4.th week

Hydrostatic Laws , Units and scales of pressure measurements

UNITS AND SCALES OF PRESSURE MEASUREMENT

Pressure can be expressed with reference to any arbitrary datum. The usual datums are *absolute zero* and *local atmospheric pressure.* When a pressure is expressed as a difference between its value and a complete vacuum, it is called an *absolute pressure.* When it is expressed as a difference between its value and the local atmospheric pressure, it is called a *gage pressure.*

The *bourdon gage* (Fig. 2.7) is typical of the devices used for measuring gage pressures. The pressure element is a hollow, curved, flat metallic tube closed at one end; the other end is connected to the pressure to be measured. When the internal

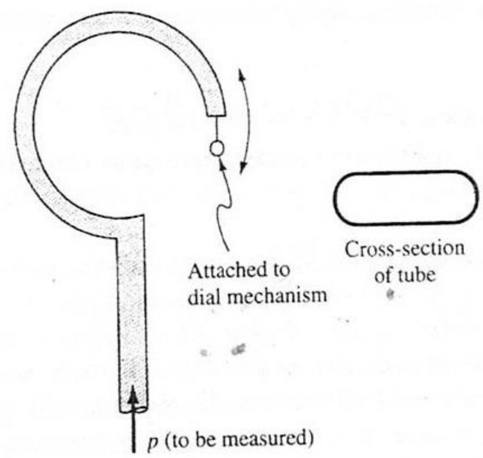

Figure 2.7 Bourdon tube schematic.

pressure is increased, the tube tends to straighten, pulling on a linkage to which is attached a pointer and causing the pointer to move. The dial reads zero when the inside and outside of the tube are at the same pressure, regardless of its particular value. The dial can be graduated to any convenient units, common ones being pascals, pounds per square inch, pounds per square foot, inches of mercury, feet of water, centimeters of mercury, and millimeters of mercury. Owing to its inherent construction, the gage measures pressure relative to the pressure of the medium surrounding the tube, which is the local atmosphere.

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Figure 2.8 illustrates the data and the relations of the common units of pressure measurement. Standard atmospheric pressure is the mean pressure at sea level, 29.92-in. Hg. A pressure expressed in terms of *the length of a column* of liquid is equivalent to the force per unit area at the base of the column. The relation for variation of pressure with altitude in a liquid $p = \gamma h$ [Eq. (2.2.8)] shows the relation between the head h, in length of fluid column of specific weight γ, and the pressure p. In consistent units, p is in pascals, γ in newtons per cubic meter, and h in meters, or p is in pounds per square foot, γ in pounds per cubic foot, and h in feet. With the specific weight of any liquid expressed as its specific gravity S times the specific

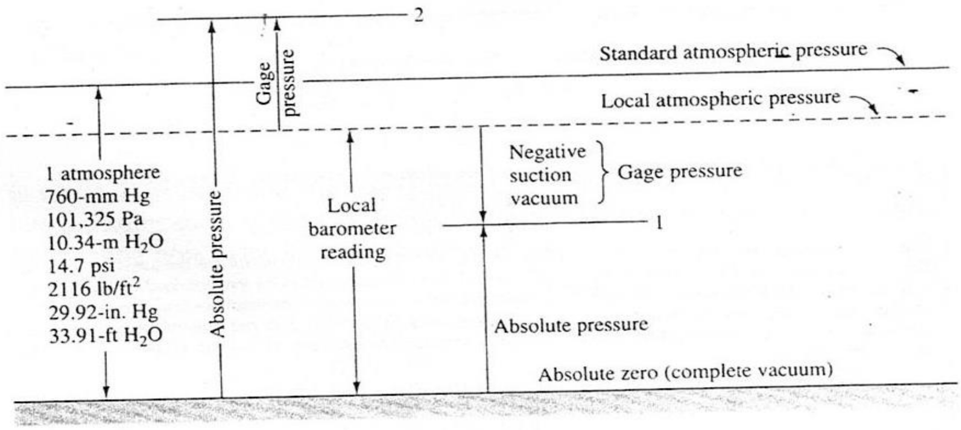

Figure 2.8 Units and scales of pressure measurement.

weight of water, Eq. (2.2.8) becomes

$$p = \gamma_w S\, h \tag{2.3.1}$$

For water γ_w can be taken as 9806 N/m^3 or 62.4 lb/ft^3.

When the pressure is desired in pounds per square inch, both sides of the equation are divided by 144:

$$p_{\text{psi}} = \frac{62.4}{144} Sh = 0.433Sh \tag{2.3.2}$$

in which h remains in feet.†

Local atmospheric pressure is measured by a mercury barometer (Fig. 2.9) or by an *aneroid* barometer, which measures the difference in pressure between the atmosphere and an evacuated box or tube in a manner analogous to the bourdon gage except that the tube is evacuated and sealed.

A mercury barometer consists of a glass tube closed at one end, filled with mercury, and inverted so that the open end is submerged in mercury. It has a scale so arranged that the height of column R (Fig. 2.9) can be determined. The space above the mercury contains mercury vapor. If the pressure of the mercury vapor h_v is given

in millimeters of mercury and R is measured in the same units, the pressure at A can be expressed as

$$h_v + R = h_A \qquad \text{mm Hg}$$

Although h_v is a function of temperature, it is very small at usual atmospheric temperatures. The barometric pressure varies with location, that is, elevation, and with weather conditions.

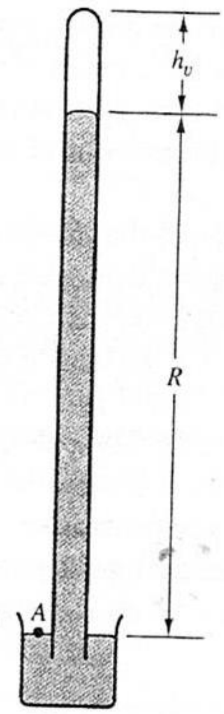

Figure 2.9 Mercury barometer.

†In Eq. (2.3.2) the standard atmospheric pressure can be expressed in pounds per square inch,

$$p_{psi} = \frac{62.4}{144}(13.6)\frac{29.92}{12} = 14.7$$

when $S = 13.6$ for mercury. When 14.7 is multiplied by 144, the standard atmosphere becomes 2116 lb/ft^2. Then 2116 divided by 62.4 yields 33.91-ft H_2O. Any of these designations is for the standard atmosphere and may be called *one atmosphere* if it is always understood that it is a standard atmosphere and is measured from absolute zero. These various designations of a standard atmosphere (Fig. 2.8) are equivalent and provide a convenient means of converting from one set of units to another. For example, to express 100-ft H_2O in pounds per square inch use

$$\frac{100}{33.91}(14.7) = 43.3 \text{ psi}$$

since 100/33.91 is the number of standard atmospheres and each standard atmosphere is 14.7 psi.

In Fig. 2.8 a pressure can be located vertically on the chart, which indicates its relation to absolute zero and to local atmospheric pressure. If the point is below the local-atmospheric-pressure line and is referred to gage datum, it is called *negative, suction,* or *vacuum.* For example, the pressure 460-mm Hg abs, as at 1, with barometer reading 720-mm Hg, can be expressed as −260-mm Hg, 11-in.-Hg suction, or 11-in.-Hg vacuum. It should be noted that

$$p_{\text{abs}} = p_{\text{bar}} + p_{\text{gage}}$$

To avoid any confusion, the convention is adopted throughout this text that a *pressure is gage unless specifically marked absolute,* with the exception of the *atmosphere,* which is an absolute pressure unit.

The rate of temperature change in the atmosphere with change in elevation is called its *lapse rate.* The motion of a parcel of air depends on the density of the parcel relative to the density of the surrounding (ambient) air. However, as the parcel ascends through the atmosphere, the air pressure decreases, the parcel expands, and its temperature decreases at a rate known as the *dry adiabatic lapse rate.* A firm wants to burn a large quantity of refuse. It is estimated that the temperature of the smoke plume at 10 m above the ground will be 11°C greater than that of the ambient air. Determine what will happen to the smoke (*a*) at standard atmospheric lapse rate $\beta = -0.00651$°C per meter and $t_0 = 20$°C and (*b*) at an inverted lapse rate $\beta = 0.00365$°C per meter.

Solution

Combining Eqs. (2.2.7) and (2.2.17) gives

$$\int_{p_0}^{p} \frac{dp}{p} = -\frac{g}{R}\int_0^y \frac{dy}{T_0 + \beta y} \quad \text{or} \quad \frac{p}{p_0} = \left(1 + \frac{\beta y}{T_0}\right)^{-g/R\beta}$$

The relation between pressure and temperature for a mass of gas expanding without heat transfer is

$$\frac{T}{T_1} = \left(\frac{p}{p_0}\right)^{(k-1)/k}$$

in which T_1 is the initial absolute temperature of the smoke; p_0 is the initial absolute pressure; and k is the specific-heat ratio, 1.4 for air and other diatomic gases. Eliminating p/p_0 in the last two equations gives

$$T = T_1\left(1 + \frac{\beta y}{T_0}\right)^{-[(k-1)/k](g/R\beta)}$$

Since the gas will rise until its temperature is equal to the ambient temperature,

$$T = T_0 + \beta y$$

the last two equations can be solved for y. Let

$$a = \frac{-1}{(k-1)g/kR\beta + 1}$$

then

$$y = \frac{T_0}{\beta}\left[\left(\frac{T_0}{T_1}\right)^a - 1\right]$$

(a) For $\beta = -0.00651$°C per meter, $R = 287$ m·N/(kg·K), $a = 2.002$, and $y = 3201$ m.

(b) For the atmospheric temperature inversion $\beta = 0.00365$°C per meter, $a = -0.2721$, and $y = 809.2$ m.

Solved problems

Ex1: A closed tank contains 1.5 m of SAE 30 oil, 1 m of water, 20 cm of mercury, and an air space on top, all at 20°C. If $p_{bottom} = 60$ kPa, what is the pressure in the air space? γ_{oil}=8720N/m^3, γ_{water}=9790N/m^3, $\gamma_{mercury}$=133100N/m^3.

Solution: Apply the hydrostatic formula down through the three layers of fluid:

$P_{bottom} = P_{air} + \gamma_{oil} * h_{oil} + \gamma_{water} * h_{water} + \gamma_{mercury} * h_{mercury}$

60000 Pa= P_{air} + (8720 N/m)(1.5 m)+ (9790)(1.0 m) +(133100)(0.2 m)

Solve for the pressure in the air space: P_{air} =**10500 Pa** *Ans.*

Ex2:

2.11 In Fig. P2.11, sensor A reads 1.5 kPa (gage). All fluids are at 20°C. Determine the elevations Z in meters of the liquid levels in the open piezometer tubes B and C.

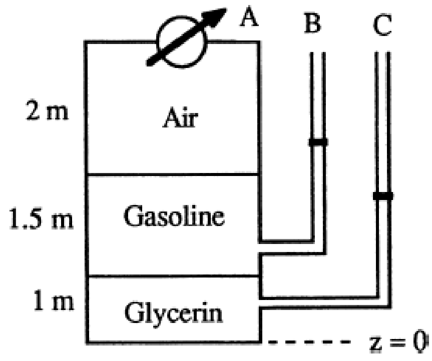

Fig. P2.11

Solution: (B) Let piezometer tube B be an arbitrary distance H above the gasoline-glycerin interface. The specific weights are $\gamma_{air} \approx 12.0$ N/m^3, $\gamma_{gasoline} = 6670$ N/m^3, and $\gamma_{glycerin} = 12360$ N/m^3. Then apply the hydrostatic formula from point A to point B:

$$1500\ \text{N/m}^2 + (12.0\ \text{N/m}^3)(2.0\ \text{m}) + 6670(1.5 - H) - 6670(Z_B - H - 1.0) = p_B = 0\ \text{(gage)}$$

Solve for $Z_B = \mathbf{2.73\ m}$ (23 cm above the gasoline-air interface) *Ans.* (b)

Solution (C): Let piezometer tube C be an arbitrary distance Y above the bottom. Then

$$1500 + 12.0(2.0) + 6670(1.5) + 12360(1.0 - Y) - 12360(Z_C - Y) = p_C = 0\ \text{(gage)}$$

Solve for $Z_C = \mathbf{1.93\ m}$ (93 cm above the gasoline-glycerin interface) *Ans.* (c)