = 0.02$$

which is less than 1.

1.23 Referring to Figure P1.20, the plate is being pulled upward in a space filled with chloroform. The plate velocity is 12 in./s and $\Delta y = 0.05$ in. The force is 2 lbf. Determine the area of contact of each side of the plate.

$$\frac{F}{A} = \mu \frac{\Delta V}{\Delta y}\ ; F = 2\ \text{lbf};\ \mu = 1.11\ \text{x}\ 10^{-5}\ \text{lbf·s/ft}^2\ ;\ \Delta V = 12\ \text{in./s} = 1\ \text{ft/s}$$

$$\Delta y = (0.05/12)\ \text{ft};\ 2A = \frac{F\Delta y}{\mu \Delta V} = \frac{2(0.05/12)}{1.11\ \text{x}\ 10^{-5}\ (1)} = 750\ \text{ft}^2$$

$$\boxed{A = 375\ \text{ft}^2}$$

1.24 In Figure P1.24, the total space between stationary boundaries is 1 cm. Ethylene glycol is placed on the left side and propylene glycol on the right. When the infinite plate that separates the liquids is pulled upward, it finds an equilibrium position. Determine the lateral location of the plate if it has a thickness of 1 mm.
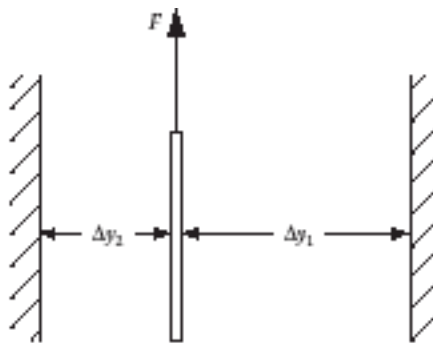

FIGURE P1.24

τ is the same on both sides. Given $\Delta y_1 + \Delta y_2 = 1 - 0.1$ or
$\Delta y_1 + \Delta y_2 = 0.9\ \text{cm} = 0.009\ \text{m}$

$$\tau = \mu_1 \frac{\Delta V}{\Delta y_1} = \mu_2 \frac{\Delta V}{\Delta y_2}\quad \text{so}\quad \frac{\mu_1}{\Delta y_1} = \frac{\mu_2}{\Delta y_2}\quad \text{From Table A-5, we get}$$

$$\frac{\mu_1}{\mu_2} = \frac{16.2}{42} = \frac{\Delta y_1}{\Delta y_2}\quad \text{or}\quad \frac{0.009\ \text{m} - \Delta y_2}{\Delta y_2} = 0.386\quad 1.386\Delta y_2 = 0.009$$

1-8

Solving,

$\boxed{\Delta y_2 = 0.006\ 5\ m = 0.65\ cm}$ $\Delta y_1 = 0.9 - 0.65$ or

$\boxed{\Delta y_1 = 0.35\ cm}$

1.25   A Saybolt viscometer is used in the petroleum industry to measure viscosity of lubricating oils. The test oil is placed in a cup surrounded by a constant temperature bath. At time zero (a stopwatch is started), test oil is allowed to flow out of the bottom of the cup, through an orifice. The oil leaves in the form of a stream and is collected in a calibrated beaker. When 60 ml of oil flows through the orifice, the elapsed time is recorded. The time required for 60 ml of oil to flow through the orifice is thus experimentally determined. The viscosity of the oil is expressed in terms of the elapsed time; e.g., one would say that the oil has "a viscosity of 100 Saybolt Universal Seconds." This is abbreviated as "100 SUS." The equation to convert SUS to units of m^2/s is given by

$$\nu\ (m^2/s) = 0.224 \times 10^{-6}\ (SUS) - \frac{185 \times 10^{-6}}{SUS}$$

Graph this equation as ν on the vertical axis vs SUS. Allow SUS to vary from 30 to 120 SUS in increments of 10 SUS. (The equation is valid over only this range.)
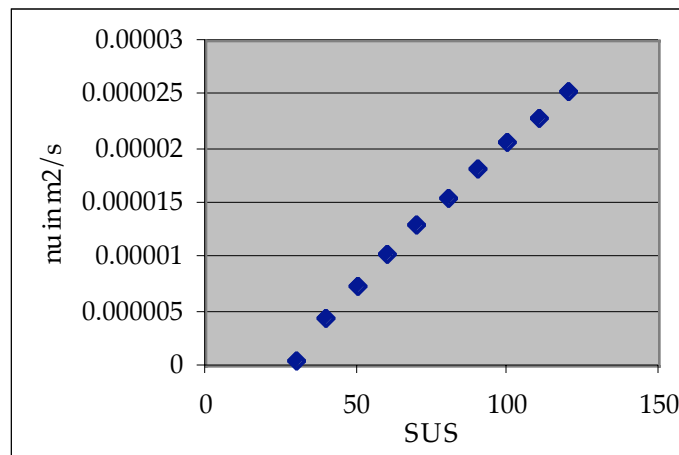
1.26   Figure P1.24 illustrates an infinite plate being pulled upward in a space filled with ethyl alcohol on the right and an unknown fluid on the left. The plate is not equidistant from the boundaries; in fact, $\Delta y_1 = 2\Delta y_2$. Determine the viscosity of the unknown fluid.

The shear applied to both fluids is the same. Thus on the left,

$\tau = \mu_1 \dfrac{\Delta V}{\Delta y_1}$ and on the right, $\tau = \mu_2 \dfrac{\Delta V}{\Delta y_2}$; so $\dfrac{\mu_1}{\Delta y_1} = \dfrac{\mu_2}{\Delta y_2}$
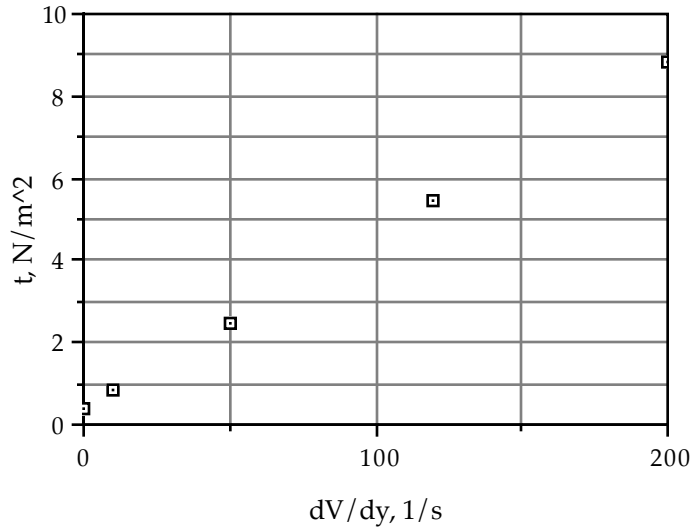
From Table A-5, $\mu_1 = 1.095 \times 10^{-3}\ N\cdot s/m^2$

Also, $\Delta y_1 = 2\Delta y_2$; With $\mu_2 = \mu_1 \dfrac{\Delta y_2}{\Delta y_1} = 1.095 \times 10^{-3} \cdot (1/2)$ or

$\boxed{\mu_2 = 0.548 \times 10^{-3}\ N\cdot s/m^2}$

1.27   What type of fluid is described by the following shear stress-strain rate data?

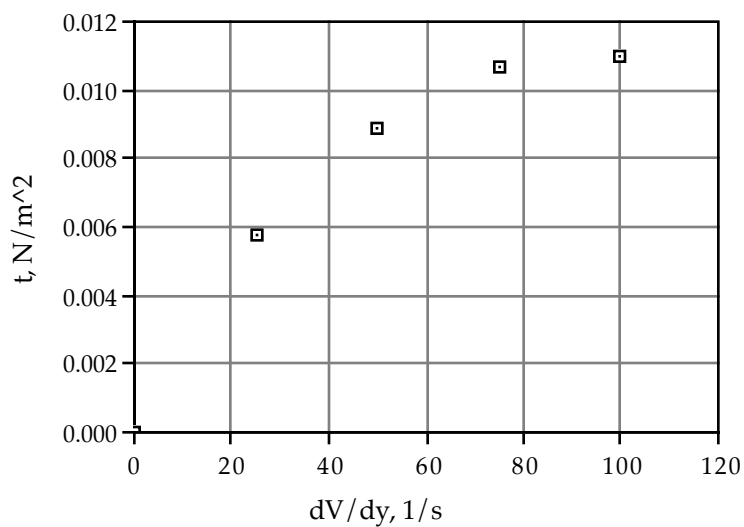| τ (N/m^2)	0.4	0.82	2.50	5.44	8.80
dV/dy (rad/s)	0	10	50	120	200

Bingham Plastic

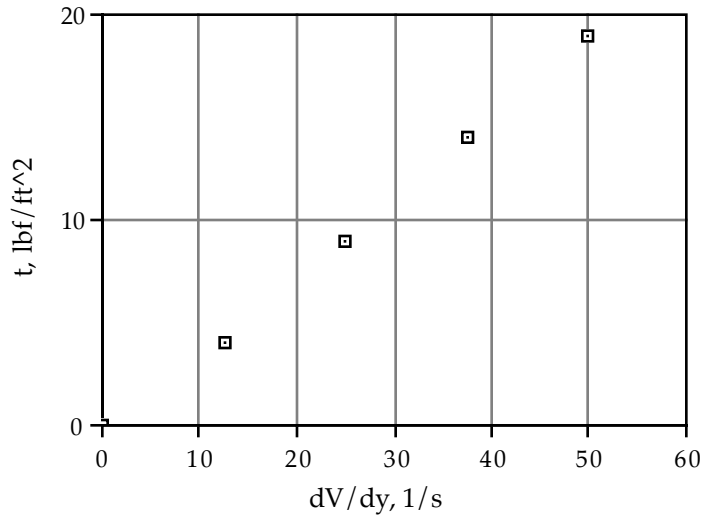1.28   What type of fluid is described by the following shear stress-strain rate data?

τ (N/m^2)	0	0.005 8	0.008 9	0.010 7	0.011
dV/dy (rad/s)	0	25	50	75	100

Pseudoplastic

1-10

1.29 What type of fluid is has the following shear stress-strain rate relationship?

τ (lbf/ft^2)	0	4	9	14	19
dV/dy (rad/s)	0	12.5	25.0	37.5	50.0

Newtonian   (close enough)

1.30 Actual tests on vaseline yielded the following data:

τ (N/m^2)	0	200	600	1 000
dV/dy (1/s)	0	500	1 000	1 200

Graph the data and determine the fluid type.

Dilatant

1-11
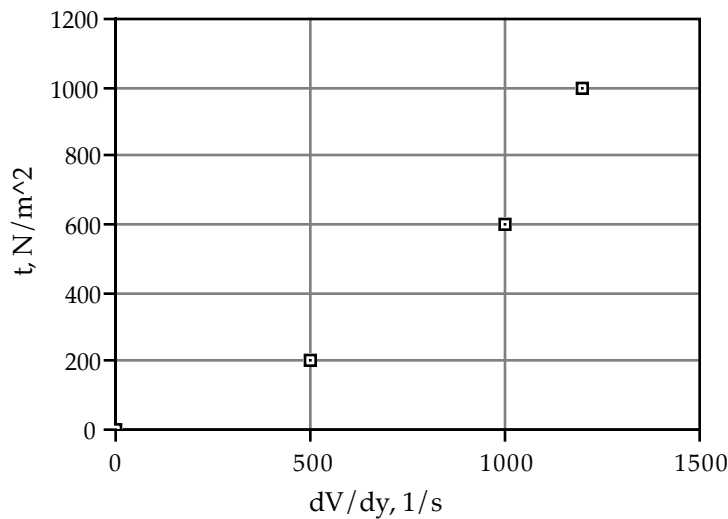
1.31   Consider the act of spreading soft butter on bread with a knife. In essence, we have a stationary surface (the bread), a moving surface (the knife), and a newtonian fluid occupying the space in between. The part of the knife in contact with the butter has dimension of 9 cm x 1.6 cm. The knife is moved across the bread at a rate of 5 cm/s. The average thickness of the butter during the process is about 2 mm (a rough approximation). (a) Calculate the shear stress exerted on the butter if the force required to move the knife is 0.07 N. (b) Calculate the strain rate. (c) Calculate the absolute viscosity of the butter.

$A = 0.09 \cdot 0.016 = 0.001\,4 \text{ m}^2$; $V = 5 \text{ cm/s} = 0.05 \text{ m/s}$

$\Delta y = 2 \text{ mm} = 0.002 \text{ m}$

a) $\tau = \dfrac{F}{A} = \dfrac{0.07}{0.001\,4} = \boxed{48.6 \text{ N/m}^2}$

b) $\dfrac{dV}{dy} = \dfrac{\Delta V}{\Delta y} = \dfrac{0.05}{0.002} = \boxed{25/\text{s}}$

c) $\mu = \dfrac{\tau}{dV/dy} = \dfrac{48.6}{25} = \boxed{1.94 \text{ N·s/m}^2}$

1.32   Figure P1.32 shows a shaft 4 in. in diameter moving through a well oiled sleeve that is 12 in. long. The force required to move the shaft is 25 lbf, and the shaft velocity is 5 in./s. The oil filled clearance between the shaft and sleeve is 0.005 in. Calculate the viscosity of the lubricating oil (a Newtonian fluid).
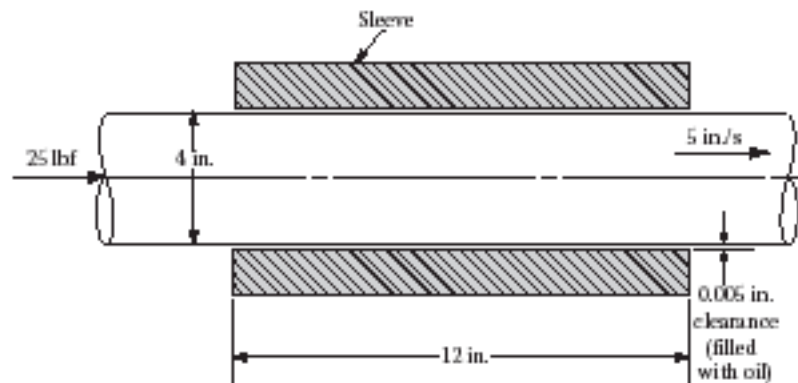

FIGURE P1.32

Assume oil is Newtonian so $\tau = \mu \dfrac{dV}{dy}$; sleeve is stationary, shaft velocity is

$V = 5 \text{ in./s} = 0.417 \text{ ft/s}; \tau = \dfrac{F}{A}$; A = area of contact. Surface area of shaft

does not equal surface of sleeve, so take an average. For shaft,

$A = \pi DL = \pi(4/12)(12/12) = 1.047 \text{ ft}^2$; for the sleeve,

$A = \pi(4.01/12)(12/12) = 1.05 \text{ ft}^2$; use $A = \dfrac{1.05 + 1.047}{2} = 1.048 \text{ ft}^2$

$\tau = \dfrac{25}{1.048} = 23.8 \text{ lbf/ft}^2$; $\dfrac{dV}{dy} = \dfrac{\Delta V}{\Delta y} = \dfrac{5/12 - 0}{0.005/12} = 1000$

$\mu = \dfrac{\tau}{dV/dy} = \dfrac{23.8}{1000}$ or $\boxed{\mu = 23.8 \text{ x } 10^{-3} \text{ lbf·s/ft}^2}$

1.33   Mayonnaise is tested in the laboratory to obtain its rheological diagram. Two data points are:
1. $\tau = 4.63 \times 10^{-2}$ lbf/ft^2 dV/dy = 25 rad/s
2. $\tau = 6.52 \times 10^{-2}$ lbf/ft^2 dV/dy = 50 rad/s

Determine the consistency index and the flow behavior index. Calculate the strain rate if the shear stress is increased to 7×10^{-2} lbf/ft^2.

Mayo pseudoplastic $\tau = K\left(\dfrac{dV}{dy}\right)^n$; substituting,

$4.63 \times 10^{-2} = K(25)^n$ and $6.52 \times 10^{-2} = K(50)^n$; dividing gives

$\dfrac{4.63}{6.52} = \left(\dfrac{25}{50}\right)^n$; which becomes $0.71 = (0.5)^n$; $\ln(0.71) = n\ln(0.5)$;

$\boxed{n = 0.494}$

$4.63 \times 10^{-2} = K(25)^{0.494}$; $K = \dfrac{4.63 \times 10^{-2}}{4.91}$

$\boxed{K = 9.44 \times 10^{-3}}$

Check with second equation: $9.44 \times 10^{-3} (50)^{0.494} = 6.52 \times 10^{-2}$ which is OK.
$\tau = 9.44 \times 10^{-3} (dV/dy)^{0.494}$; when $\tau = 7 \times 10^{-2}$,

$7 \times 10^{-2} = 9.44 \times 10^{-3} \left(\dfrac{dV}{dy}\right)^{0.494}$; $\dfrac{dV}{dy} = (7.42)^{1/0.494}$ or

$\boxed{\dfrac{dV}{dy} = 57.7 \text{ rad/s}}$

1.34   Two data points on a rheological diagram of a certain grease are:
1. dV/dy = 20 rad/s $\tau = 8.72 \times 10^{-3}$ N/m^2
2. dV/dy = 40 rad/s $\tau = 2.10 \times 10^{-3}$ N/m^2

Determine the consistency index and the flow behavior index. Calculate the strain rate if the shear stress is increased to 3×10^{-2} N/m^2.

$\tau = K\left(\dfrac{dV}{dy}\right)^n$; $8.72 \times 10^{-3} = K(20)^n$ and $2.10 \times 10^{-2} = K(40)^n$; dividing,

$\dfrac{8.72 \times 10^{-3}}{2.10 \times 10^{-2}} = \left(\dfrac{20}{40}\right)^n$; $0.415 = (0.5)^n$; $\ln(0.415) = n\ln(0.5)$

$\boxed{n = 1.27}$

$8.27 \times 10^{-3} = K(20)^{1.27}$; $\boxed{K = 1.95 \times 10^{-4}}$

Check $1.95 \times 10^{-4} (40)^{1.27} = 2.1 \times 10^{-2}$ OK
$\tau = 1.95 \times 10^{-4} \left(\dfrac{dV}{dy}\right)^{1.27}$; $\tau = 3 \times 10^{-2}$

1-13

$$\frac{dV}{dy} = \left(\frac{3 \times 10^{-2}}{1.95 \times 10^{-4}}\right)^{1/1.27}$$

$$\boxed{\frac{dV}{dy} = 53.1 \text{ rad/s}}$$

1.35 A highly viscous slow-drying paint has a viscosity μ_0 of 0.04 lbf·s/ft². At a shear stress of 2.7 lbf/ft², the strain rate is 70 rad/s. Calculate its initial yield stress.

$$\mu_o = 0.04 \text{ lbf·s/ft}^2 ; \quad \tau = 2.7 \text{ lbf/ft}^2 ; \qquad \frac{dV}{dy} = 70 \text{ rad/s}$$

$$\tau = \tau_o + \mu_o \frac{dV}{dy} ; \qquad 2.7 = \tau_o + 0.04(70); \tau_o = 2.7 - 0.04(70)$$
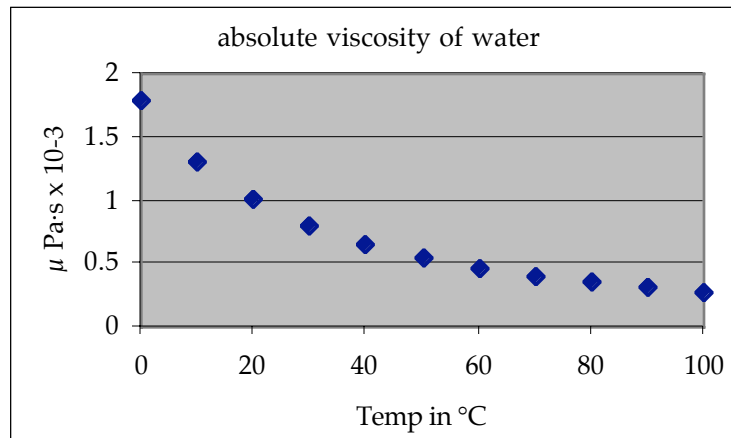
$$\boxed{\tau_o = 0.1 \text{ lbf/ft}^2}$$

1.36 A fluid with a viscosity of 8 centipoise has a density of 59 lbm/ft³. What is its kinematic viscosity in the CGS system?

$$\mu = 8 \text{ cp} \cdot 1 \times 10^{-3} = 8 \times 10^{-3} \text{ N·s/m}^2 ; \rho = 59 \text{ lbm/ft}^3 \cdot 16.01 = 945 \text{ kg/m}^3$$
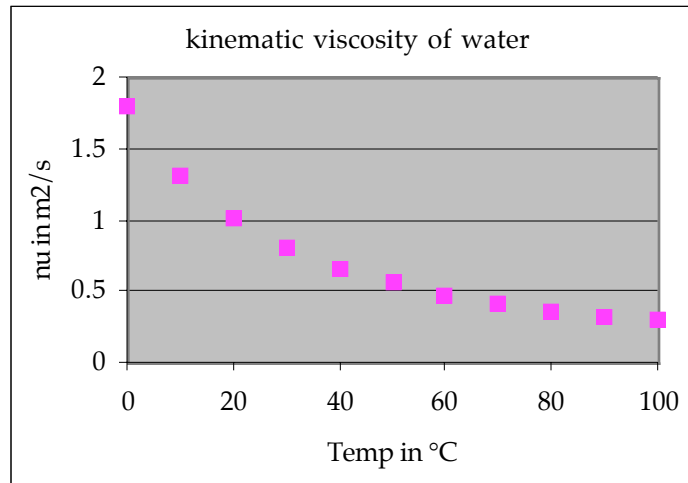
$$\nu = \frac{\mu}{\rho} = \frac{8 \times 10^{-3}}{945} = 8.47 \times 10^{-6} \text{ m}^2/\text{s} \cdot (100^2 \text{ cm}^2/\text{m}^2)$$

$$\boxed{\nu = 8.47 \times 10^{-2} \text{ cm}^2/\text{s}}$$

1.37 Graph the absolute viscosity of water as a function of temperature.

1.38 Graph the kinematic viscosity of water as a function of temperature.

1.39 Calculate the pressure inside a 2 mm diameter drop of acetone exposed to atmospheric pressure (101.3 kN/m^2).

$p_i - p_o = \dfrac{2\sigma}{R}$; $p_o = 101\ 300\ \text{N/m}^2$; $R = 0.001$ m; $\sigma = 23.1 \times 10^{-3}$ N/m, so

$p_i = 101\ 300 + \dfrac{2(23.1 \times 10^{-3})}{0.001} = \boxed{101\ 346\ \text{N/m}^2}$

1.40 Determine the pressure inside a water droplet of diameter 500 μm in a partially evacuated chamber where p = 70 kN/m^2.

$p_i - p_o = \dfrac{2\sigma}{R}$; $p_o = 70\ 000\ \text{N/m}^2$; $R = 250 \times 10^{-6}$ m; $\sigma = 72 \times 10^{-3}$ N/m, so

$p_i = 70\ 000 + \dfrac{2(72 \times 10^{-3})}{250 \times 10^{-6}} = \boxed{70\ 576\ \text{N/m}^2}$

1.41 Calculate the pressure inside a 1/16 in. diameter drop of chloroform in contact with air at a pressure of 14.7 lbf/in^2.

$p_i - p_o = \dfrac{2\sigma}{R}$; D = 1/16 in. = 0.0052 ft; R = 0.0026 ft

$p_o = 14.7(144) = 2117\ \text{lbf/ft}^2$; $\sigma = 27.14 \times 10^{-3}$ N/m (Table A-5); converting,

$\sigma = \dfrac{27.14 \times 10^{-3}}{4.448}(0.3048) = 1.86 \times 10^{-3}\ \text{lbf/ft}$ so

$p_i = 2117 + \dfrac{2(1.86 \times 10^{-3})}{0.0026}$ or $\boxed{p_i = 2118\ \text{lbf/ft}^2}$

1.42 A drop of benzene is 1 mm in diameter and is in contact with air at a pressure of 100 kN/m^2. (a) Calculate its internal pressure. (b) If the pressure difference (inside minus outside) for the benzene droplet is the same as that for a mercury droplet, what is the diameter of the mercury droplet?