

## Chapter 1 – Problem Solutions

### 1.2.1

$E_1$  = energy released in lowering steam temperature to 100°C from 110°C

$$E_1 = (500 \text{ L})(1000 \text{ g/L})(10^\circ\text{C})(0.432 \text{ cal/g}\cdot^\circ\text{C})$$

$$E_1 = 2.16 \times 10^6 \text{ cal}$$

$E_2$  = energy released when the steam liquefies

$$E_2 = (500 \text{ L})(1000 \text{ g/L})(597 \text{ cal/g})$$

$$E_2 = 2.99 \times 10^8 \text{ cal}$$

$E_3$  = energy released when the water temperature is lowered from 100°C to 50°C

$$E_3 = (500 \text{ L})(1000 \text{ g/L})(50^\circ\text{C})(1 \text{ cal/g}\cdot^\circ\text{C})$$

$$E_3 = 2.50 \times 10^7 \text{ cal};$$

Thus, the total energy released is:

$$E_{\text{total}} = E_1 + E_2 + E_3 = \mathbf{3.26 \times 10^8 \text{ cal}}$$


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### 1.2.2

First, convert kPa pressure into atmospheres:

$$84.6 \text{ kPa}(1 \text{ atm}/101.4 \text{ kPa}) = 0.834 \text{ atm}$$

From Table 1.1, the boiling temperature is 95°C

$E_1$  = energy required to bring the water temperature to 95°C from 15°C

$$E_1 = (900 \text{ g})(95^\circ\text{C} - 15^\circ\text{C})(1 \text{ cal/g}\cdot^\circ\text{C})$$

$$E_1 = 7.20 \times 10^4 \text{ cal}$$

$E_2$  = energy required to vaporize the water

$$E_2 = (900 \text{ g})(597 \text{ cal/g})$$

$$E_2 = 5.37 \times 10^5 \text{ cal}$$

$$E_{\text{total}} = E_1 + E_2 = \mathbf{6.09 \times 10^5 \text{ cal}}$$

### 1.2.3

$E_1$  = energy needed to vaporize the water

$$E_1 = (300 \text{ L})(1000 \text{ g/L})(597 \text{ cal/g})$$

$$E_1 = 1.79 \times 10^8 \text{ cal}$$

The energy remaining ( $E_2$ ) is:

$$E_2 = E_{\text{Total}} - E_1$$

$$E_2 = 2.00 \times 10^8 \text{ cal} - 1.79 \times 10^8 \text{ cal}$$

$$E_2 = 2.10 \times 10^7 \text{ cal}$$

The temperature change possible with the remaining energy is:

$$2.10 \times 10^7 \text{ cal} = (300 \text{ L})(1000 \text{ g/L})(1 \text{ cal/g}\cdot^\circ\text{C})(\Delta T)$$

$$\Delta T = 70^\circ\text{C}, \text{ making the temperature}$$

$$T = 90^\circ\text{C} \text{ when it evaporates.}$$

Therefore, based on Table 1.1,

$$\therefore \mathbf{P = 0.692 \text{ atm}}$$


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### 1.2.4

$E_1$  = energy required to warm and then melt the ice

$$E_1 = (10 \text{ g})(6^\circ\text{C})(0.465 \text{ cal/g}\cdot^\circ\text{C}) + 10\text{g}(79.7 \text{ cal/g})$$

$$E_1 = 825 \text{ cal. This energy is taken from the water.}$$

The resulting temperature of the water will decrease to:

$$825 \text{ cal} = (0.165 \text{ L})(1000 \text{ g/L})(20^\circ\text{C} - T_1)(1 \text{ cal/g}\cdot^\circ\text{C})$$

$T_1 = 15.0^\circ\text{C}$ . Now we have a mixture of water at 0°C (formerly ice) and the original 165 liters that is now at 15.0°C. The temperature will come to equilibrium at:

$$[(0.165 \text{ L})(1000 \text{ g/L})(15.0^\circ\text{C} - T_2)(1 \text{ cal/g}\cdot^\circ\text{C})] =$$

$$[(10 \text{ g})(T_2 - 0^\circ\text{C})(1 \text{ cal/g}\cdot^\circ\text{C})]; \quad \mathbf{T_2 = 14.1^\circ\text{C}}$$

### 1.2.5

$E_1$  = energy required to melt ice

$$E_1 = (5 \text{ slugs})(32.2 \text{ lbm/slug})(32^\circ\text{F} - 20^\circ\text{F}) * \\ (0.46 \text{ BTU/lbm}\cdot^\circ\text{F}) + (5 \text{ slugs})(32.2 \text{ lbm/slug}) * \\ (144 \text{ BTU/lbm})$$

$E_1 = 2.41 \times 10^4 \text{ BTU}$ . → Energy taken from the water.

The resulting temperature of the water will decrease to:

$$2.41 \times 10^4 \text{ BTU} = (10 \text{ slugs})(32.2 \text{ lbm/slug})(120^\circ\text{F} - \\ T_1)(1 \text{ BTU/lbm}\cdot^\circ\text{F})$$

$$T_1 = 45.2^\circ\text{F}$$

The energy lost by the water (to lower its temp. to  $45.2^\circ\text{F}$ ) is that required to melt the ice. Now you have 5 slugs of water at  $32^\circ\text{F}$  and 10 slugs at  $45.2^\circ\text{F}$ .

Therefore, the final temperature of the water is:

$$[(10 \text{ slugs})(32.2 \text{ lbm/slug})(45.2^\circ\text{F} - T_2)(1 \text{ BTU/lbm}\cdot^\circ\text{F})] \\ = [(5 \text{ slugs})(32.2 \text{ lbm/slug})(T_2 - 32^\circ\text{F})(1 \text{ BTU/lbm}\cdot^\circ\text{F})]$$

$$T_2 = \mathbf{40.8^\circ\text{F}}$$


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### 1.2.6

$E_1$  = energy required to raise the temperature to  $100^\circ\text{C}$

$$E_1 = (7500 \text{ g})(100^\circ\text{C} - 20^\circ\text{C})(1 \text{ cal/g}\cdot^\circ\text{C})$$

$$E_2 = 6.00 \times 10^5 \text{ cal}$$

$E_2$  = energy required to vaporize 2.5 kg of water

$$E_2 = (2500 \text{ g})(597 \text{ cal/g})$$

$$E_2 = 1.49 \times 10^6 \text{ cal}$$

$$E_{\text{total}} = E_1 + E_2 = 2.09 \times 10^6 \text{ cal}$$

$$\text{Time required} = (2.09 \times 10^6 \text{ cal}) / (500 \text{ cal/s})$$

$$\text{Time required} = \mathbf{4180 \text{ sec} = 69.7 \text{ min}}$$

### 1.3.1

$F = m \cdot a$ ; Letting  $a = g$  yields:  $W = m \cdot g$ , (Eq'n 1.1)

Then dividing both sides of the equation by volume,

$$W/\text{Vol} = (m/\text{Vol}) \cdot g; \quad \gamma = \rho \cdot g$$


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### 1.3.2

$SG_{\text{oil}} = 0.976 = \gamma_{\text{oil}}/\gamma$ ; where  $\gamma$  is for water at  $4^\circ\text{C}$ :

$\gamma = 9,810 \text{ N/m}^3$  (Table 1.2). Substituting yields,

$$0.977 = \gamma_{\text{oil}}/9,810; \quad \gamma_{\text{oil}} = (9810)(0.976) = \mathbf{9,570 \text{ N/m}^3}$$

Also,  $\gamma = \rho \cdot g$ ; or  $\rho = \gamma_{\text{oil}}/g$

Substituting (noting that  $\text{N} \equiv \text{kg}\cdot\text{m}/\text{sec}^2$ ) yields,

$$\rho_{\text{oil}} = \gamma_{\text{oil}}/g = (9,570 \text{ N/m}^3) / (9.81 \text{ m/sec}^2) = \mathbf{976 \text{ kg/m}^3}$$


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### 1.3.3

By definition,  $\gamma = W/\text{Vol} = 55.5 \text{ lb/ft}^3$ ; thus,

$$W = \gamma \cdot \text{Vol} = (55.5 \text{ lb/ft}^3)(20 \text{ ft}^3) = \mathbf{1,110 \text{ lb} (4,940 \text{ N})}$$

$$\rho = \gamma/g = (55.5 \text{ lb/ft}^3)/(32.2 \text{ ft/s}^2) = \mathbf{1.72 \text{ slug/ft}^3 (887 \text{ kg/m}^3)}$$

$$SG = \gamma_{\text{liquid}}/\gamma_{\text{water at } 4^\circ\text{C}} = (55.5 \text{ lb/ft}^3)/(62.4 \text{ lb/ft}^3) = \mathbf{0.889}$$


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### 1.3.4

The mass of liquid can be found using

$\rho = \gamma/g$  and  $\gamma = \text{weight}/\text{volume}$ , thus

$$\gamma = (47000 \text{ N} - 1500 \text{ N}) / (5 \text{ m}^3) = 9.10 \times 10^3 \text{ N/m}^3$$

$$\rho = \gamma/g = (9.1 \times 10^3 \text{ N/m}^3) / (9.81 \text{ m/sec}^2);$$

$$\rho = \mathbf{928 \text{ kg/m}^3} \quad (\text{Note: } 1 \text{ N} \equiv 1 \text{ kg}\cdot\text{m}/\text{sec}^2)$$

Specific gravity (SG) =  $\gamma/\gamma_{\text{water at } 4^\circ\text{C}}$

$$SG = (9.10 \times 10^3 \text{ N/m}^3) / 9.81 \times 10^3 \text{ N/m}^3$$

$$SG = \mathbf{0.928}$$

### 1.3.5

The force exerted on the tank bottom is equal to the weight of the water body (Eq'n 1.2).

$$F = W = mg = [\rho(\text{Vol})] (g); \rho \text{ found in Table 1.2}$$

$$920 \text{ lbs} = [1.94 \text{ slugs/ft}^3 (\pi \cdot (1.25 \text{ ft})^2 \cdot d)] (32.2 \text{ ft/sec}^2)$$

$$\mathbf{d = 3.00 \text{ ft}} \quad (\text{Note: } 1 \text{ slug} = 1 \text{ lb}\cdot\text{sec}^2/\text{ft})$$


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### 1.3.6

Weight of water on earth = 8.83 kN

$$\text{From E'qn (1.1): } m = W/g = (8,830 \text{ N})/(9.81 \text{ m/s}^2)$$

$$\mathbf{m = 900 \text{ kg}}$$

Note: mass on moon is the same as mass on earth

$$W (\text{moon}) = mg = (900 \text{ kg})[(9.81 \text{ m/s}^2)/(6)]$$

$$\mathbf{W(\text{moon}) = 1,470 \text{ N}}$$


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### 1.3.7

Density is expressed as  $\rho = m/\text{Vol}$ , and even though volume changes with temperature, mass does not.

Thus,  $(\rho_1)(\text{Vol}_1) = (\rho_2)(\text{Vol}_2) = \text{constant}$ ; or

$$\text{Vol}_2 = (\rho_1)(\text{Vol}_1)/(\rho_2)$$

$$\text{Vol}_2 = (999 \text{ kg/m}^3)(100 \text{ m}^3)/(996 \text{ kg/m}^3)$$

$$\mathbf{\text{Vol}_2 = 100.3 \text{ m}^3} \quad (\text{or a } \mathbf{0.3\%} \text{ change in volume})$$


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### 1.3.8

$$(1 \text{ N}\cdot\text{m})[(3.281 \text{ ft})/(1 \text{ m})][(0.2248 \text{ lb})/(1 \text{ N})]$$

$$\mathbf{= 7.376 \times 10^{-1} \text{ ft}\cdot\text{lb}}$$


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### 1.3.9

$$(1 \text{ N/m}^2) [(1 \text{ m})/(3.281 \text{ ft})]^2 [(1 \text{ ft})/(12 \text{ in})]^2 \cdot$$

$$[(1 \text{ lb})/(4.448 \text{ N})] = \mathbf{1.450 \times 10^{-4} \text{ psi}}$$

### 1.4.1

(a) Note that: 1 poise = 0.1 N·sec/m<sup>2</sup>. Therefore,  
 $1 \text{ lb}\cdot\text{sec/ft}^2 [(1 \text{ N})/(0.2248 \text{ lb})] \cdot [(3.281 \text{ ft})^2/(1 \text{ m}^2)] =$   
 $47.9 \text{ N}\cdot\text{sec/m}^2 [(1 \text{ poise})/(0.1 \text{ N}\cdot\text{sec/m}^2)] = 478.9 \text{ poise}$

Conversion:  $\mathbf{1 \text{ lb}\cdot\text{sec/ft}^2 = 478.9 \text{ poise}}$

(b) Note that: 1 stoke = 1 cm<sup>2</sup>/sec. Therefore,  
 $1 \text{ ft}^2/\text{sec} [(12 \text{ in})^2/(1 \text{ ft})^2] \cdot [(1 \text{ cm})^2/(0.3937 \text{ in})^2] =$   
 $929.0 \text{ cm}^2/\text{sec} [(1 \text{ stoke})/(1 \text{ cm}^2/\text{sec})] = 929.0 \text{ stokes}$

Conversion:  $\mathbf{1 \text{ ft}^2/\text{sec} = 929.0 \text{ stokes}}$

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### 1.4.2

$$[\mu(\text{air})/\mu(\text{H}_2\text{O})]_{0^\circ\text{C}} = (1.717 \times 10^{-5})/(1.781 \times 10^{-3})$$

$$[\mu(\text{air})/\mu(\text{H}_2\text{O})]_{0^\circ\text{C}} = \mathbf{9.641 \times 10^{-3}}$$

$$[\mu(\text{air})/\mu(\text{H}_2\text{O})]_{100^\circ\text{C}} = (2.174 \times 10^{-5})/(0.282 \times 10^{-3})$$

$$[\mu(\text{air})/\mu(\text{H}_2\text{O})]_{100^\circ\text{C}} = \mathbf{7.709 \times 10^{-2}}$$

$$[\nu(\text{air})/\nu(\text{H}_2\text{O})]_{0^\circ\text{C}} = (1.329 \times 10^{-5})/(1.785 \times 10^{-6})$$

$$[\nu(\text{air})/\nu(\text{H}_2\text{O})]_{0^\circ\text{C}} = \mathbf{7.445}$$

$$[\nu(\text{air})/\nu(\text{H}_2\text{O})]_{100^\circ\text{C}} = (2.302 \times 10^{-5})/(0.294 \times 10^{-6})$$

$$[\nu(\text{air})/\nu(\text{H}_2\text{O})]_{100^\circ\text{C}} = \mathbf{78.30}$$

Note: The ratio of the viscosity of air to water increases with temperature. Why? Because the viscosity of air increases with temperature and that of water decreases with temperature magnifying the effect. Also, the values of kinematic viscosity ( $\nu$ ) for air and water are much closer than those of absolute viscosity. Why?

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### 1.4.3

$$\mu_{20^\circ\text{C}} = 1.002 \times 10^{-3} \text{ N}\cdot\text{sec/m}^2; \nu_{20^\circ\text{C}} = 1.003 \times 10^{-6} \text{ m}^2/\text{s}$$

$$(1.002 \times 10^{-3} \text{ N}\cdot\text{sec/m}^2) \cdot [(0.2248 \text{ lb})/(1 \text{ N})] \cdot$$

$$[(1 \text{ m})^2/(3.281 \text{ ft})^2] = \mathbf{2.092 \times 10^{-5} \text{ lb}\cdot\text{sec/ft}^2}$$

$$(1.003 \times 10^{-6} \text{ m}^2/\text{s})[(3.281 \text{ ft})^2/(1 \text{ m}^2)] = \mathbf{1.080 \times 10^{-5} \text{ ft}^2/\text{s}}$$

#### 1.4.4

Using Newton's law of viscosity (Eq'n 1.2):

$$\tau = \mu(dv/dy) = \mu(\Delta v/\Delta y)$$

$$\tau = (1.00 \times 10^{-3} \text{ N}\cdot\text{sec}/\text{m}^2)[\{(4.8 - 2.4)\text{m}/\text{sec}\}/(0.02 \text{ m})]$$

$$\tau = \mathbf{0.12 \text{ N}/\text{m}^2}$$

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#### 1.4.5

From Eq'n (1.2):  $\tau = \mu(\Delta v/\Delta y) =$

$$\tau = (0.0065 \text{ lb}\cdot\text{sec}/\text{ft}^2)[(1.5 \text{ ft}/\text{s})/(0.25/12 \text{ ft})]$$

$$\tau = 0.468 \text{ lb}/\text{ft}^2$$

$$F = (\tau)(A) = (2 \text{ sides})(0.468 \text{ lb}/\text{ft}^2)[(0.5 \text{ ft})(1.5 \text{ ft})]$$

$$\mathbf{F = 0.702 \text{ lb}}$$

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#### 1.4.6

Summing forces parallel to the incline yields:

$$T_{\text{shear force}} = W(\sin 15^\circ) = \tau \cdot A = \mu(\Delta v/\Delta y)A$$

$$\Delta y = [(\mu)(\Delta v)(A)] / [(W)(\sin 15^\circ)]$$

$$\Delta y = [(1.52 \text{ N}\cdot\text{sec}/\text{m}^2)(0.025 \text{ m}/\text{sec})(0.80\text{m})(0.90\text{m})] / [(100 \text{ N})(\sin 15^\circ)]$$

$$\mathbf{\Delta y = 1.06 \times 10^{-3} \text{ m} = 1.06 \text{ mm}}$$

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#### 1.4.7

Using Newton's law of viscosity (Eq'n 1.2):

$$\tau = \mu(dv/dy) = \mu(\Delta v/\Delta y)$$

$$\tau = (0.04 \text{ N}\cdot\text{sec}/\text{m}^2)[(15 \text{ cm}/\text{s})/[(25.015 - 25)\text{cm}/2]]$$

$$\tau = 80 \text{ N}/\text{m}^2$$

$$F_{\text{shear resistance}} = \tau \cdot A = (80 \text{ N}/\text{m}^2)[(\pi)(0.25 \text{ m})(3 \text{ m})]$$

$$\mathbf{F_{\text{shear resistance}} = 188 \text{ N}}$$

#### 1.4.8

$v = y^2 - 3y$ , where  $y$  is in inches and  $v$  is in ft/s

$v = 144y^2 - 36y$ , where  $y$  is in ft and  $v$  is in ft/s

Taking the first derivative:  $dv/dy = 288y - 36 \text{ sec}^{-1}$

$$\tau = \mu(dv/dy) = (8.35 \times 10^{-3} \text{ lb}\cdot\text{sec}/\text{ft}^2)(288y - 36 \text{ sec}^{-1})$$

Solutions:  $y = 0 \text{ ft}$ ,  $\tau = \mathbf{-0.301 \text{ lb}/\text{ft}^2}$

$y = 1/12 \text{ ft}$ ,  $\tau = \mathbf{-0.100 \text{ lb}/\text{ft}^2}$ ;  $y = 1/6 \text{ ft}$ ,  $\tau = \mathbf{0.100 \text{ lb}/\text{ft}^2}$

$y = 1/4 \text{ ft}$ ,  $\tau = \mathbf{0.301 \text{ lb}/\text{ft}^2}$ ;  $y = 1/3 \text{ ft}$ ,  $\tau = \mathbf{0.501 \text{ lb}/\text{ft}^2}$

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#### 1.4.9

$$\mu = (16)(1.00 \times 10^{-3} \text{ N}\cdot\text{sec}/\text{m}^2) = 1.60 \times 10^{-2} \text{ N}\cdot\text{sec}/\text{m}^2$$

$$\text{Torque} = \int_0^R (r) dF = \int_0^R r \cdot \tau \cdot dA = \int_0^R (r)(\mu) \left( \frac{\Delta v}{\Delta y} \right) dA$$

$$\text{Torque} = \int_0^R (r)(\mu) \left( \frac{(\omega)(r) - 0}{\Delta y} \right) (2\pi r) dr$$

$$\text{Torque} = \frac{(2\pi)(\mu)(\omega)}{\Delta y} \int_0^R (r^3) dr$$

$$\text{Torque} = \frac{(2\pi)(1.60 \cdot 10^{-2} \text{ N}\cdot\text{sec}/\text{m}^2)(0.65 \text{ rad}/\text{sec}) \left[ \frac{(1\text{m})^4}{4} \right]}{0.0005\text{m}}$$

$$\mathbf{\text{Torque} = 32.7 \text{ N}\cdot\text{m}}$$

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#### 1.4.10

$$\mu = \tau/(dv/dy) = (F/A)/(\Delta v/\Delta y);$$

Torque (T) = Force · distance = F · R where R = radius

Thus;  $\mu = (T/R)/[(A)(\Delta v/\Delta y)]$

$$\mu = \frac{T/R}{(2\pi)(R)(h)(\omega \cdot R/\Delta y)} = \frac{T \cdot \Delta y}{(2\pi)(R^3)(h)(\omega)}$$

$$\mu = \frac{(1.10 \text{ lb} \cdot \text{ft})[(0.008/12) \text{ ft}]}{(2\pi)((1/12) \text{ ft})^3((1.6/12) \text{ ft})(2000 \text{ rpm}) \left( \frac{2\pi \text{ rad}/\text{sec}}{60 \text{ rpm}} \right)}$$

$$\mathbf{\mu = 7.22 \times 10^{-3} \text{ lb}\cdot\text{sec}/\text{ft}^2}$$

### 1.5.1

The concept of a line force is logical for two reasons:

- 1) The surface tension acts along the perimeter of the tube pulling the column of water upwards due to adhesion between the water and the tube.
- 2) The surface tension is multiplied by the tube perimeter, a length, to obtain the upward force used in the force balance developed in Equation 1.3 for capillary rise.

### 1.5.2

To minimize the error (< 1 mm) due to capillary action, apply Equation 1.3:

$$D = [(4)(\sigma)(\sin \theta)] / [(\gamma)(h)]$$

$$D = [4(0.57 \text{ N/m})(\sin 50^\circ)] / [13.6(9790 \text{ N/m}^3)(1.0 \times 10^{-3} \text{ m})]$$

$$\mathbf{D = 0.0131 \text{ m} = 1.31 \text{ cm}}$$

Note: 50° was used instead of 40° because it produces the largest D. A 40° angle produces a smaller error.

### 1.5.3

For capillary rise, apply Equation 1.3:

$$h = [(4)(\sigma)(\sin \theta)] / [(\gamma)(D)]$$

But  $\sin 90^\circ = 1$ ,  $\gamma = 62.3 \text{ lb/ft}^3$  (at 20°C), and

$\sigma = 4.89 \times 10^{-3} \text{ lb/ft}$  (from inside book cover)

thus,  $D = [(4)(\sigma)] / [(\gamma)(h)]$ ; for  $h = 1.5 \text{ in.}$

$$D = [4(4.89 \times 10^{-3} \text{ lb/ft})] / [(62.3 \text{ lb/ft}^3)(1.5/12) \text{ ft}]$$

$$D = 2.51 \times 10^{-3} \text{ ft} = 3.01 \times 10^{-2} \text{ in.}; \text{ thus,}$$

$$\mathbf{\text{for } h = 1.5 \text{ in., } D = 2.51 \times 10^{-3} \text{ ft} = 0.0301 \text{ in.}}$$

$$\mathbf{\text{for } h = 1.0 \text{ in., } D = 3.77 \times 10^{-3} \text{ ft} = 0.0452 \text{ in.}}$$

$$\mathbf{\text{for } h = 0.5 \text{ in., } D = 7.54 \times 10^{-3} \text{ ft} = 0.0904 \text{ in.}}$$

### 1.5.4

$$\text{Condition 1: } h_1 = [(4)(\sigma_1)(\sin \theta_1)] / [(\gamma)(D)]$$

$$h_1 = [(4)(\sigma_1)(\sin 30^\circ)] / [(\gamma)(0.8 \text{ mm})]$$

$$\text{Condition 2: } h_2 = [(4)(\sigma_2)(\sin \theta_2)] / [(\gamma)(D)]$$

$$h_2 = [(4)(0.88\sigma_1)(\sin 50^\circ)] / [(\gamma)(0.8 \text{ mm})]$$

$$\mathbf{h_2/h_1 = [(0.88)(\sin 50^\circ)] / (\sin 30^\circ) = 1.35}$$

alternatively,

$$\mathbf{h_2 = 1.35(h_1), \text{ about a 35\% increase!}}$$

### 1.5.5

Capillary rise (measurement error) is found using

$$\text{Equation 1.3: } h = [(4)(\sigma)(\sin \theta)] / [(\gamma)(D)]$$

where  $\sigma$  is from Table 1.4 and  $\gamma$  from Table 1.2. Thus,

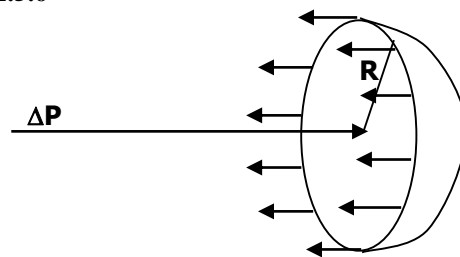
$$\sigma = (6.90 \times 10^{-2})(1.2) = 8.28 \times 10^{-2} \text{ N/m} \text{ and}$$

$$\gamma = (9750)(1.03) = 1.00 \times 10^4 \text{ N/m}^3$$

$$h = [(4)(8.28 \times 10^{-2} \text{ N/m})(\sin 35^\circ)] / [(1.00 \times 10^4 \text{ N/m}^3)(0.012 \text{ m})]$$

$$\mathbf{h = 1.58 \times 10^{-3} \text{ m} = 0.158 \text{ cm}}$$

### 1.5.6



$$\Delta P = P_i - P_e \text{ (internal pressure minus external pressure)}$$

$$\sum F_x = 0; \quad \Delta P(\pi)(R^2) - 2\pi(R)(\sigma) = 0$$

$$\mathbf{\Delta P = 2\sigma/R}$$

### 1.6.1

$$P_i = 1 \text{ atm} = 14.7 \text{ psi. and } P_f = 220 \text{ psi}$$

$$\text{From Equation (1.4): } \Delta \text{Vol}/\text{Vol} = -\Delta P/E_b$$

$$\Delta \text{Vol}/\text{Vol} = -(14.7 \text{ psi} - 220 \text{ psi})/(3.2 \times 10^5 \text{ psi})$$

$$\Delta \text{Vol}/\text{Vol} = 6.42 \times 10^{-4} = 0.0642\% \text{ (volume decrease)}$$

$$\Delta \rho/\rho = -\Delta \text{Vol}/\text{Vol} = \mathbf{-0.0642\% \text{ (density increase)}}$$


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### 1.6.2

$$m = W/g = (7,490 \text{ lb})/(32.2 \text{ ft/s}^2) = 233 \text{ slug}$$

$$\rho = m/\text{Vol} = (233 \text{ slug})/(120 \text{ ft}^3) = \mathbf{1.94 \text{ slug/ft}^3}$$

$$\Delta \text{Vol} = (-\Delta P/E_b)(\text{Vol})$$

$$\Delta \text{Vol} = [-(1470 \text{ psi} - 14.7 \text{ psi})/(3.20 \times 10^5 \text{ psi})](120 \text{ ft}^3)$$

$$\Delta \text{Vol} = -0.546 \text{ ft}^3$$

$$\rho_{\text{new}} = (233 \text{ slug})/(120 \text{ ft}^3 - 0.546 \text{ ft}^3) = \mathbf{1.95 \text{ slug/ft}^3}$$

**Note:** The mass does not change.

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### 1.6.3

$$\text{Surface pressure: } P_s = 1 \text{ atm} = 1.014 \times 10^5 \text{ N/m}^2$$

$$\text{Bottom pressure: } P_b = 1.61 \times 10^7 \text{ N/m}^2$$

$$\text{From Equation (1.4): } \Delta \text{Vol}/\text{Vol} = -\Delta P/E_b$$

$$\Delta \text{Vol}/\text{Vol} = \frac{[-(1.014 \times 10^5 - 1.61 \times 10^7) \text{ N/m}^2]}{(2.2 \times 10^9 \text{ N/m}^2)}$$

$$\Delta \text{Vol}/\text{Vol} = 7.27 \times 10^{-3} = 0.727\% \text{ (volume decrease)}$$

$$\Delta \gamma/\gamma = -\Delta \text{Vol}/\text{Vol} = \mathbf{-0.727\% \text{ (specific wt. increase)}}$$

$$\text{Specific weight at the surface: } \gamma_s = \mathbf{9,810 \text{ N/m}^3}$$

Specific weight at the bottom:

$$\gamma_b = (9,810 \text{ N/m}^3)(1.00727) = \mathbf{9,880 \text{ N/m}^3}$$

**Note:** These answers assumes that  $E_b$  holds constant for this great change in pressure.

### 1.6.4

$$P_i = 30 \text{ N/cm}^2 = 300,000 \text{ N/m}^2 = 3 \text{ bar}$$

$$\Delta P = 3 \text{ bar} - 30 \text{ bar} = -27 \text{ bar} = -2.7 \times 10^5 \text{ N/m}^2$$

$$\text{Amount of water that enters pipe} = \Delta \text{Vol}$$

$$\text{Vol}_{\text{pipe}} = [(\pi)(1.50 \text{ m})^2/(4)] \cdot (2000 \text{ m}) = 3530 \text{ m}^3$$

$$\Delta \text{Vol} = (-\Delta P/E_b)(\text{Vol})$$

$$\Delta \text{Vol} = [(-2.7 \times 10^5 \text{ N/m}^2)/(2.2 \times 10^9 \text{ N/m}^2)] \cdot (3530 \text{ m}^3)$$

$$\Delta \text{Vol} = 0.433 \text{ m}^3$$

Water in the pipe is compressed by this amount. Thus,

**the volume of H<sub>2</sub>O that enters the pipe is 0.433m<sup>3</sup>**

## Chapter 2 – Problem Solutions

### 2.2.1

a) The depth of water is determined using the relationship between weight and specific weight.

$W = \gamma \cdot \text{Vol} = \gamma(A \cdot h)$ ; where  $h$  = water depth

$$14,700 \text{ lbs} = (62.3 \text{ lb/ft}^3)[\pi \cdot (5 \text{ ft})^2](h); \quad \mathbf{h = 3.00 \text{ ft}}$$

b) Pressure on the tank bottom based on weight:

$$P = F/A = W/A = 14,700/[\pi \cdot (5 \text{ ft})^2] = \mathbf{187 \text{ lbs/in.}^2}$$

b) Pressure due to depth of water using Eq'n 2.4:

$$\mathbf{P = \gamma \cdot h = (62.3 \text{ lb/ft}^3)(3 \text{ ft}) = 187 \text{ lb/ft}^2}$$


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### 2.2.2

The absolute pressure includes atmospheric pressure.

Therefore,  $P_{\text{abs}} = P_{\text{atm}} + (\gamma_{\text{water}})(h) \leq 5(P_{\text{atm}})$ ;

Thus from Eq'n 2.4:  $h = 4(P_{\text{atm}})/\gamma_{\text{water}}$

$$h = 4(1.014 \times 10^5 \text{ N/m}^2)/(1.03)(9790 \text{ N/m}^3)$$

$$\mathbf{h = 40.2 \text{ m (132 ft)}}$$


---

### 2.2.3

$\gamma_{\text{water}}$  at  $30^\circ\text{C} = 9.77 \text{ kN/m}^3$  (from Table 1.2)

$P_{\text{vapor}}$  at  $30^\circ\text{C} = 4.24 \text{ kN/m}^2$  (from Table 1.1)

$$P_{\text{atm}} = P_{\text{column}} + P_{\text{vapor}}$$

$$P_{\text{atm}} = (8.7 \text{ m})(9.77 \text{ kN/m}^3) + (4.24 \text{ kN/m}^2)$$

$$\mathbf{P_{\text{atm}} = 85.0 \text{ kN/m}^2 + 4.24 \text{ kN/m}^2 = 89.2 \text{ kN/m}^2}$$

The percentage error if the direct reading is used and the vapor pressure is ignored is:

$$\text{Error} = (P_{\text{atm}} - P_{\text{column}})/(P_{\text{atm}})$$

$$\text{Error} = (89.2 \text{ kN/m}^2 - 85.0 \text{ kN/m}^2)/(89.2 \text{ kN/m}^2)$$

$$\mathbf{\text{Error} = 0.0471 = 4.71\%}$$

### 2.2.4

Since mercury has a specific gravity of 13.6, the water height can be found from:  $h_{\text{water}} = (h_{\text{Hg}})(SG_{\text{Hg}})$

$$\mathbf{h_{\text{water}} = (30 \text{ mm})(13.6) = 408 \text{ mm} = 40.8 \text{ cm of water}}$$

Also, absolute pressure is:  $P_{\text{abs}} = P_{\text{gage}} + P_{\text{atm}}$

$$P_{\text{abs}} = 0.408 \text{ m} + 10.3 \text{ m} = 10.7 \text{ m of water}$$

$$\mathbf{P_{\text{abs}} = (10.7 \text{ m})(9790 \text{ N/m}^3) = 1.05 \times 10^5 \text{ N/m}^2}$$


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### 2.2.5

Since force equals pressure on the bottom times area:

$$P = \gamma \cdot h = (62.3 \text{ lb/ft}^3)(10 \text{ ft}) = 623 \text{ lb/ft}^2$$

$$\mathbf{F_{\text{bottom}} = P \cdot A = (623 \text{ lb/ft}^2)(100 \text{ ft}^2) = 6.23 \times 10^4 \text{ lbs}}$$

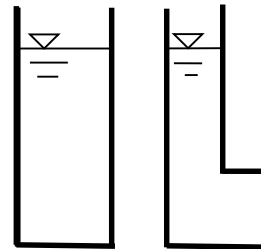
Pressure varies linearly with depth. So the average pressure on the sides of the tank occur at half the depth.

$$P_{\text{avg}} = \gamma \cdot h = (62.3 \text{ lb/ft}^3)(5 \text{ ft}) = 312 \text{ lb/ft}^2 \quad \text{Now,}$$

$$\mathbf{F_{\text{side}} = P_{\text{avg}} \cdot A = (312 \text{ lb/ft}^2)(100 \text{ ft}^2) = 3.12 \times 10^4 \text{ lbs}}$$


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### 2.2.6



Pressure and force on the bottom of both containers is:

$$P = (\gamma_{\text{water}})(h) = (9790 \text{ N/m}^3)(10 \text{ m}) = 97.9 \text{ kN/m}^2$$

$$\text{Also, } \mathbf{F = P \cdot A = (97.9 \text{ kN/m}^2)(2 \text{ m})(2 \text{ m}) = 391 \text{ kN}}$$

This may be confusing since the water weights are different. To clarify the situation, draw a free body diagram of the lower portion of the L-shaped container. (Solution explanation is continued on the next page.)