CHAPTER (1)

BUILDING A SOLID FOUNDATION

SOLVED PROBLEMS

Dr. Munzer Ebaid

Mech. Eng. Dept.

Problem (1.25)

(1.25) Calculate the density and specific weight of carbon dioxide at 300 kN/m^2 absolute 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 using $\gamma = \rho g$.

Ideal gas law

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

Specific weight

$$\gamma = \rho g$$

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

Problem (1.28)

(1.28) Natural gas is stored in a spherical tank at a temperature of 10°C. At a given initial time, the pressure in the tank is 100 kPa gage, and the atmospheric pressure is 100 kPa absolute. Some time later, after considerably more gas is pumped into the tank, the pressure in the tank is 200 kPa gage, and the temperature is still 10°C. What will be the ratio of the mass of natural gas in the tank when p = 200 kPa gage to that when the pressure was 100 kPa gage?

Problem (1.28)

Problem (1.28)

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

$$M = \rho V \quad (1)$$

Ideal gas law

$$\rho = \frac{p}{RT} \quad (2)$$

Combine Eqs. (1) and (2)

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

CONT.

Problem (1.28)

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 1.31

1.31 A 1 $4\,m^3$ oxygen tank is at $20\ ^\circ C$ and $700 kPa$ The valve is opened, and some oxygen is released until the pressure in the tank drops to $500 kPa$. Calculate the mass of oxygen that has been released from the tank if the temperature in the tank does not change during the process.

Situation:

Oxygen is released from a tank through a valve.

$\forall = 4\,\text{m}^3$.

Find:

Mass of oxygen that has been released.

Properties:

$R_{O_2} = 260 \frac{\text{J}}{\text{kg} \cdot \text{K}}$.

$p_1 = 700\,\text{kPa},\ T_1 = 20\,^\circ\text{C}$.

$p_2 = 500\,\text{kPa},\ T_2 = 20\,^\circ\text{C}$.

SOLUTION

1. Ideal gas law

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

2. Density and mass for case 1

$$\rho_1 = \frac{700,000 \frac{\text{N}}{\text{m}^2}}{(260 \frac{\text{N}\cdot\text{m}}{\text{kg}\cdot\text{K}})(293\,\text{K})}$$

$$\rho_1 = 9.19 \frac{\text{kg}}{\text{m}^3}$$

$$\begin{aligned} M_1 &= \rho_1 \forall \\ &= 9.19 \frac{\text{kg}}{\text{m}^3} \times 4\,\text{m}^3 \\ M_1 &= 36.8\,\text{kg} \end{aligned}$$

3. Density and mass for case 2

$$\rho_2 = \frac{500,000 \frac{\text{N}}{\text{m}^2}}{(260 \frac{\text{N}\cdot\text{m}}{\text{kg}\cdot\text{K}})(293\,\text{K})}$$

$$\rho_2 = 6.56 \frac{\text{kg}}{\text{m}^3}$$

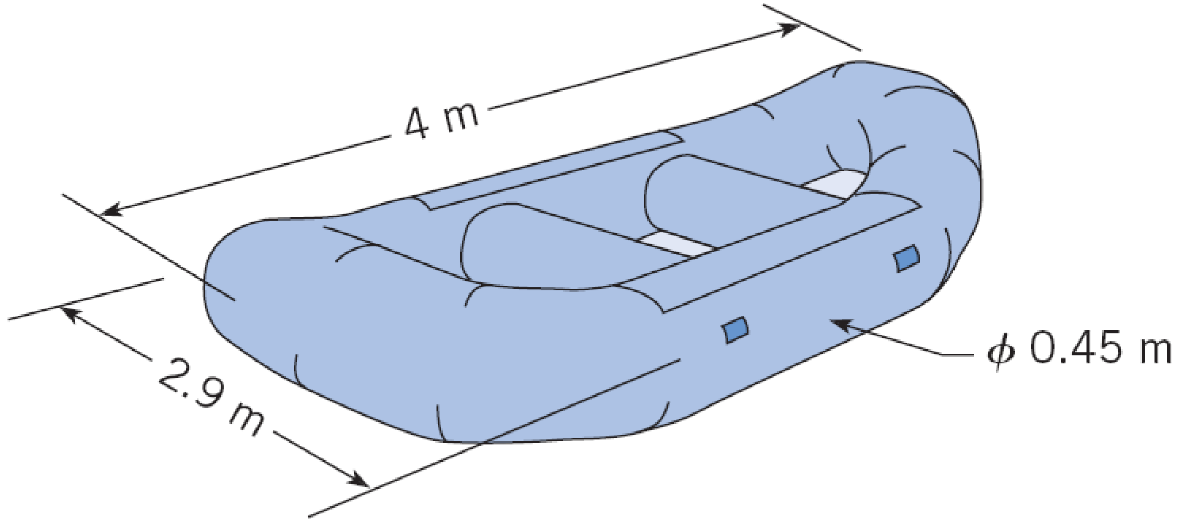
$$
\begin{aligned}
M_2 &= \rho_1 \forall \\
&= 6.56 \frac{\text{kg}}{\text{m}^3} \times 4\,\text{m}^3 \\
M_2 &= 26.3\ \text{kg}
\end{aligned}
$$

4. Mass released from tank

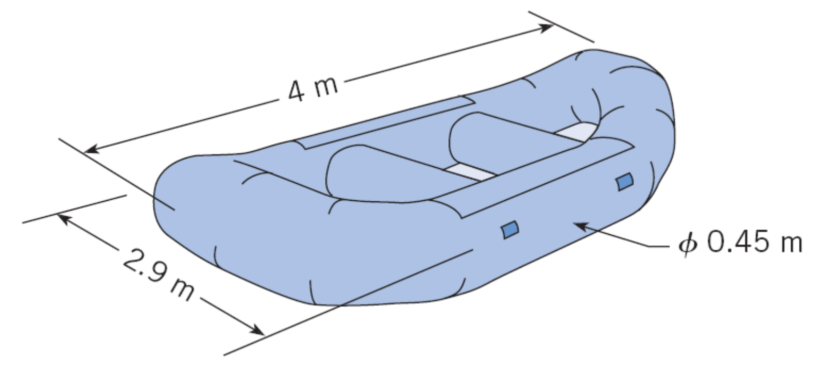
$$
\begin{aligned}
M_1 - M_2 &= 36.8 - 26.3 \\
& \boxed{M_1 - M_2 = 10.5\ \text{kg}}
\end{aligned}
$$

Problem (1.35)

(1.35) 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.



CONT.



Inflation pressure is 3 psi above local atmospheric pressure. Thus, inflation pressure is 17.7 psi = 122 kPa.

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.

CONT.

ANALYSIS

Volume contained in the tubes.

$1 psi = 6.895 kPa$

$$\Delta V = \frac{\pi D^2}{4} \times L$$
$$= \left(\frac{\pi \times 0.45^2}{4} \times 16 \right) \text{m}^3$$
$$= 2.54 \text{ m}^3$$
$$\boxed{\Delta V = 2.54 \text{ m}^3}$$

Ideal gas law

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

CONT.

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.

THE END