Pressure Measurement

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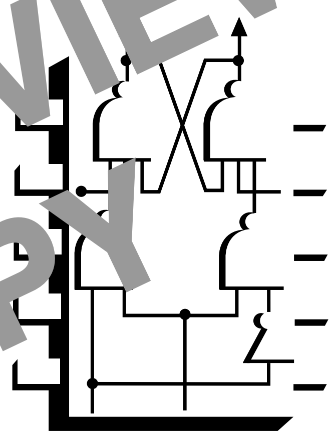
PRESSURE MEASUREMENT

Lesson One

Principles of Pressure in Liquids and Gases



TPC Training Systems

27301

Lesson

1 Principles of Pressure in Liquids and Gases

TOPICS

Properties of Matter
Principles of Liquid Pressure
Units of Pressure
Conditions Affecting Liquid Pressure
Density and Relative Density
Gauge Pressure and Absolute Pressure
Using Liquid Pressure Measurements
Gas Pressure and Volume
Gas Volume and Temperature
Gas Pressure and Temperature
Pressure, Temperature, and Volume Related
Atmospheric Pressure
Pressure and Flow

OBJECTIVES

After studying this Lesson, you should be able to…

- Compare the three forms of matter.
- Define pressure and explain the difference between gauge pressure and absolute pressure.
- Discuss the conditions that affect the pressure of a liquid.
- Describe how changes in volume affect the pressure of a gas at a constant temperature.
- Describe how changes in temperature affect the volume of a gas at constant pressure, and the pressure of a gas with a constant volume.
- Discuss the two causes of pressure drop in a pipe carrying liquid from a tank.

KEY TECHNICAL TERMS

Pressure 1.07 force per unit of area

Density 1.16 mass per unit volume of material

Specific gravity (relative density) 1.19 the ratio of the density of a volume of a substance to an equal volume of air or water at a specific temperature and pressure

Boyle's law 1.43 the principle that the pressure of a gas varies inversely with its volume at a constant temperature

Charles' law 1.45 the principle that the temperature of a gas varies directly with its volume at a constant pressure

Absolute zero 1.48 the temperature at which molecules theoretically stop moving

Kelvin 1.48 the unit of thermodynamic temperature, expressed as K

Differential pressure 1.62 the difference between two pressures

Nearly all industrial processes use liquids, gases, or both. Controlling these processes requires measuring and controlling liquid and gas pressures. Pressure measurement is one of the most important of all process measurements. In practice, many other process variables—flow, level, specific gravity (relative density), and concentration, for example—are measured directly or indirectly by pressure instruments.

In order to work effectively with pressure-measuring devices, you must understand some basic principles of pressure in liquids and gases. This Lesson covers the necessary facts and concepts. The following Lessons in this Unit cover the details of pressure instrumentation.

Properties of Matter

1.01 All matter can be classified as solid, liquid, or gas. Solids have a fixed volume and a fixed shape. Examples include stone, metal, wood, and plastic. Liquids have a fixed volume, but their shape can change. Examples include water, oil, gasoline, and alcohol. Gases have neither a fixed volume nor a fixed shape. Examples include air, carbon dioxide, and steam.

1.02 Almost every substance can be changed from one form to another by changing its temperature, pressure, or both. For example, liquid water changes to solid ice when cooled below the freezing point. Liquid water also changes to gaseous steam when its temperature rises above the boiling point. Steam condenses into liquid water if the pressure increases, even though the temperature remains constant. Solid ice changes to liquid water if the pressure increases, even if the temperature remains constant.

1.03 Liquids and gases can *flow*, because they can change shape. A material that can flow is said to be a *fluid*. Thus, we often speak of fluids rather than of liquids and gases separately. However, pressure is measured differently in liquids and gases. This Lesson will discuss the principles of pressure in liquids first, and then the principles of pressure in gases.

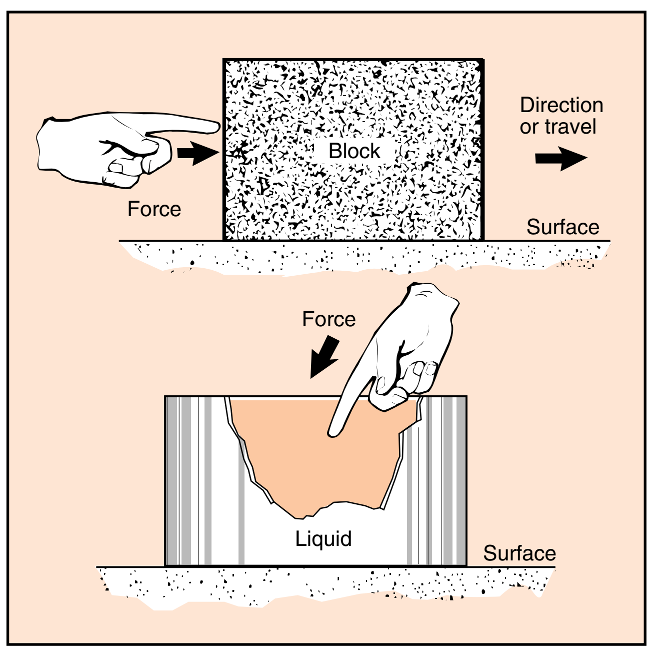
Principles of Liquid Pressure

1.04 Liquids behave differently from solids when a force is exerted on them. Figure 1-1 shows a hand trying to push on a solid and on a liquid. The hand pushing on the solid block meets resistance. That is, the block pushes back on the hand. If the hand pushes hard enough, the block slides.

1.05 The hand pushing on the liquid meets only a little resistance. The liquid simply flows around the hand. Therefore, the hand cannot exert much horizontal force, and it cannot move the container in this way. The liquid inside the container is said to be *at rest*. That is, the liquid has little or no motion. Such a liquid behaves quite differently from a flowing liquid.

1.06 Figure 1-2 on the following page shows a tank with a pressure gauge installed at the bottom. As a liquid is pumped into the tank, the gauge shows increasing pressure as the level of the liquid rises. The bottom and walls of the tank prevent the liquid from flowing out into a flat puddle. The resisting force is equal to the force of the liquid at every point, and the force increases as the liquid rises to higher levels.

Fig. 1-1. Force applied to a solid and a liquid



Application 1-1

Problem:
When to change or backwash the filter medium in a swimming pool filter.

Concern:
A dirty filter medium results in poor water quality and inefficient pump motor performance.

Solution:
Install a pressure gauge in the inlet line to the filter. As debris collects in the filter medium, the gauge will show the increase in pressure required to force the inlet water through the partially clogged medium. When pressure increases by one half of the normal operating pressure, it is time to change or backwash the filter. For example, if normal operating pressure is 12 psig, an increase to 18 psig would signal that the filter needs changing or backwashing.

1.07 *Pressure* is the amount of force applied to a unit of area. To calculate pressure, you divide the force by the area. For example, a force of 10 lb applied evenly over an area of 1 in^2 is a pressure of 10 psi (10 pounds per square inch). A force of 50 lb applied evenly over an area of 5 in^2 is also 10 psi. A force of 1 lb applied to an area of 0.1 in^2 is also 10 psi.

$$\frac{10 \text{ lb}}{1 \text{ in}^2} = 10 \text{ lb/in}^2 = 10 \text{ psi}$$

and

$$\frac{50 \text{ lb}}{5 \text{ in}^2} = 10 \text{ lb/in}^2 = 10 \text{ psi}$$

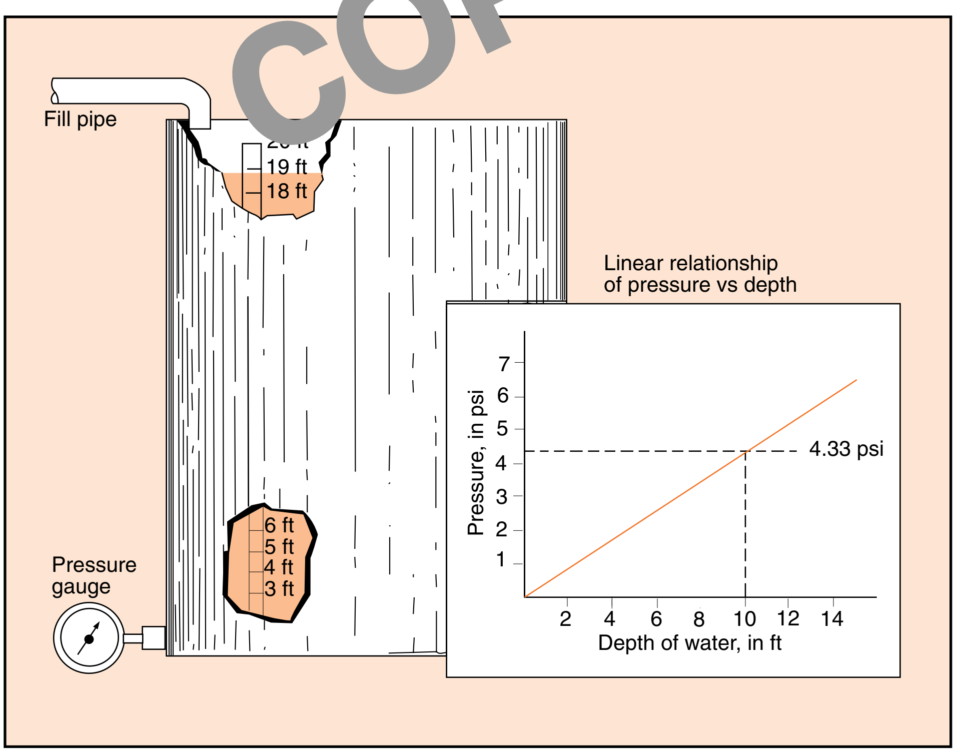
and

$$\frac{1 \text{ lb}}{0.1 \text{ in}^2} = 10 \text{ lb/in}^2 = 10 \text{ psi}$$

1.08 The force used to calculate pressure must act at a right angle to the surface. The part of the force that acts parallel to the surface does not contribute to pressure. You should use only the force that acts at a right angle to calculate pressure.

1.09 Pressure acts equally in all directions in a liquid. Think of a tiny particle of liquid within a container

Fig. 1-2. Linear relationship of pressure and liquid depth



filled with liquid. The surrounding liquid exerts equal pressure on the particle in all directions—from above, from below, and from all sides. The particle also exerts the same pressure on the surrounding liquid. This pressure is the same in all directions—upward, downward, and toward all sides.

1.10 The pressure exerted by a liquid on a particle results from the weight of the liquid above that particle. If the particle is far below the surface, the pressure on it is high. If it is near the surface, the pressure is low. The pressure at the surface of a tank open to the atmosphere is equal to atmospheric pressure. From there, the pressure increases in proportion to the depth. In a tank with a sealed top, the pressure at the surface of the liquid may be high or low. The pressure under the surface increases in proportion to depth, though, just as in an open tank.

Units of Pressure

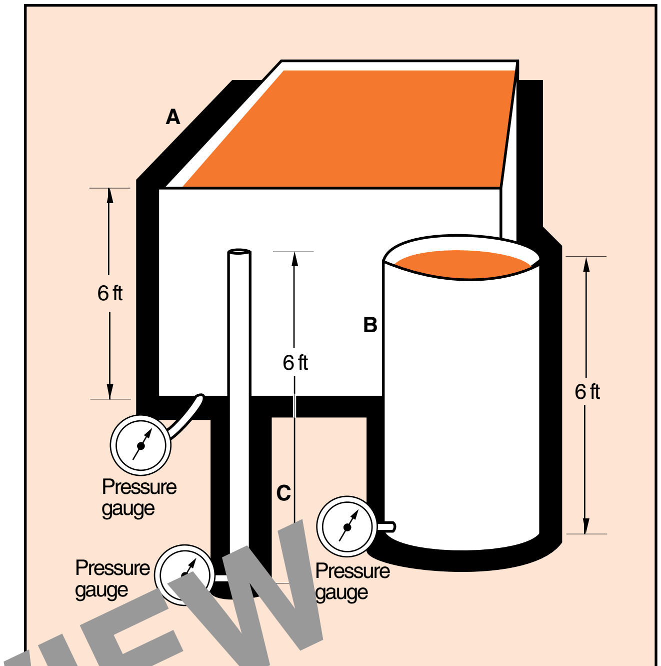
1.11 Pressure may be measured in either *English* or *metric* (also called *SI*, or *Système International*) units. In English units, pressure is measured in pounds (of force) per square inch (of area). In metric (or SI) units, pressure is measured in Newtons (of force) per square meter (of area). A pressure of one Newton per square meter (1 N/m^2) is called one pascal (1 Pa) Atmospheric pressure is 14.7 psi or 101,325 Pa (101.3 kilopascals).

Conditions Affecting Liquid Pressure

1.12 If the liquid in a tank remains at rest, the pressure at any location beneath the surface depends on only three conditions:

- **Surface pressure**. Any pressure acting on the surface (for example, atmospheric pressure if the tank is open) is transmitted throughout the liquid and contributes to the pressure at any location beneath the surface.
- **Depth**. Pressure is proportional to the depth below the surface. Doubling the depth doubles the pressure (after subtracting the pressure acting on the surface).
- **Density**. The pressure is proportional to the density (or relative density) of the liquid. Doubling the relative density doubles the pressure at a point below the surface (after subtracting the surface pressure).

Fig. 1-3. Pressure depends on depth, not volume



1.13 Liquid pressure does *not* depend on the volume of liquid in a tank. If everything else is the same—the depth of the liquid, the kind of liquid, and the amount of pressure on its surface—the pressure at the same depth will be the same in a large vat as in a narrow column of liquid.

1.14 Figure 1-3 illustrates this principle. All three containers hold the same liquid. Container A is a reservoir containing thousands of gallons. Container B is a vat containing a few hundred gallons. Container C is a pipe containing less than one gallon. All are filled to the same depth, and all are open to the atmosphere. The pressure at the bottom is the same in all three containers, as you can see on the three gauges.

Density and Relative Density

1.15 Water often is used as a *reference liquid* in measuring and calculating liquid pressures. The pressure of a liquid may be stated in terms of the depth of water required to produce the same pressure. For example, the pressure at the bottom of a tank of gasoline 6 ft deep may be stated as 3.96 ft of water. Gasoline is lighter than water and, as a result, requires 6 ft of depth to create the same pressure as 3.96 ft of water.

1.16 Water also is used as a reference in comparing the density of liquids or solids. *Density* is the mass per unit volume of material. Water has a density of 1000 kilograms per cubic meter (1000 kg/m^3). Gasoline has a density of 680 kg/m^3, and lead has a density of 11,300 kg/m^3.

1.17 Air is used as the reference to compare the density of gases. Air has a density of 1.22 kg/m^3 at 60°F, and hydrogen has a density of 0.085 kg/m^3.

1.18 The volume of a gas or vapor varies greatly with changes in pressure or temperature. (A *vapor* is a gas that is close to the liquid phase. Steam rising from the surface of boiling water is a common example.) A relatively small change in temperature or pressure can cause a vapor to return to its liquid state. However, as a vapor moves further from the liquid phase, it takes on the characteristics of the "ideal" gas.

1.19 You can use the ratio of the density of a liquid or a solid to the density of water to compare densities. For gas or vapor density comparisons, use the density of air instead of water in the ratio. This ratio is referred to as the *relative density* (also called *specific gravity)* of a material. For example, the relative density of gasoline is 0.68. To calculate this value, divide the density of gasoline by the density of water:

$$\frac{680\ \text{kg/m}^3}{1000\ \text{kg/m}^3} = 0.680$$

Table 1-1. Densities and relative densities of common substances

Substance	Density kg/m³	Specific gravity
Liquids:		
Water	1000	1.00
Methyl alcohol	810	0.81
Nitric acid	1500	1.5
Gasoline	680	0.68
Mercury	13,600	13.60
Solids:		
Aluminum	2700	2.70
Lead	11,350	11.35
Wood (average)	570	0.57
Gases:*		
Air	1.22	1.00
Argon	1.70	1.40
Helium	0.169	0.14
Hydrogen	0.085	0.069
Oxygen	1.35	1.10

*Compared to vapor air at 60°F.

1.20 The relative density of lead is 11.30:

$$\frac{11{,}300\ \text{kg/m}^3}{1000\ \text{kg/m}^3} = 11.30$$

Now use the density of air to find that the relative density of hydrogen is 0.069:

$$\frac{0.085\ \text{kg/m}^3}{1.22\ \text{kg/m}^3} = 0.069$$

1.21 Table 1-1 lists the densities and relative densities of some common materials. Notice that relative density has no unit, only a number. Because relative density is a ratio of two densities, when this ratio is written as a fraction, the units in the numerator and denominator cancel each other out.

1.22 The lack of units means that relative density can be used in either the English or the metric (SI) system. For example, suppose a tank holds 70,000 lb of water. This same tank can hold 47,600 lb of gasoline (70,000 lb x 0.68 = 47,600 lb). A tank that can hold 125,000 tons of nitric acid can hold 83,333 tons of water (125,000 tons ÷ 1.5 = 83,333 tons).

1.23 You also can use relative density to compare pressure in a liquid to the pressure at the same depth in water. The pressure 10 ft below the surface in a tank of water is 4.33 psi. In gasoline, the pressure at 10 ft would be only 2.94 psi (4.33 psi x 0.68 = 2.94 psi). The pressure 21 ft below the surface in a tank of methyl alcohol would be 7.37 psi. If the alcohol were replaced by water, the pressure 21 ft below the surface would be 9.1 psi (7.37 psi ÷ 0.81 = 9.098 psi).

Gauge Pressure and Absolute Pressure

1.24 Most pressure gauges indicate a pressure of 0 psi at the surface of a liquid, even though the pressure is actually 14.7 psi (at sea level) due to atmospheric pressure. All pressures beneath the surface read lower than actual by 14.7 psi. Pressure readings on the gauge show only the effect of the liquid depth. This kind of gauge indicates *gauge pressure*, the difference between measured pressure and atmospheric pressure. It is abbreviated *psig*, meaning pounds per square inch gauge.

Fig. 1-4. Water pressure problem

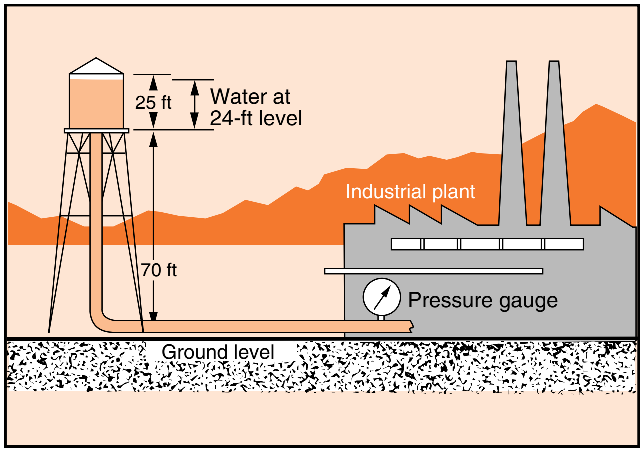
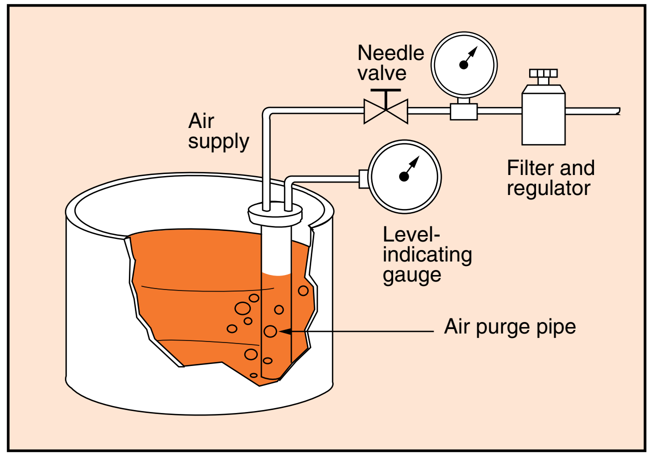


Fig. 1-5. Air purge level-measuring system



1.25 Other gauges indicate *absolute pressure*, actual pressure including atmospheric pressure. Absolute pressure is abbreviated *psia*, meaning pounds per square inch absolute. Because these gauges indicate actual atmospheric pressure—and therefore changes in atmospheric pressure—they also can be used as *barometers* for weather instruments and as *altimeters* to indicate altitude above sea level.

1.26 A *vacuum gauge* is designed to indicate pressures below zero. Gauges that indicate absolute pressure cannot indicate pressures below zero because zero is a perfect vacuum. Note that "vacuum" is actually pressure with a value lower than the prevailing atmospheric pressure.

Application 1-1

Problem:
When to change oil in an automobile engine.

Concern:
Dirty oil reduces performance and can damage internal engine parts.

Solution:
Install a pressure fitting in the engine block and a pressure gauge in the dash. The oil pump forces oil through the filter to remove harmful particles. As the oil gets older and the filter traps more particles, the gauge will show a decrease in the engine oil pressure. The normal operating pressure range is 20 to 60 psig. If the upper range pressure drops below 40 psig, it is time to change the oil.

Using Liquid Pressure Measurements

1.27 Nearly every process industry must measure and control liquid pressures. Pressure measurements indicate flow rates, levels of liquids, and other aspects of processes. The problems in the following paragraphs illustrate three ways of using liquid pressure measurements.

1.28 **Problem 1**. Suppose you need to maintain a minimum water pressure of 35 psig in a plant. To do so, water is pumped into the tank shown in Fig. 1-4. A pressure switch located at ground level turns on the pump when the pressure drops to 35 psig. At what pressure should the switch turn off the pump so that water will not fill the tank above 24 ft?

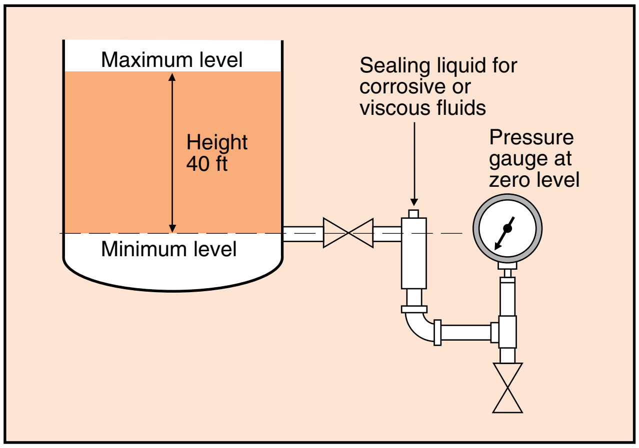
1.29 **Solution 1**. When the tank is filled to a depth of 24 ft, the water surface is 94 ft above the ground. You multiply the pressure per foot of water depth by feet of water depth by the relative density of water to find the pressure due to water:

$$0.433 \text{ psig/ft} \times 94 \text{ ft} \times 1.00 = 40.7 \text{ psig}$$

1.30 **Problem 2.** Figure 1-5 shows a holding tank in a sewage treatment plant. The tank holds a slurry of water and solids. Monitoring the level in the tank is difficult, because the slurry clogs most instruments.

1.31 To measure the level, you can use a *purge pressure system*. This system uses a slow flow of air into a pipe that extends down into the tank. The air pressure holds sewage out of the pipe. Excess air

Fig. 1-6. Pressure gauge level-measuring system



escapes from the open end of the pipe and bubbles up through the slurry. The air pressure in the pipe increases as the level in the tank rises and decreases as the level drops. As the level drops to the bottom of the pipe, the air pressure inside drops to 0 psig.

1.32 Suppose the sewage slurry has a relative density of 1.2. What is the level in the tank if the pressure in the air purge pipe is 15.5 psig?

1.33 **Solution 2**. The pressure in the air purge pipe is equal to the pressure in the slurry at the end of the pipe. Therefore, you can calculate the depth (*D*) of slurry required to create a pressure of 15.5 psig. You multiply the pressure per foot of water depth by feet of slurry depth by the relative density of the slurry:

$$0.433 \text{ psig/ft} \times D \times 1.2 = 15.5 \text{ psig}$$

$$D = \frac{15.5 \text{ psi}}{0.433 \text{ psig/ft} \times 1.2} = \frac{15.5}{0.52} = 29.8 \text{ ft}$$

Solving this equation for *D*, you get:

In other words, the surface of the slurry is 29.8 ft above the end of the air purge pipe.

1.34 **Problem 3**. A storage tank holds molasses for mixing with livestock feed. The viscosity of the liquid makes it difficult to measure. One of the simplest ways to measure the level is by mounting a pressure gauge in line with a pressure tap at the minimum level of the tank. As shown in Fig. 1-6, a sealing liquid can be used to prevent the molasses from entering the pressure gauge.

1.35 As the level changes, the pressure gauge senses the changes in the hydrostatic head of the molasses. (*Hydrostatic* refers to the liquid at rest.) The head is directly proportional to the height of the molasses and its density above the minimum level. If the relative density of the molasses is 3.3, and the maximum tank level is 40 ft above the minimum level, what pressure range must the gauge be able to measure?

1.36 **Solution 3.** You can calculate the maximum pressure for a full tank based on a height of 40 ft. The pressure per foot of water depth times the feet of molasses height times the relative density of molasses equals the maximum level pressure.

$$0.433 \text{ psig/ft} \times 40 \text{ ft} \times 3.3 = 57.2 \text{ psig}$$

The range of the gauge must be at least 0 to 60 psig.

1.37 These problems have shown you how to use pressure as a direct indicator of a liquid's level. The conversion between pressure and level requires that three conditions be met:

- The liquid must be *at rest*.
- The liquid's *relative density* must be known.
- The liquid must have the same relative density throughout its depth.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the REVEAL KEY from the back of the book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. Name the three classifications of matter.	1-1. SOLID, LIQUID, GAS Ref: 1.01
1-2. To calculate pressure, you divide ________ by ________.	1-2. FORCE; AREA Ref: 1.07
1-3. To calculate pressure, you must use only that part of the force that acts at a(n) ________ angle to the surface.	1-3. RIGHT Ref: 1.08
1-4. Three conditions affect the pressure at a point beneath the surface of a liquid at rest. One is surface pressure. Name the other two.	1-4. DEPTH, DENSITY Ref: 1.12
1-5. The reference liquid for calculating relative density is ________, and the reference gas is ________.	1-5. WATER; AIR Ref: 1.16, 1.17
1-6. The difference between gauge pressure and absolute pressure is equal to ________ pressure.	1-6. ATMOSPHERIC Ref: 1.24, 1.25
1-7. To monitor the level of a slurry in a tank, you can use a(n) ________ pressure system.	1-7. PURGE Ref: 1.31
1-8. To use pressure to measure liquid level, the liquid must be ________ and you must know its ________.	1-8. AT REST; RELATIVE DENSITY Ref: 1.37

Gas Pressure and Volume

1.38 A gas differs from a liquid in two important ways.

- A volume of gas weighs much less than an equal volume of liquid. For example, a cubic foot of air weighs only about 0.08 lb. A cubic foot of water weighs 62.4 lb, 780 times as much as air.

- A gas can be compressed or expanded to fit almost any volume. Liquids can expand or compress only slightly, about as much as solids.

1.39 Like solids and liquids, gases are composed of *molecules*. Each molecule has one atom or a combination of two or more atoms, depending on the kind of gas. For example, each molecule of helium is composed of one helium atom. Each molecule of hydrogen is composed of two hydrogen atoms joined together. Air is a mixture of nitrogen, oxygen, carbon dioxide, and other gases. There is no molecule of air, but air is made up of the molecules of nitrogen, oxygen, carbon dioxide, and other gases.

1.40 Gas molecules are constantly moving. They fly around at high speed, in all directions, colliding with each other and with any other molecules in their way. Pressure is caused by these collisions. The harder the collisions, and the more often they occur, the greater the pressure.

1.41 Even a small volume of gas contains an enormous number of molecules. For example, one cubic foot of oxygen weighs 0.089 lb at atmospheric pressure and 32°F (0°C). This cubic foot of oxygen contains about 760,000 billion billion molecules. Most of the volume occupied by a gas is empty space. The volume occupied by the molecules themselves is very small compared to the enormous amount of empty space between and around them.

1.42 To understand how a gas behaves, you can think of how a piston operates in a cylinder of an automobile engine. As the piston enters the cylinder, it decreases the volume in the cylinder. As the piston moves out of the cylinder, the volume increases. How does the decreased volume affect the pressure of the gas that was drawn into the cylinder?

1.43 *Boyle's law* helps answer this question by relating the pressure of a gas to its volume. According to Boyle's law, the pressure of a gas varies inversely with its volume when the gas is held at a constant temperature. This means that pressure increases as piston movement into the cylinder causes the volume to decrease, as shown in Fig. 1-7. As volume decreases, collisions increase among the molecules themselves and also against the cylinder wall. The pressure decreases as piston retraction increases volume in the cylinder. As the volume is increased, the collisions decrease among the gas molecules themselves and also against the cylinder wall.

Gas Volume and Temperature

1.44 Imagine a balloon filled with a certain volume of gas, as shown in Fig. 1-8. Suppose you put this balloon into a box and use a hair dyer to raise the temperature of the air inside the box. How does the increase in temperature affect the volume of gas in the balloon?

1.45 To answer this question, consider *Charles' law*, which states that the volume of a gas varies directly with its absolute temperature at a constant pressure. This means that the volume of gas in the balloon increases as the temperature inside the box increases. As temperature is increased, the motion of the gas molecules increases. As the molecules move apart, the volume increases and the balloon expands. If temperature decreases, the volume of gas also decreases. As temperature is decreased, the motion of the gas molecules decreases, causing them to come together. The volume decreases and the balloon contracts.

Fig. 1-7. Boyle's law

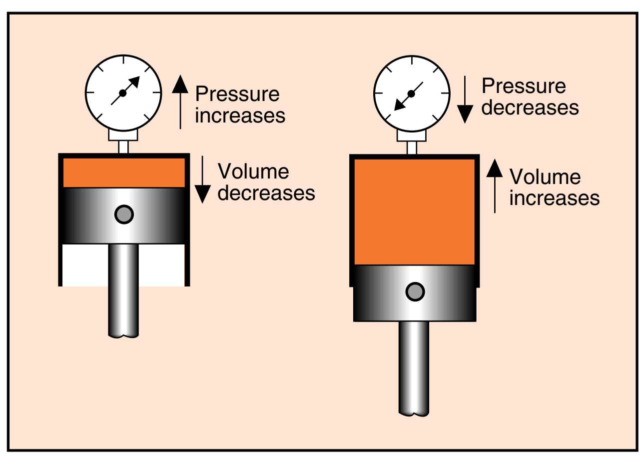
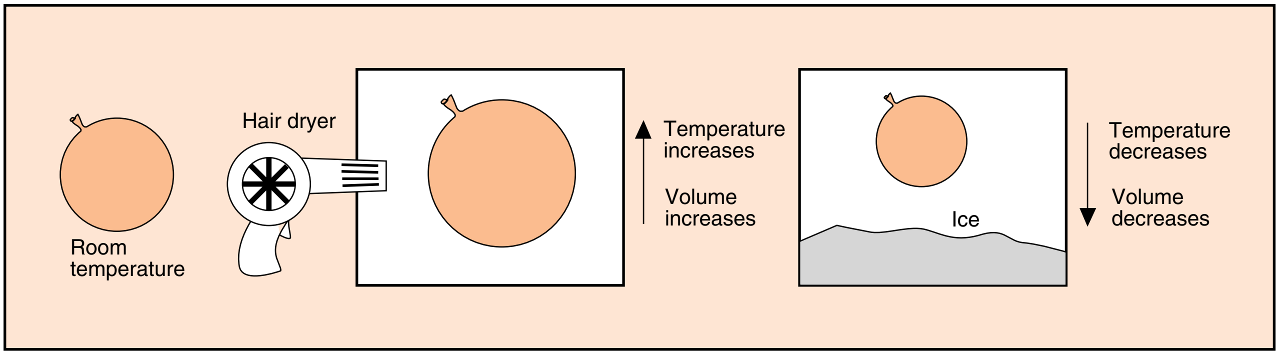


Fig. 1-8. Charles' law



Gas Pressure and Temperature

1.46 Imagine a certain volume of gas in a strong container that cannot change size. Then suppose that this gas is heated to a higher temperature. What will happen to the pressure of the gas?

1.47 To answer this question, you must understand how temperature is related to the motion of the gas molecules. Temperature is an indication of the average speed of a group of moving molecules. The lower the temperature, the slower the molecular motion.

1.48 *Absolute zero* is defined as the temperature at which molecules would stop moving. Although this temperature is only theoretical—that is, it is never actually reached—it is calculated at about -460°F or 0° Rankine (-273°C). As the speed and energy of molecules increase, the temperature rises. At the temperature of freezing water (32°F or 273 K), molecules already have a great deal of energy. The *kelvin*, expressed as K, is the unit of thermodynamic temperature, and is used without the degree symbol. Note that 32°F is equal to 492°R, 0°C, and 273 K, as shown in Fig. 1-9.

1.49 Temperature and molecular energy are proportional to each other. Doubling the *absolute* temperature means doubling the molecular energy. If the temperature increases by 50%, molecular energy increases by 50%. If the temperature of a fixed volume of gas increases from 32°F to 212°F (0°C to 100°C), the *absolute* temperature increases from 492°R to 672°R (273 K to 373 K). This is an increase in temperature of 36.6%. That means the molecular energy—and pressure—increases by 36.6%.

Pressure, Temperature, and Volume Related

1.50 The relationships among pressure, volume, and temperature can be summarized in the following equation:

Fig. 1-9. Temperature scales

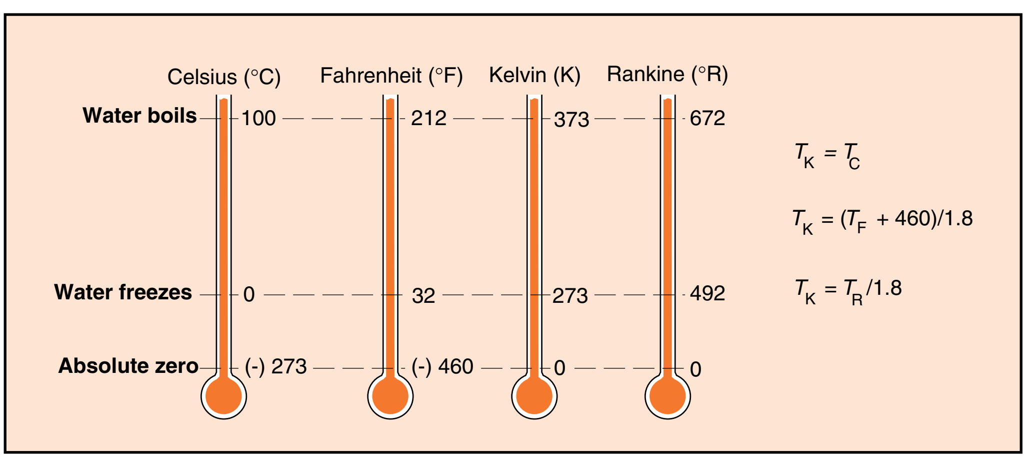
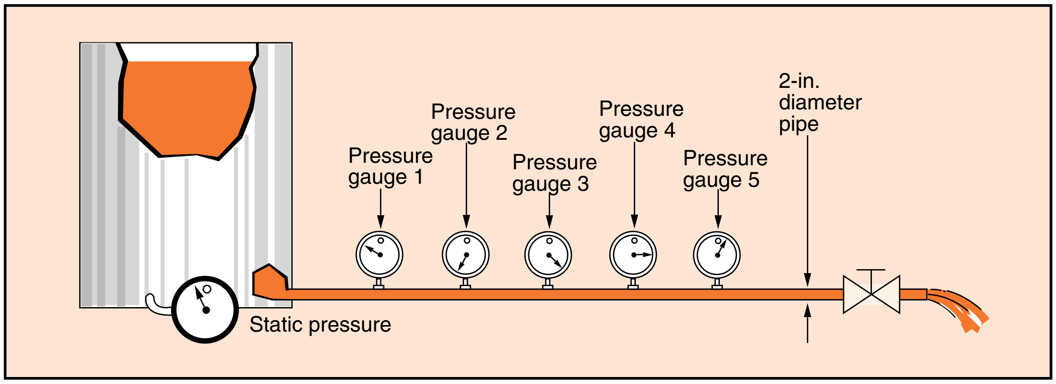


Fig. 1-10. Pressure in a flowing liquid



$$pV = nRT$$

where p = pressure

V = volume

n = number of molecules of gas

R = a constant

T = temperature (absolute)

In other words, *pressure* multiplied by *volume* is equal to the *number* of gas molecules multiplied by a *constant* multiplied by the absolute *temperature*.

1.51 This equation simplifies relationships. For example, if the temperature does not change and the amount of gas does not change, doubling the volume causes the pressure to be halved. Reducing the volume to one-third causes the pressure to be tripled. Also note the constant relationship that can be expressed as:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3}$$

1.52 If the volume of a gas is held constant, changes can occur in pressure as the temperature changes. If the absolute temperature doubles, the pressure doubles. If the absolute temperature is cut in half—for example, from +70°F to -195°F (equivalent to a drop from 530°R to 265°R, or from 294 K to 147 K)—the pressure also is cut in half.

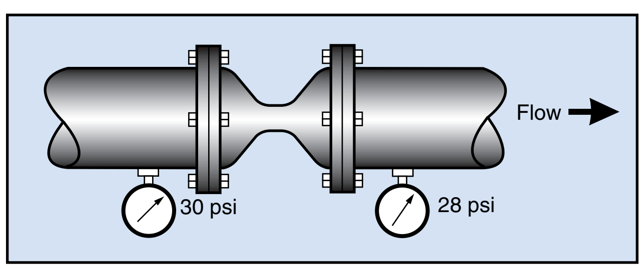
1.53 You can demonstrate this relationship by placing the gas in a cylinder with a movable piston. By keeping a constant force on the piston, you keep the gas under constant pressure. However, because the piston can move, the gas is free to expand and contract. By heating and cooling a gas in a cylinder with a piston, you can demonstrate the resulting changes in the volume of the gas. If you double the absolute temperature, the piston moves and the gas doubles in volume. If you reduce the temperature by half, the piston moves in the opposite direction and the volume is reduced by half.

Atmospheric Pressure

1.54 Atmospheric pressure, like liquid pressure, results from the weight of material above the point at which the pressure is measured. At higher levels, there is less air above the measurement point and the pressure is therefore less.

1.55 Most industrial processes take place on the earth's surface where changes in atmospheric pressure are slight. Although pressure variations caused by the weather are not very large, process instruments must take even these slight changes into account if they control pressure-sensitive processes. Aircraft instruments

Fig. 1-11. Restriction in a pipeline



are designed to allow for greater changes in atmospheric pressure because they operate over a wide range of altitudes.

1.56 Calculating air pressure at various levels in the atmosphere is rather difficult. One reason is that the air at lower altitudes is compressed by the weight of air above it. This compression makes the weight per unit volume greater at low altitudes than at high altitudes. Another reason is that the air temperature is lower at higher altitudes. The lower temperature compresses more air into a certain volume compared to a higher temperature at the same pressure.

Pressure and Flow

1.57 So far, you have considered only fluids at rest. If a liquid or gas flows through a pipe, pressure measurement is somewhat different. For example, Fig. 1-10 shows a 2-in. pipe carrying liquid from a storage tank. The tank is filled with water to a depth of 10 ft. Therefore, the static pressure at the bottom of the tank is 4.33 psig. However, the pressure gauges along the pipe show lower pressures. Whenever fluid flows, its pressure is reduced from the static pressure. If the speed of the fluid increases, the pressure drop is greater.

1.58 The pressure is even lower on the gauges farther out to the right on the pipe. The speed of the flow remains the same all along the pipe, but friction between the pipe and the water causes the pressure to decrease. If the pipe is very long, the pressure drops to near zero.

1.59 Suppose you replace the 2-in. pipe shown in Fig. 1-10 with a 1/4-in. pipe. The pressure gauges will show an even greater pressure loss because the smaller pipe has more resistance to flow. If the valve at the end of the pipe is closed, flow stops. Now all gauges indicate the same pressure because they are all at the same depth. There is no flow or friction to reduce the pressure.

1.60 Friction losses can be reduced by using a pipe with a smooth inner surface. Liquids flow more easily through a smooth plastic pipe than through a rough concrete or cast iron pipe of the same diameter. Friction losses also can be reduced by keeping the pipe as short as possible. Increasing the diameter of the pipe also reduces the pressure loss due to friction.

1.61 Figure 1-11 shows a pipe in which a pressure loss has been created deliberately by placing a narrow restriction in the line. The restriction causes a measurable loss in pressure from one side to the other. The loss in pressure increases as the flow rate increases. Thus, the pressure drop can be used to measure flow rate in the pipe.

1.62 Pressure drop is commonly referred to as *differential pressure* (ΔP). The rate of flow through a restriction in a pipe is proportional to the square root of the differential pressure. Many flow devices are based on this relationship.

1-9. Most of the volume occupied by a gas is ________ space.	1-9 . EMPTY Ref: 1.41
1-10. At a constant temperature, the pressure of a gas varies inversely with its volume, according to ________ law.	1-10. BOYLE'S Ref: 1.43
1-11. Charles' law states that the temperature of a gas varies ________ with its volume at a constant pressure.	1-11. DIRECTLY Ref: 1.45
1-12. Increasing the temperature of a gas, while holding the volume constant, increases the pressure in proportion to the ________ temperature.	1-12. ABSOLUTE Ref: 1.50, 1.51
1-13. The two conditions that cause a pressure drop along a pipe carrying liquid from a tank are ________ and ________.	1-13. MOTION, FRICTION Ref: 1.57, 1.58
1-14. A pipe with a small diameter has ________ resistance to flow than a pipe with a large diameter.	1-14. MORE Ref: 1.59
1-15. Flow can be measured by placing a(n) ________ in a pipe and measuring the pressure drop it causes.	1-15. RESTRICTION Ref: 1.61
1-16. The rate of flow through a restriction in a pipe is proportional to the square root of the ________.	1-16. DIFFERENTIAL PRESSURE Ref: 1.62

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. The three conditions that affect the pressure beneath the surface of a liquid are

- ☐ a. depth, density, and surface pressure
- ☐ b. depth, density, and volume
- ☐ c. volume, density, and surface pressure
- ☐ d. volume, depth, and surface pressure

1-2. Two open tanks contain the same liquid. Tank A contains 500 gal and is filled to a depth of 4 ft. Tank B contains 1000 gal and is filled to a depth of 2 ft. Which tank has the higher pressure at the bottom?

- ☐ a. Tank A
- ☐ b. Tank B
- ☐ c. Both have the same pressure
- ☐ d. Cannot tell from the information given

1-3. The difference between gauge pressure and absolute pressure is equal to

- ☐ a. 0.433 psi
- ☐ b. atmospheric pressure
- ☐ c. a vacuum
- ☐ d. zero

1-4. The pressure at a depth 16 ft in water is about

- ☐ a. 4.33 psia
- ☐ b. 4.33 psig
- ☐ c. 7 psia
- ☐ d. 7 psig

1-5. One difference between a liquid and a gas is that

- ☐ a. a gas can expand and contract more than a liquid can
- ☐ b. a gas weighs more than a liquid
- ☐ c. a liquid is composed of molecules
- ☐ d. a liquid occupies more volume than a gas

1-6. Which of the following causes an increase in gas pressure?

- ☐ a. Decrease in temperature
- ☐ b. Decrease in volume
- ☐ c. Increase in volume
- ☐ d. Less frequent molecular collisions

1-7. If the absolute temperature is increased by 100%, molecular energy is

- ☐ a. decreased by 50%
- ☐ b. decreased by 100%
- ☐ c. increased by 50%
- ☐ d. increased by 100%

1-8. The equation expressing the relationship among the pressure, temperature, and volume of a gas is

- ☐ a. $p = VRT$
- ☐ b. $pV = nRT$
- ☐ c. $pV = RT$
- ☐ d. $V = nRP$

1-9. Like liquid pressure, atmospheric pressure at a point is caused by the

- ☐ a. density of the air at a certain temperature
- ☐ b. temperature of the air in a certain volume
- ☐ c. volume of the air at a certain pressure
- ☐ d. weight of material above the point

1-10. Which of the following is a good way to reduce friction losses in fluid flow?

- ☐ a. Change to smoother pipe
- ☐ b. Decrease the pipe diameter
- ☐ c. Increase the length of the pipe
- ☐ d. Increase the speed of flow

SUMMARY

Pressure is defined as force per unit of area. Pressure acts equally in all directions in a liquid. Its common English unit of measurement is pounds per square inch (psi). Liquid pressure depends on depth, density, and surface pressure, but does not depend on volume.

Water is used as the reference liquid for measurements and calculations involving liquid pressure. Air is the reference for gas calculations. Many gauges indicate zero at atmospheric pressure. Others indicate actual pressure, including atmospheric pressure.

Pressure values can be used to calculate the level of a liquid in a tank or the amount of fluid flowing through a pipe. These calculations then can be used to account for temperature, atmospheric pressure, and the density of the material.

Boyle's law states that the pressure varies inversely with its volume at a constant temperature. According to Charles' law, the temperature of a gas varies directly with its volume at a constant pressure. The relationship among pressure, volume, and temperature can be expressed as $pV = nRT$.

Answers to Self-Check Quiz

1-1. a. Depth, density, and surface pressure. Ref: 1.12

1-2. a. Tank A. Ref: 1.13, 1.14

1-3. b. Atmospheric pressure. Ref: 1.24

1-4. d. 7 psig. Ref: 1.29

1-5. a. A gas can expand and contract more than a liquid can. Ref: 1.38

1-6. b. Decrease in volume. Ref: 1.43

1-7. d. Increased by 100%. Ref: 1.49

1-8. b. $pV = nRT$. Ref: 1.50

1-9. d. Weight of material above the point. Ref: 1.54

1-10. a. Change to smoother pipe. Ref: 1.60