SUMMARY

Specific Weight = $\dfrac{Weight}{volume} = \dfrac{mg}{V} = \rho g = \gamma$

Specific Gravity=S $\dfrac{\text{specific weight of fluid}}{\text{specific weight of water}} = \dfrac{\gamma_f}{\gamma_w} = \dfrac{(\rho g)_{fluid}}{(\rho g)_{water}} = \dfrac{\rho_f}{\rho_w}$

Ideal Gas Law: (Equation of State)= $P = mRT$

Shear stress= $\tau = \mu \dfrac{dV}{dy}$

Sutherland Constant= $\dfrac{\mu}{\mu_0} = \left(\dfrac{T}{T_0}\right)^{3/2} \left(\dfrac{T+S}{T_0+S}\right)$

Surface Tension= $F_s = \sigma L$

Problem (2.2)

2.2 Calculate the density and specific weight of carbon dioxide at 300 kN/m^2 absolute and 60°C.

PROBLEM 2.2

Situation: Carbon dioxide is at 300 kPa and 60°C.

Find: Density and specific weight of CO_2.

Properties: From Table A.2, $R_{CO_2} = 189$ J/kg·K.

APPROACH

First, apply the ideal gas law to find density. Then, calculate specific weight $\gamma = \rho g$.

ANALYSIS

Ideal gas law

$$\begin{aligned} \rho_{CO_2} &= \frac{P}{RT} \\ &= \frac{300,000}{189(60+273)} \\ &= \boxed{4.767 \text{ kg/m}^3} \end{aligned}$$

Specific weight

$$\gamma = \rho g$$

Thus

$$\begin{aligned} \gamma_{CO_2} &= \rho_{CO_2} \times g \\ &= 4.767 \times 9.81 \\ &= \boxed{46.764 \text{ N/m}^3} \end{aligned}$$

2

Problem (2.4)

PROBLEM 2.4

Situation: Natural gas (10 °C) is stored in a spherical tank. Atmospheric pressure is 100 kPa.
Initial tank pressure is 100 kPa-gage. Final tank pressure is 200 kPa-gage.
Temperature is constant at 10 °C.

Find: Ratio of final mass to initial mass in the tank.

APPROACH

Use the ideal gas law to develop a formula for the ratio of final mass to initial mass.

ANALYSIS

Mass

$$M = \rho V \tag{1}$$

Ideal gas law

$$\rho = \frac{p}{RT} \tag{2}$$

Combine Eqs. (1) and (2)

$$\begin{aligned} M &= \rho V\!\!\!- \\ &= (p/RT)V\!\!\!- \end{aligned}$$

Ideal Gas Law

Combine Eqs. (1) and (2)

$$\begin{aligned} M &= \rho V \\ &= (p/RT)V \end{aligned}$$

Volume and gas temperature are constant so

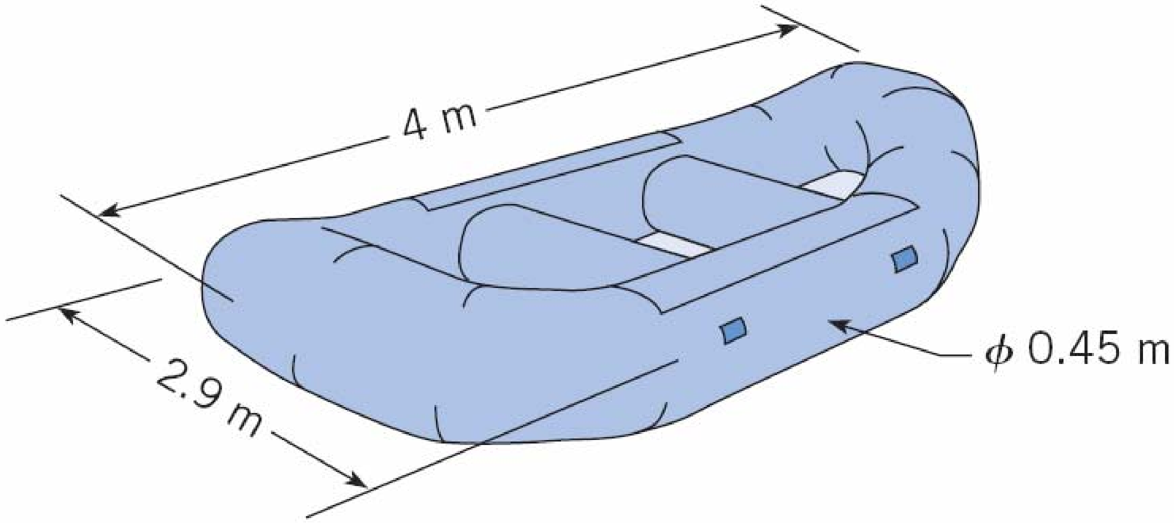
$$\frac{M_2}{M_1} = \frac{p_2}{p_1}$$

and

$$\begin{aligned} \frac{M_2}{M_1} &= \frac{300 \text{ kPa}}{200 \text{ kPa}} \\ &= \boxed{1.5} \end{aligned}$$

Problem (2.10)

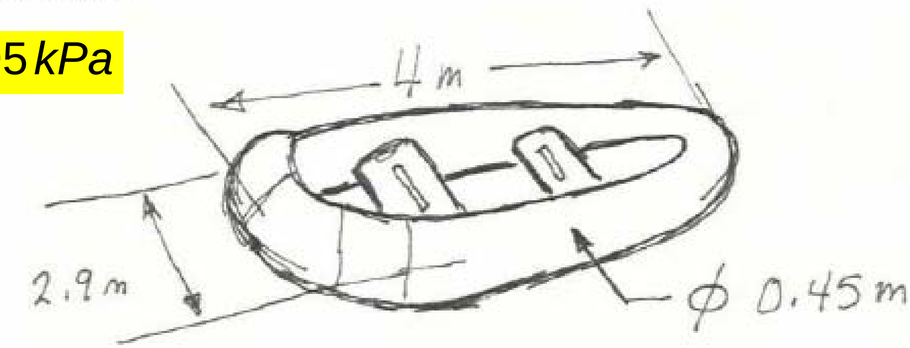
2.10 A design team is developing a prototype CO_2 cartridge for a manufacturer of rubber rafts. This cartridge will allow a user to quickly inflate a raft. A typical raft is shown in the sketch. Assume a raft inflation pressure of 3 psi (this means that the absolute pressure is 3 psi greater than local atmospheric pressure). Estimate the volume of the raft and the mass of CO_2 in grams in the prototype cartridge.



PROBLEM 2.10

Situation: A design team needs to know how much CO_2 is needed to inflate a rubber raft.
Raft is shown in the sketch below.
Inflation pressure is 3 psi above local atmospheric pressure. Thus, inflation pressure is 17.7 psi = 122 kPa.

$1 psi = 6.895 kPa$



Find: (a)Estimate the volume of the raft.
(b) Calculate the mass of CO_2 in grams to inflate the raft.

Properties: From Table A.2, $R_{CO_2} = 189$ J/kgK.

Assumptions: 1.) Assume that the CO_2 in the raft is at 62 °F = 290 K.
2.) Assume that the volume of the raft can be approximated by a cylinder of diameter 0.45 m and a length of 16 m (8 meters for the length of the sides and 8 meters for the lengths of the ends plus center tubes).

APPROACH

Mass is related to volume by $m = \rho *$Volume. Density can be found using the ideal gas law.

ANALYSIS

Volume contained in the tubes.

$$\Delta \forall = \frac{\pi D^2}{4} \times L$$
$$= \left(\frac{\pi \times 0.45^2}{4} \times 16 \right) \mathrm{m}^3$$
$$= 2.54\,\mathrm{m}^3$$

$$\boxed{\Delta \forall = 2.54\,\mathrm{m}^3}$$

<u>Ideal gas law</u>

$$\rho = \frac{p}{RT}$$
$$= \frac{122,000\,\mathrm{N/\,m^2}}{(189\,\mathrm{J/\,kg \cdot\,K})\,(290\,\mathrm{K})}$$
$$= 2.226\ \mathrm{kg/m^3}$$

Mass of CO_2

$$\begin{aligned} m &= \rho \times \text{Volume} \\ &= \left(2.226\ \text{kg/m}^3\right) \times \left(2.54\ \text{m}^3\right) \\ &= 5.66\ \text{kg} \end{aligned}$$

$$\boxed{m = 5.66\ \text{kg}}$$

COMMENTS

The final mass (5.66 kg = 12.5 lbm) is large. This would require a large and potentially expensive CO_2 tank. Thus, this design idea may be impractical for a product that is driven by cost.

Problem (2.19)

2.19 The dynamic viscosity of air at 15°C is 1.78×10^{-5} $N \cdot s/m^2$. Using Sutherland's equation, find the viscosity at 200°C.

PROBLEM 2.19

Situation: The viscosity of air is $\mu_{air}\,(15°C) = 1.78 \times 10^{-5}$ N·s/m².

Find: Dynamic viscosity μ of air at 200 °C using Sutherland's equation.

Properties: From Table A.2, $S = 111K$.

ANALYSIS

Sutherland's equation

$$\begin{aligned} \frac{\mu}{\mu_o} &= \left(\frac{T}{T_o}\right)^{3/2} \frac{T_o + S}{T + S} \\ &= \left(\frac{473}{288}\right)^{3/2} \frac{288 + 111}{473 + 111} \\ &= 1.438 \end{aligned}$$

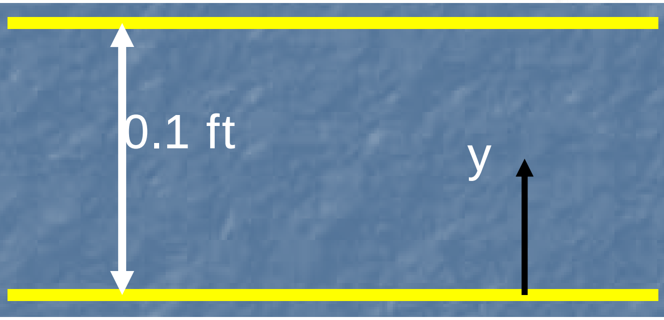
Thus

$$\begin{aligned} \mu &= 1.438\mu_o \\ &= 1.438 \times \left(1.78 \times 10^{-5}\,\mathrm{N \cdot s/\,m^2}\right) \end{aligned}$$

$$\boxed{\mu = 2.56 \times 10^{-5}\ \mathrm{N{\cdot}s/m^2}}$$

Viscosity Law

2.31 The velocity distribution for the flow of crude oil at 100°F ($\mu = 8 \times 10^{-5}$ lbf · s/ft^2) between two walls is given by $u = 100y(0.1 - y)$ ft/s, where y is measured in feet and the space between the walls is 0.1 ft. Plot the velocity distribution and determine the shear stress at the walls.



Find: Shear stress at walls. **Also, Plot the velocity distribution**

ANALYSIS

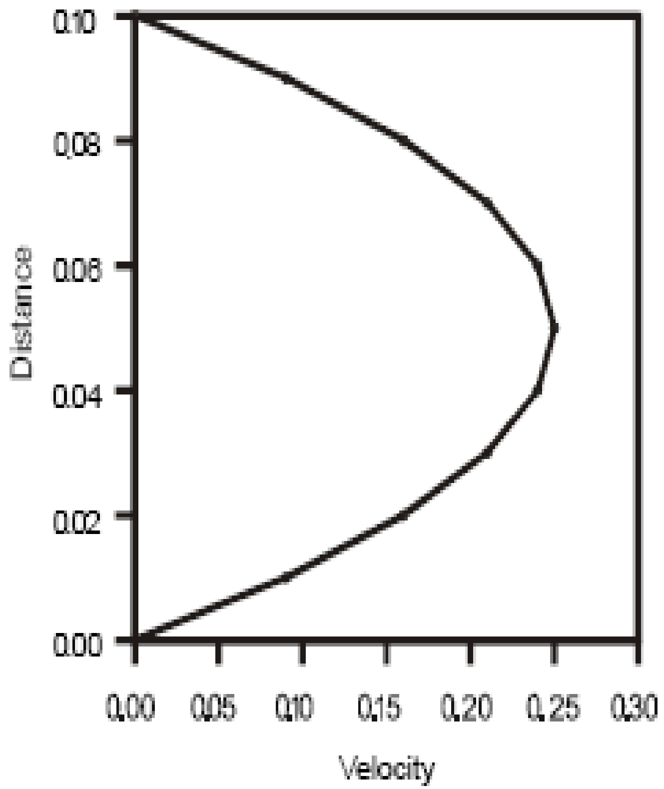
Velocity distribution

$$u = 100y(0.1 - y) = 10y - 100y^2$$

Problem (2.31)

Velocity Distribution Plot

Plot



Problem (2.31)

Shear stress at the walls can be calculated as follows

Velocity distribution

$$u = 100y(0.1 - y) = 10y - 100y^2$$

Rate of strain

$$du/dy = 10 - 200y$$

$$(du/dy)_{y=0} = 10 \text{ s}^{-2} \qquad (du/dy)_{y=0.1} = -20 \text{ s}^{-2}$$

Shear stress

$$\tau_0 = \mu \frac{du}{dy} = (8 \times 10^{-5}) \times 10 = \boxed{8 \times 10^{-4} \text{ lbf/ft}^2}$$

$$\tau_{0.1} = \boxed{16 \times 10^{-4} \text{ lbf/ft}^2}$$

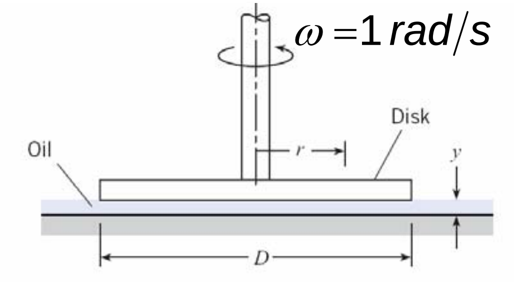
Problem (2.41)

2.41 The device shown consists of a disk that is rotated by a shaft. The disk is positioned very close to a solid boundary. Between the disk and the boundary is viscous oil.

a. If the disk is rotated at a rate of 1 rad/s, what will be the ratio of the shear stress in the oil at $r = 2$ cm to the shear stress at $r = 3$ cm?

b. If the rate of rotation is 2 rad/s, what is the speed of the oil in contact with the disk at $r = 3$ cm?

c. If the oil viscosity is 0.01 $N \cdot s/m^2$ and the spacing y is 2 mm, what is the shear stress for the conditions noted in part (b)?



PROBLEM 2.41

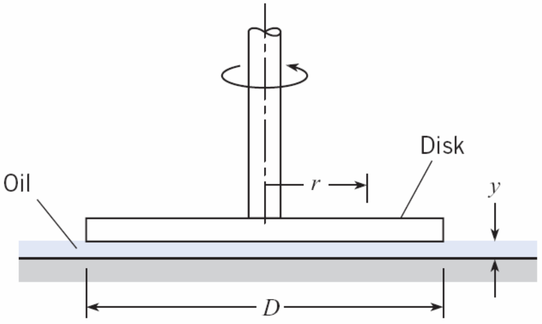
Situation: A disk is rotated very close to a solid boundary—details are provided in problem statement.

Find: (a) Ratio of shear stress at $r = 2$ cm to shear stress at $r = 3$ cm. $\omega = 1 rad/s$

(b) Speed of oil at contact with disk surface. $\omega = 2 rad/s$

(c) Shear stress at disk surface.

Problem (2.41)



Assumptions: Linear velocity distribution: $dV/dy = V/y = \omega r/y$.

ANALYSIS

$$\tau = \mu dV/dy = \mu\omega r/y$$

$$\tau_2/\tau_3 = (\mu \times 1 \times 2/y)/(\mu \times 1 \times 3/y) = 2/3 = \boxed{0.667}$$

$$V = \omega r = 2 \times 0.03 = \boxed{0.06 \text{ m/s}}$$

$$\tau = \mu dV/dy = 0.01 \times 0.06/0.002 = \boxed{0.30 \text{ N/m}^2}$$

$$V = \omega r = 2 \times 0.03 = 0.06$$

Problem (2.48) **Surface Tension**

Situation: A spherical soap bubble has an inside radius R, a wall-thickness t, and surface tension σ.

Find: (a) Derive a formula for the pressure difference across the bubble
(b) Pressure difference for a bubble with a radius of 4 mm.

Assumptions: The effect of thickness is negligible, and the surface tension is that of pure water.

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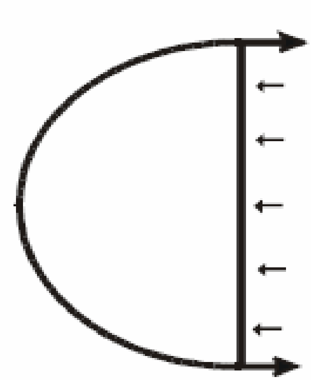
APPROACH

Apply equilibrium, then the surface tension force equation.

ANALYSIS

Force balance



Surface tension force **Pressure forces = Surface tension forces**

$$\sum F = 0$$

$$\Delta p \pi R^2 - 2(2\pi R\sigma) = 0$$

$$\Delta p = \boxed{4\sigma/R}$$

$$\sigma_{Water} = 4 \times 0.073\, N/m$$

$$\Delta p_{4\text{mm rad.}} = (4 \times 7.3 \times 10^{-2}\ \text{N/m})/0.004\ \text{m} = \boxed{73.0\ \text{N/m}^2}$$

THE END