ENGR 251: Thermodynamics

Solutions to Tutorial 1: Chapter 1

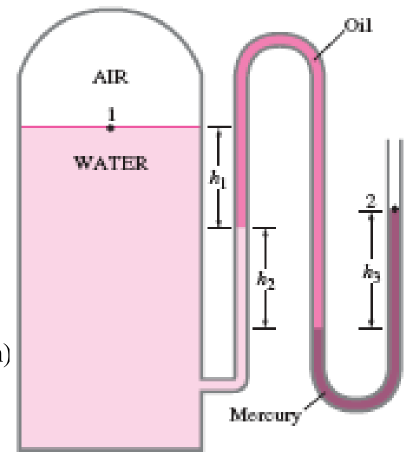
**1-50** The pressure in a pressurized water tank is measured by a multi-fluid manometer. The gage pressure of air in the tank is to be determined.

***Assumptions*** The air pressure in the tank is uniform (i.e., its variation with elevation is negligible due to its low density), and thus we can determine the pressure at the air-water interface.

***Properties*** The densities of mercury, water, and oil are given to be 13,600, 1000, and 850 kg/m$^3$, respectively.

***Analysis*** Starting with the pressure at point 1 at the air-water interface, and moving along the tube by adding (as we go down) or subtracting (as we go up) th e $\rho gh$ terms until we reach point 2, and setting the result equal to $P_{atm}$ since the tube is open to the atmosphere gives

$$P_1 + \rho_{water} g h_1 + \rho_{oil} g h_2 - \rho_{mercury} g h_3 = P_{atm}$$




Solving for $P_1$,

$$P_1 = P_{atm} - \rho_{water} g h_1 - \rho_{oil} g h_2 + \rho_{mercury} g h_3$$

or,

$$P_1 - P_{atm} = g(\rho_{mercury} h_3 - \rho_{water} h_1 - \rho_{oil} h_2)$$

Noting that $P_{1,gage} = P_1 - P_{atm}$ and substituting,

$$P_{1,gage} = (9.81\ \text{m/s}^2)[(13{,}600\ \text{kg/m}^3)(0.46\ \text{m}) - (1000\ \text{kg/m}^3)(0.2\ \text{m})$$
$$- (850\ \text{kg/m}^3)(0.3\ \text{m})]\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right)$$
$$= \mathbf{56.9\ kPa}$$

***Discussion*** Note that jumping horizontally from one tube to the next and realizing that pressure remains the same in the same fluid simplifies the analysis greatly.

**1-54E** It is to be shown that 1 kgf/cm$^2$ = 14.223 psi .

***Analysis*** Noting that 1 kgf = 9.80665 N, 1 N = 0.22481 lbf, and 1 in = 2.54 cm, we have

$$1\ \text{kgf} = 9.80665\ \text{N} = (9.80665\ \text{N})\left(\frac{0.22481\ \text{lbf}}{1\ \text{N}}\right) = 2.20463\ \text{lbf}$$

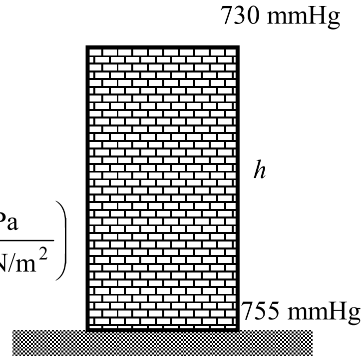
and

$$1\ \text{kgf/cm}^2 = 2.20463\ \text{lbf/cm}^2 = (2.20463\ \text{lbf/cm}^2)\left(\frac{2.54\ \text{cm}}{1\ \text{in}}\right)^2 = 14.223\ \text{lbf/in}^2 = \mathbf{14.223\ psi}$$

**1-63** A barometer is used to measure the height of a building by recording reading at the bottom and at the top of the building. The height of the building is to be determined.

***Assumptions*** The variation of air density with altitude is negligible.

***Properties*** The density of air is given to be ρ = 1.18 kg/m³. The density of mercury is 13,600 kg/m³.




***Analysis*** Atmospheric pressures at the top and at the bottom of the building are

$$
\begin{aligned}
P_{top} &= (\rho g h)_{top} \\
&= (13{,}600\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(0.730\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\
&= 97.36\ \text{kPa}
\end{aligned}
$$

$$
\begin{aligned}
P_{bottom} &= (\rho g h)_{bottom} \\
&= (13{,}600\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(0.755\ \text{m})\left(\frac{1\text{N}}{1\text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\
&= 100.70\ \text{kPa}
\end{aligned}
$$

Taking an air column between the top and the bottom of the building and writing a force balance per unit base area, we obtain

$$W_{air} / A = P_{bottom} - P_{top}$$

$$(\rho g h)_{air} = P_{bottom} - P_{top}$$

$$(1.18\ \text{kg/m}^3)(9.807\ \text{m/s}^2)(h)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) = (100.70 - 97.36)\ \text{kPa}$$

It yields $h =$ **288.6 m**

which is also the height of the building.

**1-66** A gas contained in a vertical piston-cylinder device is pressurized by a spring and by the weight of the piston. The pressure of the gas is to be determined.

***Analysis*** Drawing the free body diagram of the piston and balancing the vertical forces yield

$$PA = P_{atm}A + W + F_{spring}$$

Thus,

$$
\begin{aligned}
P &= P_{atm} + \frac{mg + F_{spring}}{A} \\
&= (95\ \text{kPa}) + \frac{(4\ \text{kg})(9.81\ \text{m/s}^2) + 60\ \text{N}}{35\times10^{-4}\ \text{m}^2}\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) \\
&= \mathbf{123.4\ kPa}
\end{aligned}
$$