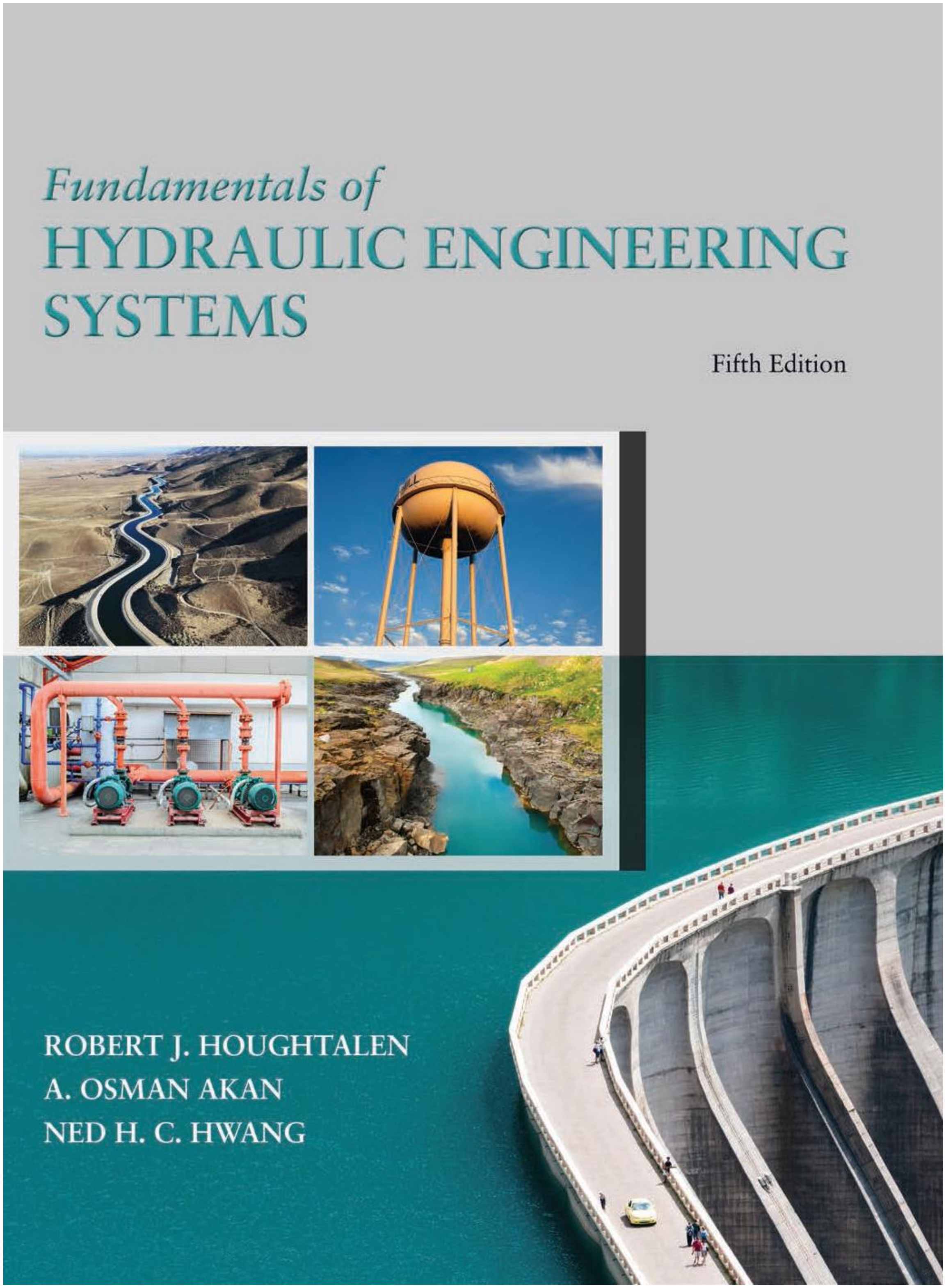
SOLUTIONS MANUAL



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Chapter 1 – Problem Solutions

1.2.1

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

E_1 = (500 L)(1000 g/L)(10°C)(0.432 cal/g·°C)

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

E_2 = energy released when the steam liquefies

E_2 = (500 L)(1000 g/L)(597 cal/g)

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

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

E_3 = (500 L)(1000 g/L)(50°C)(1 cal/g·°C)

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

Thus, the total energy released is:

$\mathbf{E_{total}} = E_1 + E_2 + E_3 = \mathbf{3.26x10^8\ cal}$

1.2.2

First, convert kPa pressure into atmospheres:

84.6 kPa(1 atm/101.4 kPa) = 0.834 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 g)(95°C - 15°C)(1 cal/g·°C)

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

E_2 = energy required to vaporize the water

E_2 = (900 g)(597 cal/g)

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

$\mathbf{E_{total}} = E_1 + E_2 = \mathbf{6.09x10^5\ cal}$

1.2.3

E_1 = energy needed to vaporize the water

E_1 = (300 L)(1000 g/L)(597 cal/g)

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

The energy remaining (E_2) is:

$E_2 = E_{Total} – E_1$

$E_2 = 2.00\text{x}10^8$ cal – $1.79\text{x}10^8$ cal

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

The temperature change possible with the remaining energy is:

$2.10\text{x}10^7$ cal = (300 L)(1000 g/L)(1 cal/g·°C)(ΔT)

ΔT = 70°C, making the temperature

T = 90°C when it evaporates.

Therefore, based on Table 1.1,

∴P = 0.692 atm

1.2.4

E_1 = energy required to warm and then melt the ice

E_1 = (10 g)(6°C)(0.465 cal/g·°C) + 10g(79.7 cal/g)

E_1 = 825 cal. This energy is taken from the water.

The resulting temperature of the water will decrease to:

825 cal = (0.165 L)(1000 g/L)(20°C - T_1)(1 cal/g·°C)

T_1 = 15.0°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 L)(1000 g/L)(15.0°C - T_2)(1 cal/g·°C)] =

[(10 g)(T_2 - 0°C)(1 cal/g·°C)] ; **T_2 = 14.1°C**

1.2.5

E_1 = energy required to melt ice

E_1 = (5 slugs)(32.2 lbm/slug)(32°F - 20°F)*
(0.46 BTU/lbm·°F) + (5 slugs)(32.2 lbm/slug)*
(144 BTU/lbm)

$E_1 = 2.41 \times 10^4$ BTU. ➔Energy taken from the water.

The resulting temperature of the water will decrease to:

2.41×10^4 BTU = (10 slugs)(32.2 lbm/slug)(120°F – T_1)(1 BTU/lbm·°F)

T_1 = 45.2°F

The energy lost by the water (to lower its temp. to 45.2°F) is that required to melt the ice. Now you have 5 slugs of water at 32°F and 10 slugs at 45.2°F. Therefore, the final temperature of the water is:

[(10 slugs)(32.2 lbm/slug)(45.2°F – T_2)(1 BTU/lbm·°F)]
= [(5 slugs)(32.2 lbm/slug)(T_2 - 32°F)(1 BTU/lbm·°F)]

T_2 = 40.8°F

1.2.6

E_1 = energy required to raise the temperature to 100°C

E_1 = (7500 g)(100°C – 20°C)(1 cal/g·°C)

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

E_2 = energy required to vaporize 2.5 kg of water

E_2 = (2500 g)(597 cal/g)

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

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

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

Time required = **4180 sec = 69.7 min**

1.3.1

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

Then dividing both sides of the equation by volume,

W/Vol = (m/Vol)·g; **$\gamma = \rho \cdot g$**

1.3.2

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

γ = 9,810 N/m^3 (Table 1.2). Substituting yields,

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

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

Substituting (noting that N ≡ kg·m/sec^2) yields,

ρ_{oil} = γ_{oil}/g = (9,570 N/m^3) / (9.81 m/sec^2) **= 976 kg/m^3**

1.3.3

By definition, γ = W/Vol = 55.5 lb/ft^3; thus,

W = γ·Vol = (55.5 lb/ft^3)(20 ft^3) = **1,110 lb (4,940 N)**

ρ = γ/g = (55.5 lb/ft^3)/(32.2 ft/s^2) = **1.72 slug/ft^3 (887 kg/m^3)**

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

1.3.4

The mass of liquid can be found using

$\rho = \gamma/g$ and γ = weight/volume, thus

γ = (47000 N – 1500 N)/(5 m^3) = 9.10×10^3 N/m^3

$\rho = \gamma/g$ = (9.1×10^3 N/m^3)/(9.81 m/sec^2);

ρ = 928 kg/m^3 (Note: 1 N ≡ 1 kg·m/sec^2)

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

SG = (9.10×10^3 N/m^3)/9.81×10^3 N/m^3)

SG = 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 = [ρ(Vol)] (g); ρ found in Table 1.2

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

d = 3.00 ft (Note: 1 slug = 1 lb·sec^2/ft)

1.3.6

Weight of water on earth = 8.83 kN

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

m = 900 kg

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

W (moon) = mg = (900 kg)[(9.81 m/s^2)/(6)]

W(moon) = 1,470 N

1.3.7

Density is expressed as ρ = m/Vol, and even though volume changes with temperature, mass does not. Thus, (ρ_1)(Vol_1) = (ρ_2)(Vol_2) = constant; or

Vol_2 = (ρ_1)(Vol_1)/(ρ_2)

Vol_2 = (999 kg/m^3)(100 m^3)/(996 kg/m^3)

Vol_2 = 100.3 m^3 (or a 0.3% change in volume)

1.3.8

(1 N·m)[(3.281 ft)/(1 m)][(0.2248 lb)/(1 N))]

= **7.376 x 10^{-1} ft·lb**

1.3.9

(1 N/m^2) [(1 m)/(3.281 ft)]^2 [(1 ft)/(12 in)]^2 ·

[(1 lb)/(4.448 N)] = **1.450 x 10^{-4} psi**

1.4.1

(a) Note that: 1 poise = 0.1 N·sec/m^2. Therefore,

1 lb·sec/ft^2 [(1 N)/(0.2248 lb)]·[(3.281 ft)^2/(1 m)^2] =

47.9 N·sec/m^2 [(1 poise)/(0.1 N·sec/m^2)] = 478.9 poise

Conversion: **1 lb·sec/ft^2 = 478.9 poise**

(b) Note that: 1 stoke = 1 cm^2/sec. Therefore,

1 ft^2/sec [(12 in)^2/(1 ft)^2]· [(1 cm)^2/(0.3937 in)^2] =

929.0 cm^2/sec [(1 stoke)/(1 cm^2/sec)] = 929.0 stokes

Conversion: **1 ft^2/sec = 929.0 stokes**

1.4.2

$[\mu(air)/\mu(H_2O)]_{0°C}$ = (1.717x10^{-5})/(1.781x10^{-3})

$[\mu(air)/\mu(H_2O)]_{0°C}$ = 9.641x10^{-3}

$[\mu(air)/\mu(H_2O)]_{100°C}$ = (2.174x10^{-5})/(0.282x10^{-3})

$[\mu(air)/\mu(H_2O)]_{100°C}$ = 7.709x10^{-2}

$[\nu(air)/\nu(H_2O)]_{0°C}$ = (1.329x10^{-5})/(1.785x10^{-6})

$[\nu(air)/\nu(H_2O)]_{0°C}$ = 7.445

$[\nu(air)/\nu(H_2O)]_{100°C}$ = (2.302x10^{-5})/(0.294x10^{-6})

$[\nu(air)/\nu(H_2O)]_{100°C}$ = 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 (ν) for air and water are much closer than those of absolute viscosity. Why?

1.4.3

$\mu_{20°C}$ = 1.002x10^{-3} N·sec/m^2; $\nu_{20°C}$ = 1.003x10^{-6} m^2/s

(1.002x10^{-3} N·sec/m^2)·[(0.2248 lb)/(1 N)]·

[(1 m)^2/(3.281 ft)^2] = **2.092x10^{-5} lb·sec/ft^2**

(1.003x10^{-6} m^2/s)[(3.281 ft)^2/(1 m)^2] = **1.080x10^{-5} ft^2/s**

1.4.4

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

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

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

$\tau = 0.12\ N/m^2$

1.4.5

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

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

$\tau = 0.468\ lb/ft^2$

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

F = 0.702 lb

1.4.6

Summing forces parallel to the incline yields:

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

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

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

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

1.4.7

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

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

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

$\tau = 80\ N/m^2$

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

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

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: $dv/dy = 288y - 36\ sec^{-1}$

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

Solutions: y = 0 ft, **$\tau = -0.301 lb/ft^2$**

y = 1/12 ft, **$\tau = -0.100\ lb/ft^2$**; y = 1/6 ft, **$\tau = 0.100\ lb/ft^2$**

y = 1/4 ft, **$\tau = 0.301\ lb/ft^2$**; y = 1/3 ft, **$\tau = 0.501\ lb/ft^2$**

1.4.9

$\mu = (16)(1.00\times10^{-3}\ N\cdot sec/m^2) = 1.60\times10^{-2}\ N\cdot sec/m^2$

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

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

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

$$\text{Torque} = \frac{(2\pi)(1.60\cdot10^{-2}\ N\cdot sec/m^2)(0.65 rad/sec)}{0.0005m}\left[\frac{(1m)^4}{4}\right]$$

Torque = 32.7 N·m

1.4.10

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

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

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

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

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

$\mu = 7.22\times10^{-3}\ lb\cdot sec/ft^2$

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:

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

$D = [4(0.57\ N/m)(\sin 50°)]/[13.6(9790N/m^3)(1.0x10^{-3}\ m)]$

$D = 0.0131\ m = 1.31\ cm$

Note: 50° was used instead or 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˚ = 1, $\gamma = 62.3\ lb/ft^3$ (at 20˚C), and

$\sigma = 4.89x10^{-3}\ lb/ft$ (from inside book cover)

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

$D = [(4)(4.89x10^{-3}\ lb/ft)] / [(62.3\ lb/ft^3)(1.5/12)ft]$

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

for h = 1.5 in., $D = 2.51x10^{-3}$ ft = 0.0301 in.

for h = 1.0 in., $D = 3.77x10^{-3}$ ft = 0.0452 in.

for h = 0.5 in., $D = 7.54x10^{-3}$ ft = 0.0904 in.

1.5.4

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

$h_1 = [(4)(\sigma_1)(\sin 30°)] / [(\gamma)(0.8\ mm)]$

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

$h_2 = [(4)(0.88\sigma_1)(\sin 50°)] / [(\gamma)(0.8\ mm)]$

h_2/h_1 $= [(0.88)(\sin 50°)] / (\sin 30°) =$ **1.35**

alternatively,

$h_2 = 1.35(h_1)$, about a 35% increase!

1.5.5

Capillary rise (measurement error) is found using

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

where σ is from Table 1.4 and γ from Table 1.2. Thus,

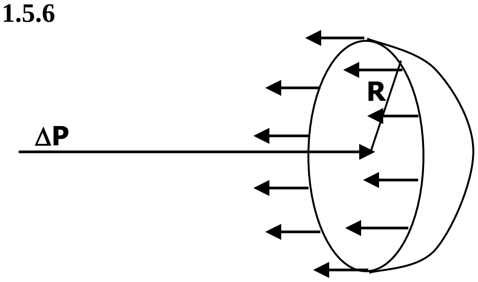
$\sigma = (6.90 \times 10^{-2})(1.2) = 8.28 \times 10^{-2}\ N/m$ and

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

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

$h = 1.58x10^{-3}\ m = 0.158\ cm$

1.5.6



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

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

$\Delta P = 2\sigma/R$

1.6.1

P_i = 1 atm = 14.7 psi. and P_f = 220 psi

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

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

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

$\Delta\rho/\rho = -\Delta Vol/Vol$ = **-0.0642% (density increase)**

1.6.2

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

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

$\Delta Vol = (-\Delta P/E_b)(Vol)$

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

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

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

Note: The mass does not change.

1.6.3

Surface pressure: P_s = 1 atm = 1.014×10^5 N/m^2

Bottom pressure: P_b = 1.61×10^7 N/m^2

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

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

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

$\Delta\gamma/\gamma = -\Delta Vol/Vol$ = **-0.727% (specific wt. increase)**

Specific weight at the surface: **γ_s = 9,810 N/m^3**

Specific weight at the bottom:

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

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

1.6.4

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

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

Amount of water that enters pipe = ΔVol

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

$\Delta Vol = (-\Delta P/E_b)(Vol)$

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

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

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

the **volume of H_2O that enters the pipe is 0.433m^3**