# CHAPTER C15
# COMPRESSED AIR PIPING SYSTEMS

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## *INTRODUCTION*

Compressed air is an often-used utility system found in facilities. It is used to do work by producing linear motion and actuation through a piston and cylinder or a diaphragm for air-actuated valves, doors, dampers, brakes, and so forth. Atomizing and spraying as well as providing the moving force for hard-to-pump fluids are other applications. Compressed air can be bubbled up to measure fluid levels, agitate liquids, and inhibit ice formation in bodies of water. Air circuits also satisfy complex problems in automatic control, starting/stopping, and modulation of valves in machines and processes. This chapter will discuss centrally distributed compressed air piping used in various types of facilities for light industrial and control purposes. Compressed gases for laboratories are discussed in Chap. C16.

## *GENERAL*

Air is a fluid. The two types of fluids are *liquids* and *gases*. A gas has a weaker cohesive force holding its molecules together than does a liquid. Air is a mixture of gases, and its main components are oxygen and nitrogen, with many other gases in minor concentrations. Air is the standard from which specific gravity is calculated, and which can be found by dividing the molecular weight of the subject gas into the molecular weight of air (which is 29).

The actual solid volume that the atomic structure of gas occupies in relation to the total volume of a gas molecule is quite small, so gases are mostly empty space. This is why gases can be compressed. Pressure is produced when molecules of a gas in an enclosed space rapidly strike the enclosing surfaces. If this gas is confined into a smaller and smaller volume, molecules strike the container walls more frequently, producing a greater pressure.

## DEFINITIONS AND PRESSURE MEASUREMENTS

### Definition of Compressed Gases

A compressed gas is any gas stored or distributed at a pressure greater than atmospheric.

### Definitions of Basic Compressed Air Processes

An *isobaric process* takes place under constant pressure.

An *isochoric process* takes place under constant volume.

An *isothermal process* takes place under constant temperature.

A *polytropic process* is a generalized expression for all of the three above processes when variations in pressure, temperature, or volume occur during the compression cycle.

An *adiabatic process* of compression allows a gas to gain temperature. This is the most commonly used process in facility compressed-air production.

### Units of Measurement

Pressure measurements are made using force acting upon an area. In metric (SI) units, the most common method of measuring pressure is in kilograms per square centimeter ($kg/cm^2$) and kilopascals (kPa). In inch pound (IP) units, pressure is expressed as pounds per square inch (psi). For low-pressure measurements in IP units, inches of water column (in WC) is a commonly accepted standard. SI units use kPa.

### Standard Reference Points

The two basic reference points for measuring pressure are *standard atmospheric pressure* and a *perfect vacuum*. When the point of reference is taken from standard atmospheric pressure to a specified higher pressure this is called *gauge pressure*. In SI units, this is expressed as either the preferred kPa or the lesser-used Bars. In IP units it is expressed as pounds per square inch (psi). If the reference pressure level is measured from barometric pressure, it is referred to as *psi gauge pressure* (psig). From a perfect vacuum, the term used is *psi absolute pressure* (psia). Refer to Fig. C15.1 for a graphical relationship between gauge and absolute pressure measurements. For the relationship between SI and IP units to theoretical standard barometric pressure at sea level, refer to Table C15.1. One note of caution: *local barometric pressure*, which is the prevailing pressure at any specific location, is variable and should not be confused with *standard atmosphere*, which is mean theoretical barometric pressure at sea level.

### Normal Air (SI Units) and Standard Air (IP Units)

The terms *standard air* and *normal air* are interchangeable, and are a set of conditions intended to provide design professionals with a common reference that will allow

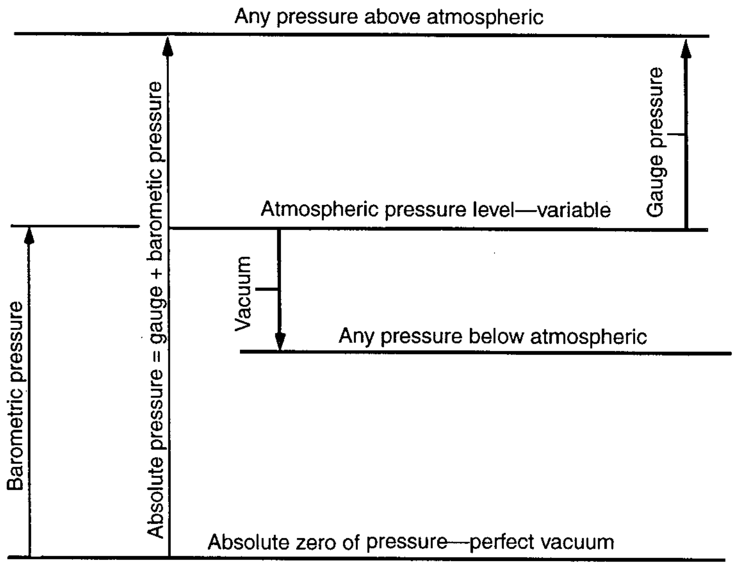



**FIGURE C15.1** Standard reference points.

comparison of various parameters of the air and air compressor performance. *Standard* and *normal* air conditions are not universal, and in fact are different for various disciplines.

The most commonly used standard in the United States is that established by the Compressed Air and Gas Institute, having a relative humidity of 0.0 percent (dry), a temperature of 60°F (15.6°C), and a pressure of 14.7 psig (101.4 kPa). For the ASME Performance Test Code (PTC-9) and the chemical industry, standard air has a relative humidity of 36 percent, a temperature of 68°F (20°C), and a pressure of 14.7 psig (101.4 kPa). Some manufacturers use a relative humidity of 36 percent, a temperature of 68°F (20°C), and a pressure of 14.2 psig (98 kPa) for performance test ratings. It is imperative that the conditions under which a compressor rating and flow rate are calculated by the manufacturer be obtained when selecting a compressor.

All references in this chapter to standard air, unless specifically noted otherwise, shall mean those established by the Compressed Air and Gas Institute (0.0 percent relative humidity, 60°F [15.6°C] temperature, and 14.7 psig [101.4 kPa] pressure).

**TABLE C15.1** Relationship of Pressure in Various SI and IP Units to Theoretical Standard Barometric Pressure at Sea Level

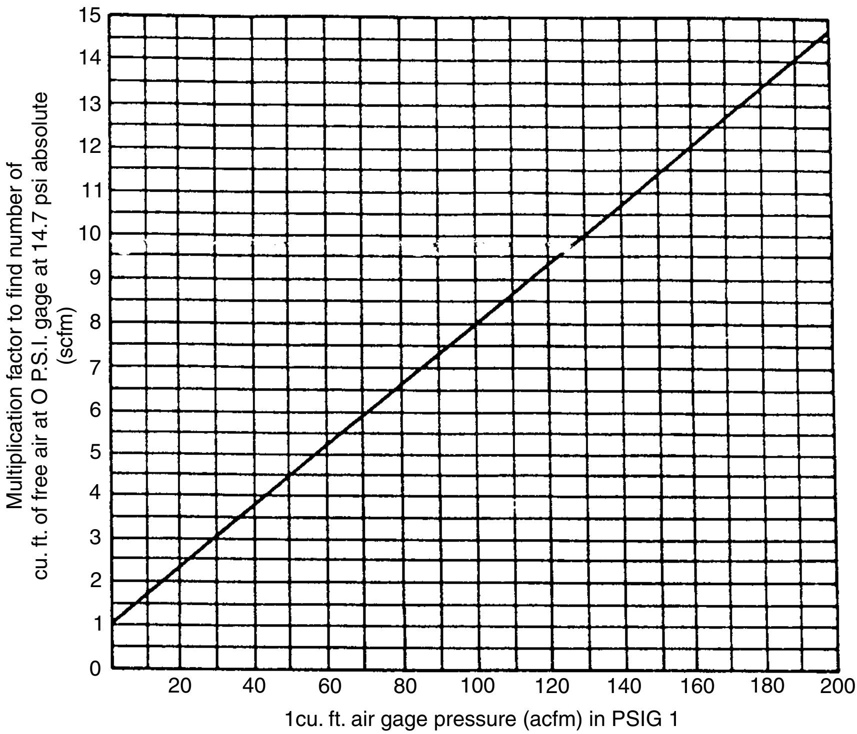
| Torr | kPa | In Hg | M Bar | Psia | Psig |
|---|---|---|---|---|---|
| 760 | 101.4 | 29.92 | 1000 | 14.696 | 0.0 |

## Free Air

*Free air* is air at ambient conditions at a specific location. The term free air is not complete unless the ambient temperature, moisture content, and barometric pressure conditions at the specific location are stated. To convert free air to compressed air equivalents at different pressures, refer to Fig. C15.2.

## Flow Rate Measurement

The most common measurements of flow rate in SI units are cubic meters per minute ($m^3$pm), liters per minute (lpm), and liters per second (l/s). IP units generally use cubic feet per minute (cfm). If the flow rate is low, cubic feet per hour (cfh)




To find the free air equivalent for 100 acfm of compressed air refer to the vertical line at 100 psi, go up to the diagonal, then horizontal to the left, to find the multiplier of 8. Then, 100 × 8 = 800 scfm

1. Multiply psig by 6.9 to obtain KPa
2. Multiply scfm by 0.5 to obtain nl/s

**FIGURE C15.2** Ratio of compression-free air to compressed air.

is commonly used. It is mandatory that all equipment selection flow rate criteria be in the same units.

In order for the flow rate measurement to have any validity, it must reference standard air conditions. For SI units, these reference terms are normal liters per second (nlps) and normal liters per minute (nlpm). Some manufacturers use normal cubic meters per minute ($nm^3m$) or normal liters per minute (nlm). For IP units, standard cubic feet per second (scfs) and standard cubic feet per minute (scfm) are most commonly used.

### Actual Cubic Liters (feet) per Minute—aclm (acfm)

Actual cubic liters per minute aclm (acfm) is a volume measurement of standard air after being compressed. The terms aclm and acfm are not complete unless the pressure is stated.

## PHYSICAL PROPERTIES OF AIR

Because free air is less dense at higher elevations, air at the same pressure will occupy a greater volume at higher elevations. A correction factor must be used to determine the equivalent volume of air. Refer to Table C15.2 for the elevation correction factor. To use this table, multiply the volume of standard air at sea level by the correction factor to find the equivalent volume of standard air at the higher elevation.

**TABLE C15.2** Elevation Correction Factor

| Altitude, ft | Meters | Correction factor |
|---|---|---|
| 0 | 0 | 1.00 |
| 1600 | 480 | 1.05 |
| 3300 | 990 | 1.11 |
| 5000 | 1500 | 1.17 |
| 6600 | 1980 | 1.24 |
| 8200 | 2460 | 1.31 |
| 9900 | 2970 | 1.39 |

Temperature is also a consideration. Because an equal volume of free air at a higher temperature will exert a higher pressure (or occupy a greater volume at the same pressure) than air at a lower temperature, a correction factor must be used to determine the equivalent volume of air at different temperatures. Refer to Table C15.3 for the temperature correction factor. To use this table, multiply the volume of standard air at 0 psig sea level by the correction factor to find the equivalent volume of standard air at the higher elevation.

The volume relationship of air compressed to a higher pressure to that of free air can be found in Fig. C15.2.

**TABLE C15.3** Temperature Correction Factor

| Temperature of intake, °F | °C | Correction factor | Temperature of intake, °F | °C | Correction factor |
|---|---|---|---|---|---|
| −50 | −46 | 0.773 | 40 | 4 | 0.943 |
| −40 | −40 | 0.792 | 50 | 10 | 0.962 |
| −30 | −34 | 0.811 | 60 | 18 | 0.981 |
| −20 | −28 | 0.830 | 70 | 22 | 1.000 |
| −10 | −23 | 0.849 | 80 | 27 | 1.019 |
| 0 | −18 | 0.867 | 90 | 32 | 1.038 |
| 10 | −9 | 0.886 | 100 | 38 | 1.057 |
| 20 | −5 | 0.905 | 110 | 43 | 1.076 |
| 30 | −1 | 0.925 | 120 | 49 | 1.095 |

## WATER VAPOR IN AIR

Air contains varying amounts of water vapor depending on its temperature and pressure. When a given volume of free air is compressed, an increase in temperature generally occurs. Increased temperature results in an increased ability of air to retain moisture. An increase in pressure results in a decreased ability to hold water. With each 20°F (12°C) increase in temperature, the ability of air to accept water vapor doubles. Because of the high temperature given to air in a compressor during the compression cycle, no water will be precipitated inside the compressor, but it

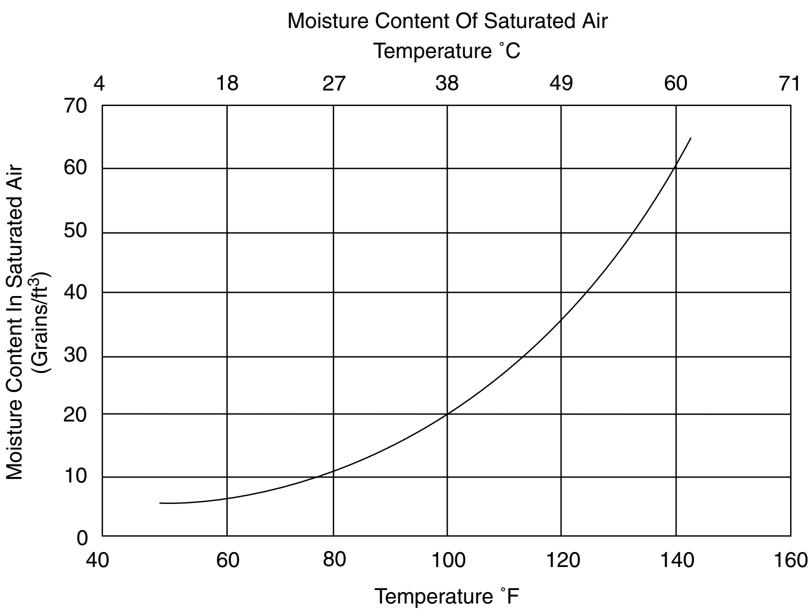
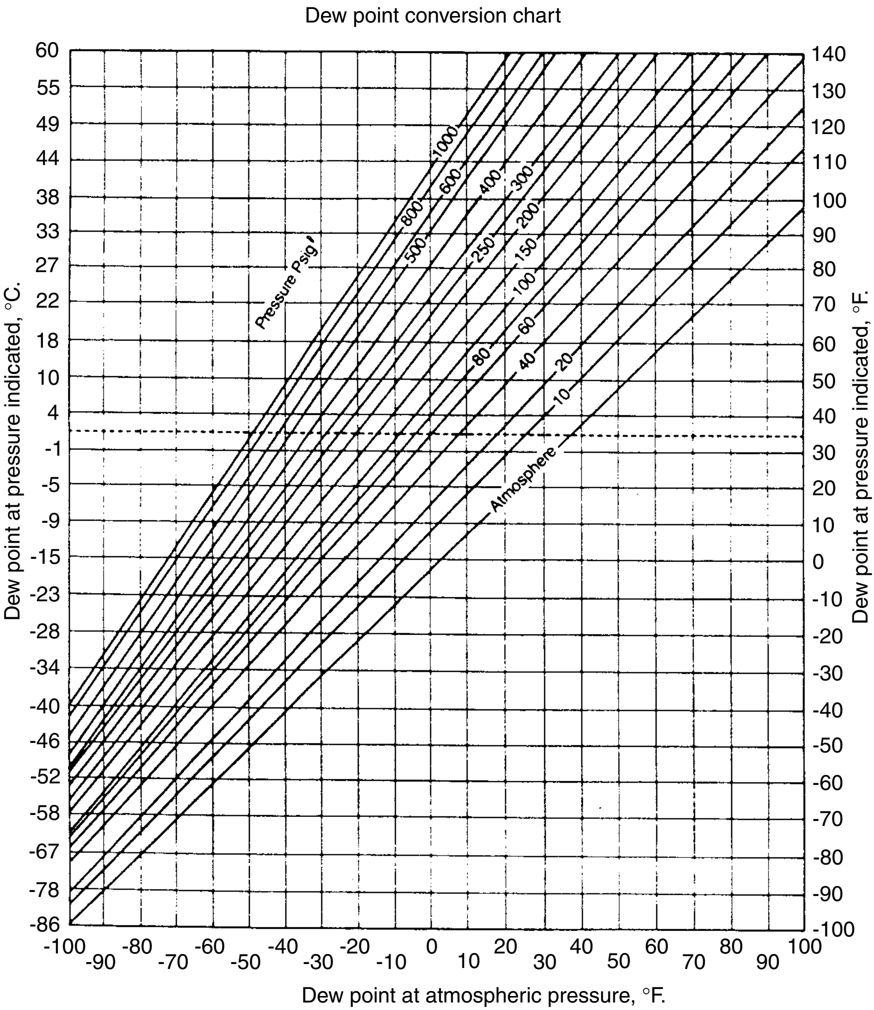



**FIGURE C15.3** Moisture content of saturated air.




Courtesy Hankison Corp.

Note: 1 multiply pressure in psig by 6.9 to obtain kPa

Dew point conversion:
To obtain the dew point temperature expected if the gas were expanded to a lower pressure proceed as follows:

1. Using "dew point at pressure", locate this temperature on scale at right hand side of chart.
2. Read horizontally to intersection of curve corresponding to the operating pressure at which the gas was dried.
3. From that point read vertically downward to curve corresponding to the expanded lower pressure.
4. From that point read horizontally to scale on right hand side of chart to obtain dew point temperature at the expanded lower pressure.
5. If dew point temperatures at atmospheric pressure are desired, after step 2 above read vertically downward to scale at bottom of chart which gives "Dew point at atmospheric pressure".

**FIGURE C15.4** Dew point conversion chart.

**TABLE C15.4** Weight of Water Vapor in Air*

| Temp. | | RH% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| °C | °F | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| −1 | 30 | 3 | 5 | 7 | 9 | 12 | 14 | 17 | 19 | 21 |
| 4 | 40 | 4 | 7 | 10 | 14 | 16 | 18 | 20 | 22 | 24 |
| 10 | 50 | 6 | 10 | 14 | 20 | 26 | 32 | 38 | 42 | 48 |
| 18 | 60 | 8 | 16 | 22 | 30 | 39 | 48 | 54 | 62 | 70 |
| 22 | 70 | 11 | 21 | 34 | 44 | 55 | 66 | 78 | 88 | 100 |
| 27 | 80 | 16 | 30 | 46 | 62 | 78 | 92 | 108 | 125 | 140 |
| 32 | 90 | 21 | 42 | 65 | 85 | 108 | 128 | 158 | 173 | 195 |
| 38 | 100 | 29 | 58 | 87 | 116 | 147 | 176 | 208 | | |

* Grains of moisture/lb of dry air and standard barometric pressure.

will precipitate in the piping system after the cycle has been completed. There are various methods of expressing the amount of water vapor present.

### Relative Humidity

*Relative humidity* is the amount of water vapor actually present in air, expressed as a percent of the amount capable of being present when the air is saturated. Relative humidity is dependent on both pressure and temperature. The moisture content of saturated air at atmospheric conditions is shown in Fig. C15.3.

### Dew Point

The *dew point* is that temperature at which water in the air will start to condense on a surface and is the preferred method to express the dryness of compressed air. The dew point of compressed air is not affected by its temperature. The lower the dew point, the dryer the air. Since the dew point of air varies with the air pressure, it must be referred to as the *pressure dew point*. Fig. C15.4 is a conversion chart to convert from one pressure dew point to another.

The relationship of dew point to weight of water per cubic meter (foot) of air at a constant temperature is about the same for all different pressures in the range common to facility compressed air systems. Refer to Table C15.4 for the weight of water vapor in air at different temperatures and relative humidity values. For a conversion table giving different methods expressing moisture content of air and their numerical values, refer to Table C15.5.

## IMPURITIES AND CONTAMINATION

The level of protection from various impurities and contaminants in compressed-air systems depends upon the proposed use of the air. Performance criteria for each individual system must be determined prior to selection of any equipment, along with identification and quantifying of pollutants. There are four general classes of contamination in compressed-air systems: (1) *liquids* (oil & water), (2) *vapor* (oil, water, and hydrocarbons), (3) *gas*, and (4) *particulates*.

### Liquids

Water enters a system with the intake air, passes through the compressor as a vapor, and condenses afterwards into liquid droplets. Most liquid oil contamination originates at the intake location or in an oil-lubricated compressor. As liquid molecules are swept through the system at velocities approaching 4000 feet per minute, ft/min (1240 meters per minute, m/min) they gradually erode obstructions in their path by repeated collisions; when water settles on pipes, corrosion begins; at end use, it ruins machinery and tools, and causes product rejection and product contamination. At high temperatures, oils break down to form acids. With particulates, oil will form sludge. Oil can also act like water droplets and cause erosion. Liquid chemicals react with water and corrode surfaces. Water also allows microorganisms to grow.

### Vapor

Oil, water, and chemical vapors enter the system in the same manner as liquids, and contribute to corrosion of surfaces in contact with the air. Oil vapor reacts with oxygen to form varnish buildup on surfaces. Various chemicals cause corrosion and are often toxic.

### Gas

Gases such as carbon dioxide, sulfur dioxide and nitrogen compounds react with heat and water to form acids.

### Particulates

Particulates enter the system from the air intake, originate in the compressor due to mechanical action, or are released from some air drying systems. These particles erode piping and valves or cause product contamination. However, the most harmful effect is clogged orifices or passages of tools and so forth at end-use points. These particulates include metal fines, carbon and Teflon particles, pollen, dust, rust, and scale. Organisms enter through the inlet and reproduce in a moist warm environment.

### Combating Contamination

The following principles apply regarding contamination in compressed-air systems:

1. There is no safe level of liquids in the air stream. They should be removed completely.
2. The level of acceptable water vapor varies with end-use requirements. A dew

**TABLE C15.5a** Moisture Content of Air*

| Dew point, °F | Dew point, °C | Grains moisture lb air | # Moisture lb air | Grains moisture cu/ft air | PPM | Vol. per cent |
|---|---|---|---|---|---|---|
| 110 | 44 | | .0600 | | 60,000 | |
| | | 400 | | 25 | | 9 |
| | | | .0500 | | 50,000 | 8 |
| | | | | | | 7 |
| 100 | 38 | 300 | | 20 | | |
| | | | .0400 | | 40,000 | |
| | | | | | | 6 |
| | | | | 15 | | |
| 90 | 33 | | | | | 5 |
| | | | .0300 | | | |
| | | 200 | | | | |
| | | | | | | 4 |
| 80 | 27 | | | | | |
| | | 150 | .0200 | 10 | 20,000 | |
| | | | | 9 | | 3 |
| 70 | 22 | | | 8 | | |
| | | 100 | .0150 | | 15,000 | |
| | | 90 | | 7 | | 2 |
| | | 80 | | 6 | | |
| 60 | 18 | | | | | |
| | | 70 | .0100 | | 10,000 | |
| | | 60 | .0090 | | 9,000 | 1.5 |
| | | | .0080 | | 8,000 | |
| 50 | 10 | | | | | |
| | | 50 | .0070 | | 7,000 | 1 |
| | | 40 | .0060 | 3 | 6,000 | .9 |
| 40 | 4 | | | | | |
| | | | | | | .8 |
| | | | .0050 | | 5,000 | |
| | | 30 | | | | .7 |
| | | | .0040 | 2 | 4,000 | |
| | | | | | | .6 |
| 30 | −1 | | | | | |
| | | 20 | .0030 | 1.5 | 3,000 | .5 |
| | | | | | | .4 |
| 20 | −5 | | | | | |
| | | | .0020 | 1 | 2,000 | .3 |
| | | 10 | | .8 | | |
| 10 | −9 | | | | | |
| | | 8 | .0010 | .6 | 1,000 | .2 |
| | | 6 | .0008 | | 800 | |
| 0 | −15 | | | | | |
| | | | .0006 | .4 | 600 | .1 |
| | | 4 | | | | .08 |

**TABLE C15.5b** Moisture Content of Air

| Dew point, °F | Dew point, °C | Grains moisture lb Air | # Moisture lb air | Grains moisture cu/ft air | PPM | Vol. per cent |
|---|---|---|---|---|---|---|
| −10 | −23 | | | | | |
| | | | .0004 | | 400 | .06 |
| | | 2 | | .2 | | |
| −20 | −28 | | | | | .04 |
| | | | .0002 | | 200 | |
| −30 | −34 | 1 | | .1 | | |
| | | .8 | | .08 | | .02 |
| | | .6 | .0001 | .06 | 100 | |
| −40 | −40 | | .00008 | | 80 | |
| | | .4 | .00006 | .04 | 60 | .01 |
| | | | | | | .008 |
| −50 | −46 | | .00004 | | 40 | |
| | | .2 | | .02 | | .006 |
| | | | | | | .004 |
| −60 | −52 | | | | | |
| | | | .00002 | | 20 | |
| | | .1 | | .01 | | |
| | | .08 | | .008 | | .002 |
| −70 | −58 | | .00001 | | 10 | |
| | | .06 | .000008 | .006 | 8 | |
| | | .04 | .000006 | .004 | 6 | .001 |
| −80 | −67 | | | | | .0008 |
| | | | .000004 | | 4 | .0006 |
| | | .02 | | .002 | | .0004 |
| −90 | −78 | | | | | |
| | | | .000002 | | 2 | |
| | | .01 | | .001 | | .0002 |
| −100 | −86 | .008 | | | | |
| | | | .000001 | .0008 | 1 | |

***Source:*** Hankison Corp.

point of −30°F (−34°C) is required to minimize corrosion in pipelines. For critical applications a dew point of −100°F (−73°C) may be required. Oil vapor remaining in the air should be as close to zero as practical. Chemical concentration should be reduced to zero, where practical.

**3.** Gases in any quantity that are potentially harmful to the system or process requirements should be reduced to zero, or to a point that will cause no harm, depending on practical considerations. Condensable hydrocarbons should be removed as completely as practical.

**4.** Particulate contamination must be reduced to a level low enough to minimize end-use machine or tool clogging, cause product rejection or contaminate a process. These values must be established by the engineer and client, and will vary widely. The general range of particle size in a typical system are between 10 to .01 $\mu$ ($10^{-3}$ in) in diameter. All organisms, living and dead, can be removed with a 0.20 micron absolute filter.

When selecting appropriate and specific components for contaminant removal, there is no single type of equipment or device that can accomplish complete removal. Objective performance criteria must be used to determine the desired reduction level and the means to achieve such removal. Such criteria must include pressure drop, efficiency, dependability, service life, energy efficiency, and ease of maintenance. Contaminant removal will also be discussed under individual system components.

## AIR COMPRESSORS

The purpose of an air compressor is to concentrate free air into a smaller volume, thereby increasing its pressure. There are two general categories of air compressors; the *positive displacement* and the *dynamic types*. Positive displacement compressors can be further separated into *reciprocating* and *rotary* machines. Typical reciprocating compressors include piston and diaphragm types. Rotary compressors include sliding vane, liquid ring (or liquid piston), and screw types. The most widely used dynamic compressors are the centrifugal and axial flow types.

The positive displacement compressor is essentially a constant volume, variable pressure machine capable of operating over a wide range of discharge pressures at a relatively constant capacity. Positive displacement compressors include sliding vane, liquid ring, and helical lobe compressors.

Dynamic compressor characteristics are the opposite to those just described. Dynamic compressors operate over a relatively wide range of capacity at a relatively constant discharge pressure.

### Reciprocating Compressor

A reciprocating compressor is a positive displacement machine. This is accomplished by a moving piston in a cylinder. When compression occurs on only one stroke it is called a *single-acting cylinder*, and when air is compressed on both strokes the machine is called a *double-acting compressor*. The cylinders can be horizontal, vertical, or angled. The cylinders can be sealed and lubricated with oil when traces of oil in the discharge air will cause no problems. Oil-free machines are also available at a higher cost.

### Sliding Vane Compressor

Sliding vane compressors operate by utilizing vanes mounted eccentrically in a cylindrical rotor which are free to slide in and out of slots. As the rotor turns, the space between the compressor casing and the vanes decreases, and the air is compressed.

The best application is for use where small, low-capacity compressors are required, generally in the range of 100 cfm and up to 75 psi (2830 lpm and up to 518 kPa).

### Liquid Ring Compressor

Liquid ring compressors, sometimes referred to as *liquid piston*, are rotary positive displacement units that use a fixed blade rotor in an elliptical casing. The casing is partially filled with liquid. As the rotor turns, the blades set the liquid in motion. As they rotate, the blades extend deeper into the liquid ring, compressing the trapped air.

The resulting air is completely oil-free. This type of compressor will also handle wet, corrosive, or explosive gases. This unit is well-suited for hospital and laboratory use, with a practical limitation of 100 psi (690 kPa).

### Straight Lobe Compressor

Straight lobe compressors function in a manner similar to a gear pump. A pair of identical rotors, each with lobes shaped like the figure 8 in cross section, are mounted inside a casing. As they rotate, air is trapped between the impeller lobes and pump casing, carrying it around without compression.

### Rotary Screw Compressor

Rotary screw compressors use a pair of close-clearance helical lobe rotors turning in unison. As air enters the inlet, the rotation of the rotors causes the cavity in which air is trapped to become smaller and smaller, increasing pressure. The air reaches the end of the screw at high pressure and flows out smoothly at the discharge port.

### Centrifugal Compressor

Centrifugal compressors are dynamic machines that utilize impellers to impact kinetic energy to the air stream by centrifugal action. The velocity of the air is increased as it passes through each impeller. A diffuse section decelerates the high-velocity, air, converting the kinetic energy into potential energy. The volute increases the pressure further and directs the air into the discharge piping.

Centrifugal compressors typically produce large volumes of air at relatively low pressures. Higher pressures can be attained by additional stages with intercooling between stages.

## *AFTER COOLERS*

An aftercooler is a device used to lower the temperature of compressed air immediately after the compression process. A secondary function, due to the lower temperature, is to remove moisture that would otherwise condense elsewhere in the system as the air cools to ambient conditions. The unit is installed as close to the compressor discharge as practical. An aftercooler is also useful to first precondition air where additional conditioning is necessary. There are three general types of aftercoolers:

1. Water-cooled
2. Air-cooled
3. Refrigerant cooled

If a facility has a plentiful supply of reusable and/or recirculated cooling water, the first choice would be a water-cooled aftercooler. These units are selected on the basis of maximum inlet compressed air temperature, highest temperature and quantity of cooling water available, desired outlet compressed air temperature, and maximum flow in cfm of compressed air. Typical cooling capacity will bring the compressed air to within 10 to 15°F (6 to 9°C) of the water temperature used for cooling. This figure is often called the *approach* temperature because of how close the temperature of the compressed air comes to, or approaches, the temperature of the cooling medium.

A refrigerant type of aftercooler is rarely used. If, due to job conditions, one is required, consult manufacturer's literature for applications. Used for this purpose, a refrigerated aftercooler will follow the same principles for air dryers, which will be discussed later in this chapter.

Since large amounts of water are usually removed from the air in an aftercooler, a moisture separator is often provided. The separator could be either an integral part of the aftercooler or a separate unit. A typical aftercooler and separator are illustrated in Fig. C15.5.

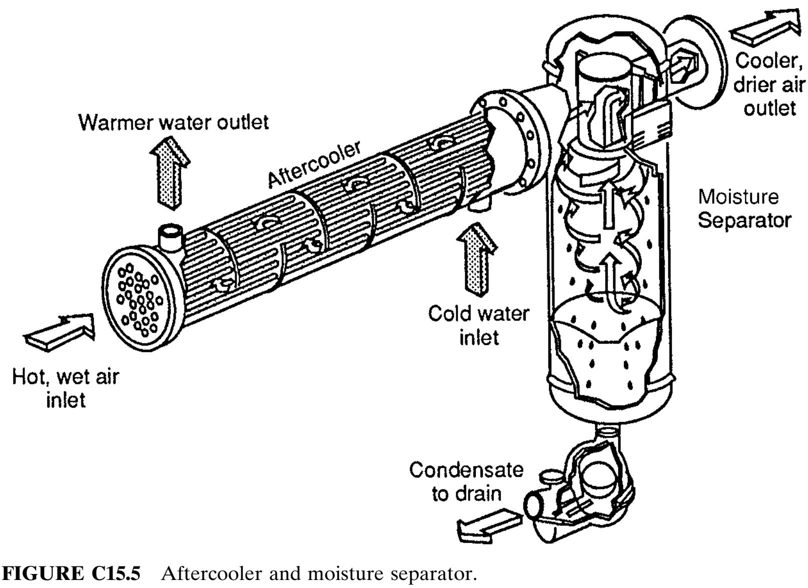



**FIGURE C15.5** Aftercooler and moisture separator.

## COMPRESSED AIR RECEIVERS

The primary purpose of a receiver is to store air. A secondary purpose is to even out pulsations from a compressor. The determination as to the need for a receiver is always based on the type of regulation the system will use. If the compressor runs 100 percent of the time and has constant blow-off, an air receiver will not be required.

For most applications, an air compressor is regulated by starting and stopping, with a receiver used to store air and prevent the compressor from cycling too often. Generally accepted practice for reciprocating compressors is to limit starts to about 10 per hour, with a maximum running time of 70 percent Centrifugal, screw, and sliding vane compressors are best run 100 percent of the time.

An air receiver serves the following purposes:

1. Storage of air
2. Equalize pressure variations (pulsations)
3. Collects residual condensate

Piping connections should be made in such a way that the incoming air is forced to circulate and mix with the air already inside the tank before being discharged. Receivers should be designed in accordance with Section VIII, Pressure Vessels Division 1, of the ASME Boiler and Pressure Vessel Code. An automatic drain valve is required for the receiver. Manufacturers have standard receiver sizes, measured in gallons of water capacity.

There is no generally accepted method of sizing receivers. They should be sized on the basis of system demand and compressor size, using the starts per hour and running time best-suited for the project. The design engineer must keep in mind that the compressor will operate to satisfy the pressure switch rather than the use of air, and the receiver is an integral part of the system that must function in respect to load conditions, amount of storage, and pressure differential. Often, the manufacturer has a standard size receiver for specific compressor models. An often-used formula to find the receiver size is:

$$T = \frac{V \times (P1 - P2)}{C \times Pa} \tag{C15.1}$$

where $T$ = time receiver will go from the upper to lower pressure limits, min
$V$ = volume of tank, $\text{ft}^3$
$P1$ = maximum tank pressure, psia
$C$ = free air needed, scfm
$Pa$ = atmosphere pressure, psia
$P2$ = Minimum tank absolute pressure, psia

## COMPRESSED AIR DRYERS

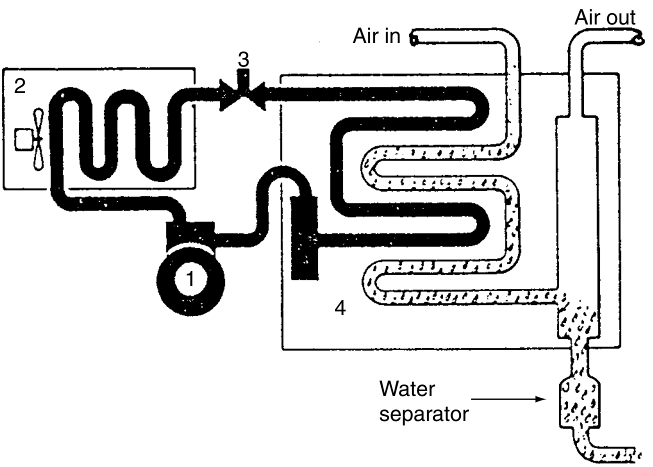
Large volumes of water consisting of larger droplets are removed from compressed-air systems by a moisture separator. If additional reduction of water vapor content is desired, it must be accomplished by the use of an air dryer. There are five general methods of drying compressed air: (1) high pressurization of the compressed air,

(2) refrigeration (condensation), (3) absorption, (4) adsorption, and (5) heat of compression.

### High Pressurization Dryer

High pressurization reduces water vapor by compressing air to greater pressures than that required for actual use. When pressure is increased, it decreases the ability of air to hold moisture. Since pressurization requires large amounts of energy, this process is rarely used.

Typical refrigerated dryer




Major components
of the refrigerated air dryer

1. Refrigeration compressor: A hermetically sealed motor driven compressor operates continuously. It generates a high pressure refrigerant gas.
2. Hot gas condenser: The high pressure refrigerant gas enters an air cooled condenser where it is partially cooled by a continuously running fan.
3. Automatic expansion valve: The high pressure liquid enters an automatic expansion valve where it thermodynamically changes to a subcooled low pressure liquid.
4. Heat exchanger: A system of coils where dry air is produced.

**FIGURE C15.6** Typical refrigerated dryer. (*Courtesy Arrow Pneumatics.*)

### Refrigeration (Condensation) Dryer

Commonly called a refrigerated air dryer, the condensation-type dryer utilizes the principle of lowering the temperature of the airstream through a heat exchanger, producing a lower dew point. The lower dew point reduces the capacity of air to retain moisture. Moisture condenses out of the air onto the coils of the dryer, and then drains out of the unit by gravity. The cooling medium in the coil could be water, brine, or a refrigerant. The most common type uses a refrigerant. A schematic diagram of a refrigerated air dryer is shown in Fig. C15.6.

To be most effective, a refrigerated dryer requires operation within a narrow range of temperature, pressure, and flow rate. All cycling refrigerated air dryer ratings and capacity are based on National Fluid Power Association manual T/3.27.2 (Recommended Practice for Refrigerated Air Dryers), with saturated entering inlet air at 100°F (38°C) and 100 psig (690 kPa), with 100°F (38°C) ambient temperature. At these standard conditions, the dryer must be capable of producing outlet air with a dew point in a range of between 33° to 39°F (0° to 5°C) and a pressure drop of 5 psig (34 kPa), or less. For correction factors when selecting a unit based on other factors, refer to Table C15.6. To select a refrigerated dryer based on pressure drop and rated flow, refer to Fig. C15.7, entering with the actual pressure of the compressed air and an allowable pressure drop through the unit.

The advantages of refrigerated air dryers are that they have a low operating cost and do not introduce impurities into the airstream. The greatest limitation is that they cannot practically produce a pressure dew point lower than 35°F, (2°C); otherwise the condensed moisture would freeze on the coils. For practical purposes, a figure of between 37° to 40°F (3° to 4°C) is generally used. In some cases, reheating of the dried air may be necessary because the low air temperature may produce condensation on the discharge pipe exterior. General operating cost is moderate. An adjacent floor drain is necessary to remove condensate. Initial cost is moderate.

### Absorption Dryer

Also known as *deliquescent* dryers, absorption dryers use either solid or liquid medium, and operate on the principle of having the airstream pass through or over

**TABLE C15.6** Correction Factors for Refrigerated Air Dryers

| Inlet air pressure | | Inlet air temperature | | Ambient air temperature | |
|---|---|---|---|---|---|
| Pressure psig* | Correction factor | Temperature °F/°C | Correction factor | Temperature °F/°C | Correction factor |
| 50 | 1.19 | 80/27 | .66 | 80/27 | .92 |
| 75 | 1.06 | 90/32 | .82 | 90/32 | .95 |
| 100 | 1.00 | 100/38 | 1.00 | 100/38 | 1.00 |
| 150 | .95 | 110/43 | 1.21 | 110/43 | 1.07 |
| 175 | .94 | | | | |
| 255 | .92 | 120/49 | 1.42 | 120/49 | 1.16 |

* Multiply psig by 6.9 to obtain kPa.

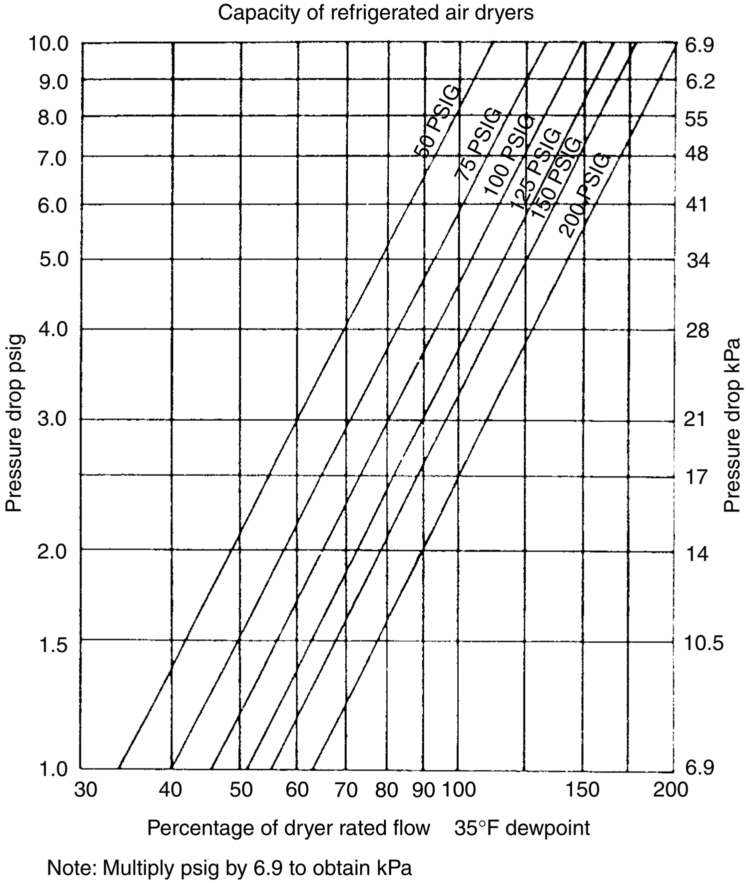



**FIGURE C15.7** Capacity of refrigerated air dryers.

a deliquescent medium. This medium changes state (or dissolves) in the presence of water. The resulting solvent is then drained away, removing the water and reducing the amount of material available for absorption. Solid absorbers are much more common than liquid. The advantage of this type of dryer is that it requires no outside source of power or connection to any other system. Only a floor drain is required to drain off the moisture. A deliquescent dryer using a solid medium is illustrated in Fig. C15.8.

The deliquescent dryer is the least efficient method of drying compressed air, but it requires no power to operate, and the initial cost is the lowest of any type of dryer. It has a moderate operating cost, since only the drying medium must be replenished at regular intervals. This type of dryer loses efficiency if the inlet air temperature is over 100°F (38°C), and so an efficient aftercooler is mandatory. The type of deliquescent material used will effect the quality of air. Salt-type deliquescent dryers normally reduce dew points about 12° to 20°F (7° to 12°C), while potassium carbonate will lower the dew point about 30°F (18°C). A filter is necessary after

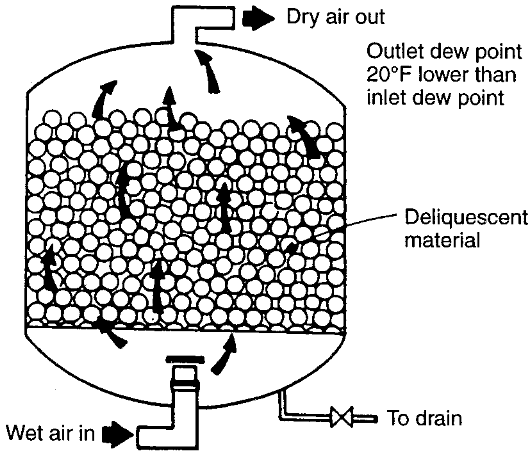



**FIGURE C15.8** Solid-type deliquescent dryer.

the dryer to prevent any drying medium carryover (fines) from entering the piping system.

## Adsorption Dryer

Adsorption dryers, also known as *desiccant dryers*, use a porous, nonconsumable material that causes water vapor to condense as a very thin film on the material's surface. This material is called a *desiccant*. There is no chemical interaction, and the adsorption process is reversible. Desiccant dryers will produce the lowest pressure dew points, often as low as −100°F (−73°C). A typical twin-tower desiccant dryer is illustrated in Fig. C15.9.

The method of regeneration is the primary way of distinguishing between types of desiccant dryers. The two general types of regeneration method are *duplex bed pressure swing* (heatless) dryers and *heat-activated* (internal-or external-type heaters). Pressure swing types use approximately 15 percent of the compressor capacity to dry one bed while the other is operating. The addition of heat reduces the amount of purge air necessary.

Desiccant materials include silica gel, activated alumina, and aluminosilicate (molecular sieve). Each material also has application for removal of specific impurities other than water. Desiccant materials will age in use over a period of years, which may affect capacity. In addition, care must be taken to avoid contamination of the material by impurities in the air stream, particularly oils. An aftercooler is usually recommended for most dryer installations because it is an economical way to reduce the moisture content of air, and should be selected in conjunction with the dryer.

The twin-tower (pressure swing) desiccant dryer will produce the lowest dew points. They are the highest in initial cost and the highest in operating cost. The pressure-swing purge is the fastest, but it uses about 15 percent of system air for purging. Too high an incoming air temperature is detrimental to the desiccant material. An aftercooler is usually recommended for most desiccant dryer installa-

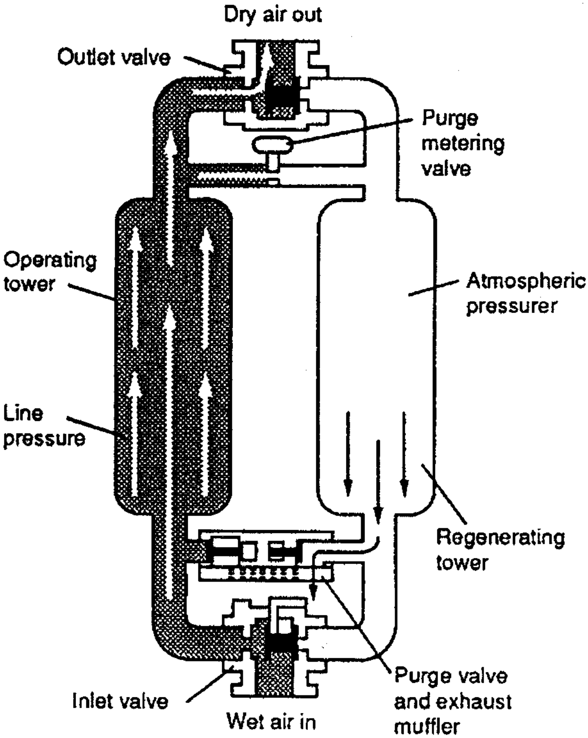



**FIGURE C15.9** Pressure swing twin-tower desiccant dryer.

tions because it is an economical way to reduce the moisture content of air, and should be selected in conjuction with the dryer.

## Heat of Compression Dryer

This type of dryer also uses a desiccant to adsorb the moisture in the compressed air stream. The material is housed in a rotating shell that uses the hot air directly discharged from the compressor before it goes into the aftercooler. The desiccant material in one portion of the drum is regenerated while the air stream from the compressor is dried in the other portion. The difference between this and the pressure-swing type is that for continuous duty the pressure swing regenerates one whole bed at once, requiring a second bed to dry the air stream. The heat of compression dryer has only one bed that rotates and regenerates a portion of the desiccant material on a continuous basis, leaving the remainder of the bed to dry the air also on a continuous basis. The air used to regenerate the desiccant is then returned into the main air stream. There are no regeneration air losses or electric heaters used. This dryer could be cooled by a fan (air cooled) or water cooled. Units that are cooled with ambient air at 95°F (35°C) often give a compressed air pressure dew point of −10°F (−23°C).

**TABLE C15.7** General Performance of Different Types of Air Dryers

| | Inlet air capacity at 100°F (38°C) | | | | Outlet air at 100°F ambient (38°C) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dryer type | Flow, scfm[1] | Press[2] psig | Max. temp. °F | Moisture, % RH | Pressure[2] psig | Moisure, °F pdp | Cooling | Power required | Prefilter | Afterfilter | Installation |
| Deliquescent | 5–30,000 | 100 | 100 38°C | Saturated | 95 | 80 (27°C) | None | None (requires replenishment of drying medium) | Recommended | Required* | Indoor and outdoor |
| Refrigerated | 5–25,000+ | 100 | 130 | Saturated | 95 | 35 to 50 (2 to 10°C) | Air at 100°F (38°C) or water at 85°F (30°C) | Electrical‡ | Recommended | Not required | Indoor |
| Desiccant, regenerative | 1–20,000 | 100 | 120 | Saturated | 95 | −40 to −100 (−40 to −86°C) | None | Electrical + 7% purge air, steam + 7% purge air, or dry air (15 to 35% of system capacity) | Required§ | Recommended | Indoor and outdoor |

* Some deliquescent dryers have built-in afterfilters. Do not add an additional filter (energy consumer) to the system if unnecessary.

† Higher flow rates will not damage, but air quality is reduced and pressure drop incresed. Not sensitive to oil and particulate.

‡ The thermal refrigeration type of refrigeration dryer is the only one that does not run continuously. A thermostatically controlled switch turns the refrigeration unit on as needed.

[1] Multiply scfm by 0.5 to obtain nl/s.

[2] Multiply pressure in psig by 6.9 to obtain kPa.

PDP = pressure dew point.

The heat of compression dryer does not require additional compressor capacity. It does require an electrical supply for a fan that is used for additional cooling.

### Dryer Selection Considerations

The single most important requirement in the dryer selection process is to determine the lowest pressure dew point required for the intended application. This may eliminate some types of dryers. An excessive flow rate may eliminate other dryer types. The economics of initial and operating costs between various units will also be determining factor. Space conditions should also be considered. When different degrees of dryness are required in a facility, it is more economical to use a point-of-use dryer at the specific location rather than to dry the air used by the entire facility to the lower figure.

The following information shall be obtained or calculated in order to select a dryer.

1. Determine the lowest required pressure dew point. This information is usually supplied by the facility based on the equipment that will be used.
2. Obtain from the compressor manufacturer the temperature of the air at the inlet of the dryer.
3. Determine maximum system pressure.
4. Determine maximum flow rate for the system.
5. Determine whether electrical power is available where the dryer is to be installed.
6. Refer to a manufacturers catalog to select the required dryer capable of meeting these requirements. Consideration should be given to initial and operating costs.

A comparison of the general performance for different types of dryers is given in Table C15.7.

## *FILTERS AND SEPARATORS*

The purpose of any filter or separator is to reduce or remove impurities or contaminants, other than water vapor, in the airstream to an acceptable or predetermined level. Filters operate by having the air stream pass through a porous, granular, or other type of medium. A separator is generally a passive mechanical device that removes large particles of a liquid, such as water and oil.

### Filter Nomenclature

Filter nomenclature has been developed based on the individual type of filter medium and generally where it is placed in a compressed air system. Inlet filters, prefilters, afterfilters, and point-of-use filters are some examples. Generally speaking, nothing prevents any kind of filter from being used for any application, provided that the required reduction of contaminants is achieved and it is suitable for the intended purpose. Following is a brief discussion in general terms of various types of filters.

Inlet filters of some type are required for every installation to protect the compressor from damage. They remove large amounts of contaminants at the inlet to the air compressor. These filters are integral in compressors that draw air from the room they are installed in, and separate units for compressors that take air from the outside.

Prefilters are generally used before air enters a dryers, to remove various contaminants that might foul the unit. These filters are usually of the coalescing type so as to remove particulates and vapors such as oil, hydrocarbons, and water. When combined with separators at this point, these filters may be called *separator/filters*.

Afterfilters are generally used after the drying process to remove smaller particulates than those handled by a prefilter. Some dryers produce a very-small-diameter dust (fines) that must be removed from the airstream. These filters remove particulates only.

Point-of-use filters are generally used immediately prior to any individual tool or piece of equipment that requires removal of particulates of a smaller size than an after-filter.

Oil removal filters are special filters used only for removal of unwanted amount of oil aerosols too small to be removed by coalescing.

Activated carbon filters are used to remove gaseous oil and other hydrocarbons as well as particulates too small to be removed by coalescing.

Separators are a type of filter used to remove large quantities of liquid water or oil, individually or in combination with each other, from the air stream. Oil and water often form an emulsion inside the compressor and are discharged together.

## CONTAMINATION REMOVAL

Contaminants are removed from compressed-air systems by (1) mechanical separation (interception), (2) coalescence, (3) adsorption, or (4) a combination of all these principles.

### Mechanical Separation

Mechanical separation, often referred to as a *depth* or *membrane-type* filter, is used to remove solid particles from the airstream. The filter element is a thick material or a thin sheet or membrane whose passages are smaller than the particles to be retained. Dirt, scale, dust, and other solid particles are intercepted and held in the matrix of the filter element.

### Coalescing

Coalescing filters are used to remove aerosols from the airstream. This is accomplished by impingement of the small-diameter aerosols onto a passive portion of the device that causes them to randomly collide and merge into larger droplet that drain from the filter by gravity.

## Adsorption

Adsorption is used to remove vapors from the airstream by causing the contaminant molecules to be trapped into the small pores of the filter medium. To be effective this medium should have a very high surface-to-volume ratio.

## Combination Filters

Combination filters use two or more filtration principals in a single unit. Manufacturers should be consulted to obtain the most effective combinations to remove specific contaminants.

## Specialized Filters

***Intake Air Filters.*** Intake air filters are required for every installation to protect the compressor from damage. A properly selected air filter will return dividends in the form of reduced wear and maintenance by assuring that sufficiently clean air is supplied to the compressor.

Intake air can be taken from either the outside or from the room where the compressor is installed. The air must be clean and free of foreign matter such as leaves or insects, solid and gaseous impurities, and abrasive dust particles. In addition, the air should be as cold as possible in order to increase compressor efficiency. In certain urban locations and industrial applications, air is often contaminated with corrosive and acid gases, which might damage the compressor. Unusual volumes of any objectionable contaminant gas in vapor or aerosol form must be considered. Filters should have the following characteristics:

1. High efficiency. The filter should remove large amounts of particulates from intake air and allow them to accumulate on the filter elements while keeping a low pressure drop.
2. Large storage capacity of particulates before requiring replacement due to reduced flow of intake air.
3. Low resistance to flow of intake air.
4. Mechanically and structurally sound. Filters must be capable of withstanding any possible air pressure surge as well as resistance to physical damage.

Filters for intake air fall into the following general categories:

1. *Paper filters.* These are dry and disposable, consisting of corrugated paper, usually impregnated by some material to improve performance. Filter efficiency is high with low pressure drop when new. Paper filters are not recommended for inlet air temperatures greater than 150°F (64°C) or where strong air pulsations may occur (as with some piston compressors). They are recommended for air compressors of any capacity.
2. *Felt Filters.* These are dry, reusable, pleated felt elements, often reinforced with wire screens. These filters have a large particulate capacity. They are cleaned by using compressed air or by washing, as per manufacturers' instructions. Recommended for oil-free air and other compressors of any capacity.
3. *Oil-wetted labyrinth filters.* These are reusable, of metal construction, and use

the principle of separating particulates by rapid changes of direction, causing particles to adhere on surfaces wet by a film of oil. These filters require careful maintenance to ensure that the oil surface neither drys out nor becomes saturated. Recommended for small-capacity units of up to about 100 cfm (2.9 cmm) and where large amounts of particulates are present at inlet.

4. *Oil bath filters.* These filters are reusable, with an improved type of wetted labyrinth, using a surface of liquid oil to trap particulates. This filter has large capacity of particulates, usually equal to the weight of oil in the filter. Careful maintenance is required to regularly change the oil. If an unloader is used on the air compressor, there is a potential for the oil to be blown out of the filter. These filters are recommended where large amounts of particulates are present at inlet.

For most installations, the design engineer would select the inlet location, and investigate known and potential pollutants based on the intended use of the air. This is ideally obtained from many tests of air at the proposed intake location taken over several months spanning the different seasons and at different times of the day. This is rarely possible. In some urban areas, tests have already been taken by some authority such as the state or federal Environmental Protection Agency (EPA) or a health department. In actual practice, during the design phase of a project, tests could be taken and analyzed if required. Then the purity of air for final use should be determined. With this criteria, the inlet filter, based on the type of compressor used, can be selected. manufacturers, with a knowledge of their own product line, should be consulted to recommend filter types capable of meeting the established criteria. Refer to Table C15.8 for typical inlet air filter characteristics.

For outdoor installations, provide a weatherproof rain cap and an insect screen around and over the actual inlet. Do not locate close to any exhausts or vent pipes.

**TABLE C15.8** Inlet Air Filter Characteristics

| Filter type | Filtration efficiency —% | Particle size $\mu$m | Maximum drop when clean —in. $H_2O$ | Comments (see key) |
|---|---|---|---|---|
| Dry | 100<br>99<br>98 | 10<br>5<br>3 | 3–8<br>75–200 Pa | (1) |
| Viscous impingement (oil-wetted) | 100<br>95<br>85 | <br>20<br>10 | ¼–2<br>6–50 Pa | (2) (3) |
| Oil bath | 98<br>90 | 10<br>3 | 6–10 = nominal (150–250 Pa)<br>2 = low drop 50 Pa | (2) (3) (4) |
| Dry with silencer | 100<br>99<br>98 | 10<br>5<br>3 | 5 (125 Pa)<br>7 (175 Pa) | |

(1) Recommended for non-lubricated compressors and for rotary vane compressors in a high dust environment. (2) Not recommended for dusty areas or for non-lubricated compressors. (3) Performance requires that oil is suitable for both warm and cold weather operation. (4) Recommended for rotary vane compressors in normal service.

The inlet should be mounted no less than 3 ft (1 m) above roof or ground level, or above possible snow level.

***Separators.*** Separators are a type of filter used to remove large quantities of liquid water or oil, individually or in combination with each other, from the air stream. Oil and water often form an emulsion inside the compressor and are discharged together. The purpose of an oil separator is to remove oil present in the air stream, regardless of the quantity or form (drops, aerosol, or vapor). An oil separator can be selected to obtain any degree of removal. Separators can be combined with integral air filters to increase the efficiency of the combined unit. They can also be provided with integral drain traps. If not, a separate drain trap shall be provided. Oil and moisture separators should never be considered similar types of units, as their functions are quite different.

There are two general types of separators: *passive* and *active*. The passive type uses no moving parts and depends on the impaction of the liquid on internal surfaces, along with coalescence, for its effectiveness. Active units use moving internal parts (often centrifugal action) to remove liquid drops.

Since suspended liquids are present in air leaving the aftercooler or compressor, the best location to prevent the liquids from entering the piping network is at that point.

## Filter Selection

Just as the degree of contamination in compressed air varies, so do the requirements for purity of the system and at various points of use. These requirements must be established prior to the selection of filters in the system.

Filters should be selected by their ability to meet established design criteria. The manufacturer, who is the most knowledgeable about specific conditions, should be consulted as part of the selection process. The following items must be considered:

1. Maximum flow rate expected
2. Desired pressure drop across filter
3. Temperature of air stream
4. Contaminants to be removed (requirement for filter type and housing material)
5. Pressure rating
6. Is drain trap required? (automatic type preferable)
7. Is a sampling port required?
8. Filter efficiency

### *Filter Selection Procedure*

1. Calculate the maximum flow rate of air expected. This figure should be in the same units as the manufacturer's rating units, usually in scfm.
2. Determine the lowest pressure that the filter can be expected to operate with during operation. This pressure must be used in conjunction with the pressure lost in other system equipment.
3. Based on the filter's position in the system, determine what the contaminant or contaminants to be removed will be.

4. Determine the maximum pressure drop across the filter. Manufacturers often use such values as ''wetted pressure drop'' and ''dry pressure drop'' that do not take into consideration dirty elements. The average pressure drop ranges between 6 and 10 psig (41 to 69 kPa).
5. Determine whether monitoring of the filter element for replacement (such as watching for a color change) be required.
6. Select the appropriate filter from a manufacturer's catalog.

The two most important factors to consider when selecting a filter are effectiveness and pressure drop. Do not specify a filter that will produce cleaner air than actually necessary. If one station or process requires a purity much higher than all other points, use a point-of-use filter for only that area and a less restricted filter for the main supply. It is possible for a filter to have the largest pressure drop of any equipment in the system. In general, a filter will produce a 3 to 10 psig (21 to 69 kPa) pressure drop when dirty. If the actual figure proves to be too high, it would be a good idea to oversize the filter to cut down the pressure drop, or to use two filters in parallel. In most cases, it would be more economical to pay the added initial cost of a larger or second filter than to increase energy requirements to compress air to a higher pressure for the life of the system.

## SILENCERS

With today's emphasis on noise control, the installation of an intake silencer will probably be necessary for most projects. There are two types of silencers: *reactive* and *absorptive*. The reactive type is used to attenuate (reduce) low-frequency sound in the order of 500 cycles per second (cps), which is most often found on reciprocating compressors. The absorptive type is often used on centrifugal and screw type compressors, where frequencies are above 500 cps. There is no practical limit in cfm for either type.

The selection of a silencer should be made in conjunction with the manufacturer. In order to accomplish this, it will be necessary for the engineer to determine two things: (1) the sound power level of the compressor (which data must be obtained from the compressor manufacturer) and (2) the highest level of sound permitted by the Occupational Safety and Health Administration (OSHA), local authorities, or facility personnel. With the establishment of this design criteria, selection of a silencer can be made if the final level of sound desired is included in the specifications. This will allow the various manufacturers to suggest the correct silencer for that purpose, for final acceptance by the engineer.

Silencers may be combined with the inlet filter for a more economical installation. They could also be mounted directly on the compressor or at the roof level as separate units.

## COMPRESSOR REGULATION

If the total system demand for both air pressure and volume exactly matched the compressor output for as long as the compressor is operating, no regulation would be required. This does not usually happen, however, as whenever system demand varies it will be necessary to regulate the compressor. Some means must be found to adjust output to match the variable demands of the system.

Compressor capacity can be regulated either by *continuous* or *discontinuous* methods. Continuous means would require control of the compressor by using either an adjustable speed coupling or control of the drive motor speed. Another method would be to bleed compressed air from the discharge either to atmosphere or back into the inlet. This is called *unloading* or *blow-off,* and is wasteful of energy. Yet another would be alteration of the internals of a compressor; by adjusting valves, clearances, and so forth. The last method is the least desirable of all, because the correct speed and the adjustment of the compressor internal can only be determined and accomplished by the manufacture for specific projects. This makes it almost impossible for maintenance personnel to repair in the field.

Discontinuous regulation is the most common method of controlling compressor capacity. This is accomplished by using a pressure-regulating device (either mechanical or electro mechanical) arranged to stop the compressor at a preset high pressure and start it again a preset low pressure. A receiver (tank) is used to store air. This gives a reserve capacity to keep the compressor from starting too often. Often, a compressor is allowed to run a predetermined minimum time each time it is started to avoid potential problems.

## STARTING UNLOADER

The starting unloader is used only when starting a compressor. After the first time pressure has been established in the system and the compressor has stopped, the system remains pressurized. When the compressor must start again, it has to overcome the force exerted by the air remaining under pressure inside the casing. There is not enough power in the drive motor to overcome this pressure. Therefore, a means must be provided to vent only the air under pressure in the compressor casing to atmosphere, and to allow the compressor to start under no load. This is done with a starting unloader.

## PIPING NETWORK DESIGN

### General

The compressed air system must be controlled, regulated, and sized to ensure that an adequate volume of air, at a pressure and purity necessary to satisfy user requirements, is delivered to the most remote outlet during the period of heaviest anticipated use. Some safety factor must be also incorporated into the system design to accommodate additional pressure drop for some period of extremely high use if appropriate for the facility.

The design process is an iterative one, because the performance of one or several components may have an effect on the performance of other equipment. Therefore, various adjustments will usually be necessary as the design progresses.

### Design Sequence

1. Locate and identify each process, work station, or piece of equipment using compressed air. This is known as the *total connected load.* These elements

should be located on a plan, and a complete list should be made to simplify record keeping.

2. Determine volume of air used at each location.
3. Determine pressure range required at each location.
4. Determine conditioning requirements for each item, such as allowable moisture content, particulate size, and oil content.
5. Establish how much time the individual tool or process will be in actual use for a specific period of time. This is referred to as the *duty cycle.* This information will help determine the simultaneous-use factor by eliminating some locations during periods of use at other locations.
6. Establish the maximum number of locations that may be used simultaneously on each branch, main, and for the project as a whole. This is known as the *use factor.*
7. Establish the extent of allowable leakage.
8. Establish any allowance for future expansion.
9. Make a preliminary piping layout, and assign preliminary pressure drop.
10. Select the air compressor type, conditioning equipment, equipment and air inlet locations making sure that consistent scfm (scmm) or acfm (acmm) is used for both the system and compressor capacity rating.
11. Produce a final piping layout, and size the piping network.

## DISCUSSION OF ITEMS IN THE DESIGN SEQUENCE

### Project Air-Consuming Device Locations

This speaks for itself. In order to accomplish this task, the location of all air-consuming devices and their requirements should be marked on a plan in order to facilitate the piping layout. For future reference prepare a list of all devices noted on the plans, their location, and actual flow rates.

### Pressure and Flow Rate Requirement

All tools use air either through an orifice or to drive a piston to do work. The data relative to pressure and flow rate parameters for individual equipment and tools are usually obtained from the manufacturer, end-user, facility planner, or owner. It is quite common for this information to be incomplete, with additional investigation required to find the specific values needed. Very often, it is useful to assign preliminary pressure and flow rate requirements of the system, in order to arrange equipment space and give preliminary mechanical data to other disciplines. Table C15.9 lists general air requirements for various tools. For equipment that may have only orifice size and/or piston information, Table C15.10 gives the amount of air in cfm passing through an orifice at various pressures, and Table C15.11 provides the actual volume of air required to drive a single-acting piston. The figures should be doubled for double-acting pistons.

The best method is to obtain actual equipment cuts from the proposed equipment manufacturer.

## Compressed-Air Purification

The selection of purification and conditioning equipment depends upon end-use requirements, usually obtained when items 2, 3, and 4 in the design sequence are

**TABLE C15.9** General Air Requirements for Tools

| Tools or equipment | Size or type[a] | Air pressure, psi | Air consumed, scfm[b] |
|---|---|---|---|
| Hoists | 1 ton | 70–100 | 1 |
| Blow guns | | 70–90 | 3 |
| Bus or truck lifts | 14,000-lb cap | 70–90 | 10 |
| Car lifts | 8,000-lb cap | 70–90 | 6 |
| Car rockers | | 70–90 | 6 |
| Drills, rotary | ¼-in cap | 70–90 | 20–90 |
| Engine, cleaning | | 70–90 | 5 |
| Grease guns | | 70–90 | 4 |
| Grinders | 8″-in wheel | 70–90 | 50 |
| Grinders | 6″-in wheel | 70–90 | 20 |
| Paint sprayers | Production gun | 40–70 | 20 |
| Spring oilers | | 40–70 | 4 |
| Paint sprayers | Small hand | 70–90 | 2–7 |
| Riveters | Small to large | 70–90 | 10–35 |
| Drills, piston | ½-in cap, 3-in cap | 70–90 | 50–110 |
| Spark plug cleaners | Reach 36–45 | 70–90 | 5 |
| Carving tools | | 70–90 | 10–15 |
| Rotary sanders | | 70–90 | 50 |
| Rotary sanders | | 70–90 | 30 |
| Tire changers | | 70–90 | 1 |
| Tire inflaters | | 70–90 | 1½ |
| Tire spreaders | | 70–90 | 1 |
| Valve grinders | | 70–90 | 2 |
| Air hammers | Light to heavy | 70–90 | 30–40 |
| Sand hammers | | 70–90 | 25–40 |
| Nut setters and runners | ¼-in cap to ¾-in cap | 70–90 | 20–30 |
| Impact wrenches/screwdrivers | Small to large | 70–90 | 4–10 |
| Air bushings | Small to large | 80–90 | 4–10 |
| Pneumatic doors | | 40–90 | 2 |
| File and burr tools | | 70–90 | 20 |
| Wood borers | 1–2 in | 70–90 | 40–80 |
| Rim strippers | | 100–120 | 6 |
| Body polishers | | 70–90 | 2 |
| Vacuum cleaners | | 100–120 | 6 |
| Carbon removers | | 70–100 | 3 |
| Sand blasters | Wide variation | 90 | 6–400 |

[a] 1 inch = 24.5 mm
[b] 1 cubic foot = 0.0283 $m^3$

**TABLE C15.10** Air Volume Passing through an Orifice, scfm[3]

| Gauge pressure,[2] psi | Orifice size, inches diameter[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1/64 | 1/32 | 3/64 | 1/16 | 3/32 | 1/8 | 3/18 | 1/4 |
| 50 | 0.225 | 0.914 | 2.05 | 3.64 | 8.2 | 14.5 | 32.8 | 58.2 |
| 60 | 0.26 | 1.05 | 2.35 | 4.2 | 9.4 | 16.8 | 37.5 | 67 |
| 70 | 0.295 | 1.19 | 2.68 | 4.76 | 10.7 | 19.0 | 43.0 | 76 |
| 80 | 0.33 | 1.33 | 2.97 | 5.32 | 11.9 | 21.2 | 47.5 | 85 |
| 90 | 0.364 | 1.47 | 3.28 | 5.87 | 13.1 | 23.5 | 52.5 | 94 |
| 100 | 0.40 | 1.61 | 3.66 | 6.45 | 14.5 | 25.8 | 58.3 | 103 |
| 110 | 0.43 | 1.76 | 3.95 | 7.00 | 15.7 | 28.0 | 63 | 112 |
| 120 | 0.47 | 1.90 | 4.27 | 7.58 | 17.0 | 30.2 | 68 | 121 |
| 130 | 0.50 | 2.04 | 4.57 | 8.13 | 18.2 | 32.4 | 73 | 130 |
| 140 | 0.54 | 2.17 | 4.87 | 8.68 | 19.5 | 34.5 | 78 | 138 |
| 150 | 0.57 | 2.33 | 5.20 | 9.20 | 20.7 | 36.7 | 83 | 147 |
| 175 | 0.66 | 2.65 | 5.94 | 10.6 | 23.8 | 42.1 | 95 | 169 |
| 200 | 0.76 | 3.07 | 6.90 | 12.2 | 27.5 | 48.7 | 110 | 195 |

[1] 1 inch = 25.4 mm
[2] 1 psig = 6.9 kPa
[3] 1 scfm = 0.472 nl/s

obtained. Conditioning equipment includes dryers, filters, lubricators, and pressure regulators.

Dryer selection is based on the most demanding user requirement except where special, dedicated equipment may be required. If a very low dew point is required, the only selection possible is a desiccant-type dryer. However, if a high dew point is acceptable, several different types of dryers can be considered. Refer to discussion under "Air Dryers" for specific characteristics.

## Duty Cycle

The *duty cycle* is how long a tool or device will be available for use during any specific period of time or production operation. In order to determine the duty cycle, the end-user should be consulted, for in most cases end users are the ones most capable of discussing the actual operations of their processes. In most industrial applications, tasks of a similar nature are usually grouped together. This will allow sections or branches to be calculated independently.

## Use Factor

The use factor is the maximum number of connected load devices or pieces of equipment that will actually be used at the same time. Experience indicates that it is almost impossible to accurately determine a use factor. Therefore, sufficient receiver capacity or larger compressor capacity to allow for possible variances must be made. For laboratories, air is used mostly for chemical reactions, and is not used as much as in industrial applications.

**TABLE C15.11** Volume of Air Used by Single-Acting Piston

| Piston dia. in inches[1] | Length of stroke in inches[1] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1¼ | .00139 | .00278 | .00416 | .00555 | .00694 | .00832 | .00972 | .0111 | .0125 | .0139 | .0153 | .01665 |
| 1⅞ | .00158 | .00316 | .00474 | .00632 | .0079 | .00948 | .01105 | .01262 | .0142 | .0158 | .0174 | .01895 |
| 2 | .00182 | .00364 | .00545 | .00727 | .0091 | .0109 | .0127 | .0145 | .01636 | .0182 | .020 | .0218 |
| 2⅛ | .00205 | .0041 | .00615 | .0082 | .0103 | .0123 | .0144 | .0164 | .0185 | .0205 | .0226 | .0244 |
| 2¼ | .0023 | .0046 | .0069 | .0092 | .0115 | .0138 | .0161 | .0184 | .0207 | .0230 | .0253 | .0276 |
| 2⅜ | .00256 | .00512 | .00768 | .01025 | .0128 | .01535 | .01792 | .02044 | .0230 | .0256 | .0282 | .0308 |
| 2½ | .00284 | .00568 | .00852 | .01137 | .0142 | .0171 | .0199 | .0228 | .0256 | .0284 | .0312 | .0343 |
| 2⅝ | .00313 | .00626 | .0094 | .01254 | .01568 | .0188 | .0219 | .0251 | .0282 | .0313 | .0345 | .0376 |
| 2¾ | .00343 | .00686 | .0106 | .0137 | .0171 | .0206 | .0240 | .0272 | .0308 | .0343 | .0378 | .0412 |
| 2⅞ | .00376 | .00752 | .0113 | .01503 | .01877 | .0226 | .0263 | .0301 | .0338 | .0376 | .0413 | .045 |
| 3 | .00409 | .00818 | .0123 | .0164 | .0204 | .0246 | .0286 | .0327 | .0368 | .0409 | .0450 | .049 |
| 3⅛ | .00443 | .00886 | .0133 | .0177 | .0222 | .0266 | .0310 | .0354 | .0399 | .0443 | .0488 | .0532 |
| 3¼ | .0048 | .0096 | .0144 | .0192 | .024 | .0288 | .0336 | .0384 | .0432 | .0480 | .0529 | .0575 |
| 3⅜ | .00518 | .01036 | .0155 | .0207 | .0259 | .031 | .0362 | .0415 | .0465 | .0518 | .037 | .062 |
| 3½ | .00555 | .0112 | .0167 | .0222 | .0278 | .0333 | .0389 | .0445 | .050 | .0556 | .061 | .0644 |
| 3⅝ | .00595 | .0119 | .0179 | .0238 | .0298 | .0357 | .0416 | .0477 | .0536 | .0595 | .0655 | .0715 |
| 3¾ | .0064 | .0128 | .0192 | .0256 | .032 | .0384 | .0447 | .0512 | .0575 | .064 | .0702 | .0766 |
| 3⅞ | .0068 | .01362 | .0205 | .0273 | .0341 | .041 | .0477 | .0545 | .0614 | .068 | .075 | .082 |
| 4 | .00725 | .0145 | .0218 | .029 | .0363 | .0435 | .0508 | .058 | .0653 | .0725 | .0798 | .087 |
| 4⅛ | .00773 | .01547 | .0232 | .0309 | .0386 | .0464 | .0541 | .0618 | .0695 | .0773 | .0851 | .092 |
| 4¼ | .0082 | .0164 | .0246 | .0328 | .041 | .0492 | .0574 | .0655 | .0738 | .082 | .0903 | .0985 |
| 4⅜ | .0087 | .0174 | .0261 | .0348 | .0435 | .0522 | .0608 | .0694 | .0782 | .087 | .0958 | .1042 |
| 4½ | .0092 | .0184 | .0276 | .0368 | .046 | .0552 | .0643 | .0735 | .0828 | .092 | .101 | .1105 |
| 4⅝ | .0097 | .0194 | .0291 | .0388 | .0485 | .0582 | .0679 | .0775 | .0873 | .097 | .1068 | .1163 |
| 4¾ | .01025 | .0205 | .0308 | .041 | .0512 | .0615 | .0717 | .0818 | .0922 | .1025 | .1125 | .123 |
| 4⅞ | .0108 | .0216 | .0324 | .0431 | .054 | .0647 | .0755 | .0862 | .097 | .108 | .1185 | .1295 |
| 5 | .0114 | .0228 | .0341 | .0455 | .0568 | .0681 | .0795 | .091 | .1023 | .114 | .125 | .136 |
| 5⅛ | .01193 | .0239 | .0358 | .0479 | .0598 | .0716 | .0837 | .0955 | .1073 | .1193 | .1315 | .1435 |
| 5¼ | .0125 | .0251 | .0376 | .0502 | .0627 | .0753 | .0878 | .100 | .1128 | .125 | .138 | .151 |
| 5⅜ | .0131 | .0263 | .0394 | .0525 | .0656 | .0788 | .092 | .105 | .118 | .131 | .144 | .158 |
| 5½ | .01375 | .0275 | .0412 | .055 | .0687 | .0825 | .0962 | .110 | .1235 | .1375 | .151 | .165 |
| 5⅝ | .0144 | .0288 | .0432 | .0575 | .072 | .0865 | .101 | .115 | .1295 | .144 | .1585 | .173 |
| 5¾ | .015 | .030 | .045 | .060 | .075 | .090 | .105 | .120 | .135 | .150 | .165 | .180 |
| 5⅞ | .0157 | .0314 | .047 | .0628 | .0785 | .094 | .110 | .1254 | .142 | .157 | .1725 | .188 |
| 6 | .0164 | .032 | .0492 | .0655 | .082 | .0963 | .1145 | .131 | .147 | .164 | .180 | .197 |

These volumes are for single acting cylinders. For double acting cylinders, multiply by two and subtract the volume of the piston rod.

[1] 1 in = 25.4 mm

[2] 1 cf = 0.0283 $m^3$

### Allowable Leakage

This is an often-overlooked waste of air for facilities. No method exists for accurately determining a reasonable figure. Leakage is a function of the number and type of connections, the age of the system, and the quality of pipe assembly. Many smaller tools and operations will generally have a greater total leakage of air than a few larger use-points. A well-maintained system will have a leakage of about 2 percent to 5 percent. Average conditions in aged facilities may have 10 percent leakage. Poorly maintained systems have been known to have a leakage factor as high as 25 percent. The facility maintenance or engineering department should be consulted when selecting a value. The leakage should be considered when the selected compressor capacity barely meets system requirements.

### Future Expansion

The owner must give guidance as to the possibility and extent of any future expansion. Consideration should be given to oversizing some components (such as filters, dryers, and main pipe sizes) in anticipation of expansion, to avoid costly replacement in the future, and to save downtime while expansion is under way.

## *PIPING SYSTEM DESIGN*

Piping layout on the plans shall be reasonably complete, with checking for space, clearances, interferences, and equipment drops. Also, the following information must be available:

1. A list of all air-consuming devices
2. Minimum and maximum pressure requirements for each device
3. Actual volume of air used by each device
4. Duty cycle and use factor
5. Special individual air-conditioning equipment requirements.

It will now be possible to start sizing the piping network using the following sequence:

1. In order to use pressure drop tables, it is necessary to find the equivalent length of run from the compressor to the farthest point in the piping system. The reason for this is that the various pipe sizing tables are developed for a pressure drop using friction loss for a given length of pipe. Measuring the actual length is the first step. In addition to the actual measured pipe length, the effect of fittings must be considered. This is because fittings and valves hinder the flow of air. This degree of obstruction has been converted to an equivalent straight length of pipe in order to make calculations easy. Table C15.12 has been developed to provide the equivalent pipe length for fittings and valves, which should be added to the actual measured run to establish a total equivalent run. Instead of actually counting the number of valves and fittings, it is accepted practice to add between

**TABLE C15.12** Loss of Pressure Through Various Fittings as Equivalent Length, in Feet, of Straight Pipe[1]

| Nominal pipe size[1] | | See note 2 | | | Standard ell | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Long radius all or on run | or on run of tee reduced | | Close | Tee | |
| | | Actual inside | Gate | of standard | in size | Angle | return | through | Glove |
| NPS | DN | diameter (in.) | valve | tee | 50 percent | valve | bend | side outlet | valve |
| ½ | 15 | 0.622 | 0.36 | 0.62 | 1.55 | 8.65 | 3.47 | 3.10 | 17.3 |
| ¾ | 20 | .824 | .48 | .82 | 2.06 | 11.4 | 4.60 | 4.12 | 22.9 |
| 1 | 25 | 1.049 | .61 | 1.05 | 2.62 | 14.6 | 5.82 | 5.24 | 29.1 |
| 1¼ | 32 | 1.380 | .81 | 1.38 | 3.45 | 19.1 | 7.66 | 6.90 | 38.3 |
| 1½ | 40 | 1.610 | .94 | 1.61 | 4.02 | 22.4 | 8.95 | 8.04 | 44.7 |
| 2 | 50 | 2.067 | 1.21 | 2.07 | 5.17 | 28.7 | 11.5 | 10.3 | 57.4 |
| 2½ | 65 | 2.469 | 1.44 | 2.47 | 6.16 | 34.3 | 13.7 | 12.3 | 68.5 |
| 3 | 80 | 3.068 | 1.79 | 3.07 | 6.16 | 42.6 | 17.1 | 15.3 | 85.2 |
| 4 | 100 | 4.026 | 2.35 | 4.03 | 7.67 | 56.0 | 22.4 | 20.2 | 112.0 |
| 5 | 125 | 5.047 | 2.94 | 5.05 | 10.1 | 70.0 | 28.0 | 25.2 | 140.0 |
| 6 | 150 | 6.065 | 3.54 | 6.07 | 15.2 | 84.1 | 33.8 | 30.4 | 168.0 |
| 8 | 200 | 7.981 | 4.65 | 7.98 | 20.0 | 111.0 | 44.6 | 40.0 | 222.0 |
| 10 | 250 | 10.020 | 5.85 | 10.00 | 25.0 | 139.0 | 55.7 | 50.0 | 278.0 |
| 12 | 300 | 11.940 | 6.96 | 11.00 | 29.8 | 166.00 | 66.3 | 59.6 | 332.0 |

Note 1 1 ft = 0.304 m
Note 2 1″ = 25.4 mm

40 and 50 percent of the actual measured run to get an approximation of the total equivalent run.

2. Determine the actual pressure drop that will occur only in the piping system. Generally accepted practice is to allow 10% of the proposed system pressure for pipe friction loss. For example, in a 100 psi (690 kPa) system, start using a figure of 10 psi (69 kPa). Since the air compressor has not been selected yet, this figure is variable. A smaller pipe size may lead to higher compressor horsepower. It is considered good practice to oversize distribution mains to allow for future growth and also to allow for the future addition of conditioning equipment that may add a pressure drop not anticipated at the time of original design.
3. Size the piping using the appropriate charts, having calculated the SCFM and the allowable friction loss in each section of the piping being sized. Since all pipe-sizing charts are formulated on the loss of pressure per some length of piping (usually 100 ft), it will be necessary to arrive at the required value for the specific chart you are using. Tables C15.13 through C15.16 present friction loss of air in psi for a 100 ft (31 m) length of pipe, and from 50 to 125 psig (345 to 862 kPag) line pressure. Use the highest system working pressure to determine pipe size.
4. The temperature used to calculate the friction loss is 60°F (16°C). For 100°F (38°C), increase drop figures in the tables by 7.7% for greater accuracy.

The charts were calculated using the following formula:

$$P = Q\frac{FV^2}{2gD} \qquad \text{(C15.2)}$$

**TABLE C15.13** Pressure Drop of Air in Pounds Per Square Inch Per 100 Feet of Pipe (30 m) for Air at 50 psig (345 kPa)

| cfm at 60°F, 14.6 psia | Pipe size (NPS) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ½ | ¾ | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 4 | 5 | 6 |
| 1 | .006 | | | | | | | | | | |
| 2 | .024 | .006 | | | | | | | | | |
| 3 | .055 | .012 | | | | | | | | | |
| 4 | .098 | .022 | .006 | | | | | | | | |
| 5 | .153 | .034 | .009 | | | | | | | | |
| 6 | .220 | .050 | .013 | | | | | | | | |
| 8 | .391 | .088 | .023 | .006 | | | | | | | |
| 10 | .611 | .138 | .036 | .009 | | | | | | | |
| 15 | 1.374 | .310 | .082 | .020 | .009 | | | | | | |
| 20 | 2.443 | .551 | .146 | .035 | .016 | | | | | | |
| 25 | 3.617 | .861 | .227 | .055 | .024 | .007 | | | | | |
| 30 | 5.497 | 1.240 | .328 | .079 | .035 | .010 | | | | | |
| 35 | | 1.688 | .446 | .108 | .047 | .013 | .005 | | | | |
| 40 | | 2.205 | .582 | .141 | .062 | .017 | .007 | | | | |
| 45 | | 2.791 | .737 | .178 | .078 | .021 | .009 | | | | |
| 50 | | 3.445 | .910 | .220 | .097 | .026 | .011 | | | | |
| 60 | | 4.961 | 1.310 | .317 | .140 | .038 | .016 | .005 | | | |
| 70 | | | 1.783 | .432 | .190 | .052 | .021 | .007 | | | |
| 80 | | | 2.329 | .564 | .248 | .068 | .028 | .009 | | | |
| 90 | | | 2.948 | .713 | .314 | .086 | .035 | .011 | | | |
| 100 | | | 3.639 | .881 | .388 | .106 | .044 | .014 | | | |
| 125 | | | 5.686 | 1.376 | .606 | .165 | .068 | .022 | | | |
| 150 | | | | 1.982 | .872 | .238 | .098 | .031 | .007 | | |
| 175 | | | | 2.697 | 1.187 | .324 | .133 | .043 | .010 | | |
| 200 | | | | 3.523 | 1.550 | .423 | .174 | .056 | .013 | | |
| 225 | | | | 4.459 | 1.962 | .536 | .220 | .070 | .016 | | |
| 250 | | | | 5.505 | 2.423 | .662 | .272 | .087 | .020 | .006 | |
| 275 | | | | | 2.931 | .801 | .329 | .105 | .024 | .007 | |
| 300 | | | | | 3.489 | .953 | .392 | .125 | .029 | .009 | |
| 325 | | | | | 4.094 | 1.118 | .460 | .147 | .034 | .010 | |
| 350 | | | | | 4.748 | 1.297 | .533 | .170 | .039 | .012 | |
| 375 | | | | | 5.451 | 1.489 | .612 | .195 | .045 | .014 | .005 |
| 400 | | | | | 6.202 | 1.694 | .696 | .222 | .051 | .015 | .006 |
| 425 | | | | | | 1.912 | .786 | .251 | .057 | .017 | .007 |
| 450 | | | | | | 2.144 | .881 | .281 | .064 | .019 | .008 |
| 475 | | | | | | 2.388 | .982 | .313 | .072 | .022 | .009 |
| 500 | | | | | | 2.464 | 1.088 | .347 | .079 | .024 | .010 |
| 550 | | | | | | 3.202 | 1.317 | .420 | .096 | .029 | .012 |
| 600 | | | | | | 3.811 | 1.567 | .500 | .114 | .035 | .014 |
| 650 | | | | | | 4.473 | 1.839 | .587 | .134 | .041 | .016 |

Where $P$ = Pressure loss due to friction, psi for 100 ft of pipe run
$F$ = Friction factor (use 4000 as average figure)
$V$ = Velocity in ft/sec
$g$ = Acceleration due to gravity−32.2 ft/sec
$D$ = Pipe diameter, ft
$Q$ = Specific weight of air in lb/ft$^3$

**TABLE C15.14** Pressure Drop of Air in Pounds Per Square Inch Per 100 Feet of Pipe For Air at 75 psig (517 kPa)

| cfm at 60°F, 14.6 psia | Pipe size (NPS) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ½ | ¾ | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 4 | 5 | 6 |
| 1 | | | | | | | | | | | |
| 2 | .018 | | | | | | | | | | |
| 3 | .040 | .009 | | | | | | | | | |
| 4 | .070 | .016 | | | | | | | | | |
| 5 | .110 | .025 | | | | | | | | | |
| 6 | .159 | .036 | .009 | | | | | | | | |
| 8 | .282 | .064 | .017 | | | | | | | | |
| 10 | .441 | .099 | .026 | | | | | | | | |
| 15 | .991 | .224 | .059 | .014 | | | | | | | |
| 20 | 1.762 | .398 | .105 | .025 | .011 | | | | | | |
| 25 | 2.753 | .621 | .164 | .040 | .017 | | | | | | |
| 30 | 3.965 | .895 | .236 | .057 | .025 | | | | | | |
| 35 | 5.396 | 1.218 | .322 | .078 | .034 | .009 | | | | | |
| 40 | 7.048 | 1.590 | .420 | .102 | .045 | .012 | | | | | |
| 45 | 8.921 | 2.013 | .532 | .129 | .057 | .015 | | | | | |
| 50 | | 2.485 | .656 | .159 | .070 | .019 | .008 | | | | |
| 60 | | 3.579 | .945 | .229 | .101 | .027 | .011 | | | | |
| 70 | | 4.871 | 1.286 | .311 | .137 | .037 | .015 | | | | |
| 80 | | 6.362 | 1.680 | .407 | .179 | .049 | .020 | | | | |
| 90 | | 8.052 | 2.126 | .515 | .226 | .062 | .025 | .008 | | | |
| 100 | | | 2.625 | .635 | .280 | .076 | .031 | .010 | | | |
| 125 | | | 4.101 | .993 | .437 | .119 | .049 | .016 | | | |
| 150 | | | 5.906 | 1.429 | .629 | .172 | .071 | .023 | | | |
| 175 | | | 8.039 | 1.946 | .856 | .234 | .096 | .031 | | | |
| 200 | | | | 2.541 | 1.118 | .305 | .126 | .040 | .009 | | |
| 225 | | | | 3.216 | 1.415 | .387 | .159 | .051 | .012 | | |
| 250 | | | | 3.971 | 1.747 | .477 | .196 | .063 | .014 | | |
| 275 | | | | 4.804 | 2.114 | .577 | .237 | .076 | .017 | | |
| 300 | | | | 5.718 | 2.516 | .687 | .283 | .090 | .021 | | |
| 325 | | | | 6.710 | 2.953 | .807 | .332 | .106 | .024 | | |
| 350 | | | | 7.782 | 3.425 | .935 | .385 | .123 | .028 | .008 | |
| 375 | | | | 8.934 | 3.932 | 1.074 | .441 | .141 | .032 | .010 | |
| 400 | | | | | 4.473 | 1.222 | .502 | .160 | .037 | .011 | |
| 425 | | | | | 5.050 | 1.379 | .567 | .181 | .041 | .013 | |
| 450 | | | | | 5.662 | 1.546 | .636 | .203 | .046 | .014 | |
| 475 | | | | | 6.308 | 1.723 | .708 | .226 | .052 | .016 | |
| 500 | | | | | 6.990 | 1.909 | .785 | .251 | .057 | .017 | |
| 550 | | | | | 8.458 | 2.310 | .950 | .303 | .069 | .021 | .008 |
| 600 | | | | | | 2.749 | 1.130 | .361 | .082 | .025 | .010 |
| 650 | | | | | | 3.226 | 1.326 | .423 | .097 | .029 | .012 |

The following general design parameters for end-use equipment can be used as a guide when calculating a piping systems total pressure drop:

1. Equipment drop leg: 2 psi loss (1 psi if possible)
2. Hose allowance: refer to Table C15.17.
3. Quick disconnect coupling: 4 psi loss

**TABLE C15.15** Pressure Drop of Air in Pounds Per Square Inch Per 100 Feet of Pipe For Air at 100 Pounds Per Square Inch Gauge Pressure and 60°F Temperature

| Cubic feet of free air at 60°F, 14.6 psia | Pipe size (NPS) ½ | ¾ | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | .014 | | | | | | | | | |
| 3 | .031 | | | | | | | | | |
| 4 | .055 | .012 | | | | | | | | |
| 5 | .086 | .019 | | | | | | | | |
| 6 | .124 | .028 | | | | | | | | |
| 8 | .220 | .050 | .013 | | | | | | | |
| 10 | .345 | .078 | .021 | | | | | | | |
| 15 | .775 | .175 | .046 | .011 | | | | | | |
| 20 | 1.378 | .311 | .082 | .020 | | | | | | |
| 25 | 2.153 | .486 | .128 | .031 | .014 | | | | | |
| 30 | 3.101 | .700 | .185 | .045 | .020 | | | | | |
| 35 | 4.220 | .952 | .251 | .061 | .027 | | | | | |
| 40 | 5.512 | 1.244 | .328 | .079 | .035 | | | | | |
| 45 | 6.976 | 1.574 | .416 | .101 | .044 | .012 | | | | |
| 50 | 8.613 | 1.943 | .513 | .124 | .055 | .015 | | | | |
| 60 | 12.402 | 2.799 | .739 | .179 | .079 | .021 | | | | |
| 70 | | 3.809 | 1.006 | .243 | .107 | .029 | .012 | | | |
| 80 | | 4.975 | 1.314 | .318 | .140 | .038 | .016 | | | |
| 90 | | 6.297 | 1.663 | .402 | .177 | .048 | .020 | | | |
| 100 | | 7.774 | 2.053 | .497 | .219 | .060 | .025 | | | |
| 125 | | 12.147 | 3.207 | .776 | .342 | .093 | .038 | .012 | | |
| 150 | | | 4.619 | 1.118 | .492 | .134 | .055 | .018 | | |
| 175 | | | 6.287 | 1.522 | .670 | .183 | .075 | .024 | | |
| 200 | | | 8.211 | 1.987 | .875 | .239 | .098 | .031 | | |
| 225 | | | 10.392 | 2.515 | 1.107 | .302 | .124 | .040 | | |
| 250 | | | 12.830 | 3.105 | 1.367 | .373 | .153 | .049 | .011 | |
| 275 | | | | 3.757 | 1.654 | .452 | .186 | .059 | .014 | |
| 300 | | | | 4.471 | 1.968 | .537 | .221 | .071 | .016 | |
| 325 | | | | 5.248 | 2.309 | .631 | .259 | .083 | .019 | |
| 350 | | | | 6.086 | 2.678 | .731 | .301 | .096 | .022 | |
| 375 | | | | 6.987 | 3.075 | .840 | .345 | .110 | .025 | |
| 400 | | | | 7.949 | 3.498 | .955 | .393 | .125 | .029 | |
| 425 | | | | 8.974 | 3.949 | 1.079 | .443 | .142 | .032 | |
| 450 | | | | 10.061 | 4.428 | 1.209 | .497 | .159 | .036 | .011 |
| 475 | | | | 11.210 | 4.933 | 1.347 | .554 | .177 | .040 | .012 |
| 500 | | | | 12.421 | 5.466 | 1.493 | .614 | .196 | .045 | .014 |
| 550 | | | | | 6.614 | 1.806 | .743 | .237 | .054 | .016 |
| 600 | | | | | 7.871 | 2.150 | .884 | .282 | .064 | .020 |
| 650 | | | | | 9.238 | 2.523 | 1.037 | .331 | .076 | .023 |

**4.** Lubricator: 1 to 4 psi loss
**5.** Point-of-use filter: ½ to 2 psi loss

## Selecting the Air-Compressor Assembly

The first step will be to calculate the air-compressor capacity. To start, the following information shall be available:

**TABLE C15.16** Pressure Drop of Air in Pounds Per Square Inch Per 100 Feet of Pipe For Air at 125 Pounds Per Square Inch Gauge Pressure and 60°F Temperature

| cfm at 60°F, 14.6 psia | Pipe size (NPS) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ½ | ¾ | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 4 | 5 |
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | .025 | | | | | | | | | |
| 4 | .045 | | | | | | | | | |
| 5 | .071 | .016 | | | | | | | | |
| 6 | .102 | .023 | | | | | | | | |
| 8 | .181 | .041 | | | | | | | | |
| 10 | .283 | .064 | .017 | | | | | | | |
| 15 | .636 | .144 | .038 | | | | | | | |
| 20 | 1.131 | .255 | .067 | .016 | | | | | | |
| 25 | 1.768 | .399 | .105 | .025 | | | | | | |
| 30 | 2.546 | .574 | .152 | .037 | .016 | | | | | |
| 35 | 3.465 | .782 | .206 | .050 | .022 | | | | | |
| 40 | 4.526 | 1.021 | .270 | .065 | .029 | | | | | |
| 45 | 5.728 | 1.292 | .341 | .083 | .036 | | | | | |
| 50 | 7.071 | 1.596 | .421 | .102 | .045 | | | | | |
| 60 | 10.183 | 2.298 | .607 | .147 | .065 | .018 | | | | |
| 70 | 13.860 | 3.128 | .826 | .200 | .088 | .024 | | | | |
| 80 | | 4.085 | 1.079 | .261 | .115 | .031 | .013 | | | |
| 90 | | 5.170 | 1.365 | .330 | .145 | .040 | .016 | | | |
| 100 | | 6.383 | 1.685 | .408 | .180 | .049 | .020 | | | |
| 125 | | 9.973 | 2.633 | .637 | .281 | .077 | .031 | | | |
| 150 | | 14.361 | 3.792 | .918 | .404 | .110 | .045 | .014 | | |
| 175 | | | 5.162 | 1.249 | .550 | .150 | .062 | .020 | | |
| 200 | | | 6.742 | 1.632 | .718 | .196 | .081 | .026 | | |
| 225 | | | 8.533 | 2.065 | .909 | .248 | .102 | .033 | | |
| 250 | | | 10.534 | 2.550 | 1.122 | .306 | .126 | .040 | | |
| 275 | | | 12.746 | 3.085 | 1.358 | .371 | .152 | .049 | | |
| 300 | | | 15.169 | 3.671 | 1.616 | .441 | .181 | .058 | .013 | |
| 325 | | | | 4.309 | 1.896 | .518 | .213 | .068 | .016 | |
| 350 | | | | 4.997 | 2.199 | .601 | .247 | .079 | .018 | |
| 375 | | | | 5.736 | 2.525 | .689 | .283 | .090 | .021 | |
| 400 | | | | 6.527 | 2.872 | .784 | .323 | .103 | .024 | |
| 425 | | | | 7.368 | 3.243 | .886 | .364 | .115 | .027 | |
| 450 | | | | 8.260 | 3.635 | .993 | .408 | .130 | .030 | |
| 475 | | | | 9.204 | 4.050 | 1.106 | .455 | .145 | .033 | |
| 500 | | | | 10.198 | 4.488 | 1.226 | .504 | .161 | .037 | |
| 550 | | | | 12.340 | 5.430 | 1.483 | .610 | .195 | .044 | .013 |
| 600 | | | | 14.685 | 6.463 | 1.765 | .726 | .232 | .053 | .016 |
| 650 | | | | | 7.585 | 2.071 | .852 | .272 | .062 | .019 |

1. Total connected cfm of all air-using devices, including flow to the air dryer system if applicable
2. Maximum worst-case pressure these devices require
3. Duty cycle and use factors giving maximum expected use of air by devices
4. cfm leakage and future expansion allowance

**TABLE C15.17** Recommended Hose Sizes Pressure Drops in psi For Air-Operated Tools

| Free[2] air flow —cfm | 6-ft—1/8-in | 8-ft—5/32-in | 8-ft—1/4-in | 8-ft—5/16-in | 8-ft—3/8-in | 12.5-ft—1/2-in | 25-ft—1/2-in | 50-ft—1/2-in | 25-ft—3/4-in | 50-ft—3/4-in | {8-ft—5/32-in, 25-ft—1/2-in} | {8-ft—1/4-in, 50-ft—1/2-in} | {12.5-ft—1/2-in, 25-ft—3/4-in} | {12.5-ft—1/2-in, 50-ft—3/4-in} |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 3.5 | 1.2 | | | | | | | | | 1.3 | | | |
| 3 | 7.3 | 2.7 | | | | | | | | | 2.8 | | | |
| 4 | 12.5 | 4.4 | | | | | | | | | 4.6 | | | |
| 5 | | 6.7 | | | | | | | | | 6.9 | | | |
| 6 | | 9.3 | | | | | | | | | 9.7 | 1.2 | | |
| 7 | | 12.4 | 1.3 | | | | | | | | 12.9 | 1.6 | | |
| 8 | | | 1.6 | | | | | | | | | 2.1 | | |
| 10 | | | 2.5 | | | | | | | | | 3.2 | | |
| 12 | | | 3.5 | 1.3 | | | | | | | | 4.5 | | |
| 15 | | | 5.3 | 2.0 | | | | 1.1 | | | | 6.9 | | |
| 20 | | | 9.0 | 3.4 | 1.4 | | 1.0 | 1.9 | | | | 11.8 | | |
| 25 | | | 13.8 | 5.1 | 2.2 | | 1.5 | 3.0 | | | | | 1.3 | 1.5 |
| 30 | | | | 7.3 | 3.1 | 1.1 | 2.1 | 4.2 | | | | | 1.8 | 2.1 |
| 35 | | | | 9.8 | 4.1 | 1.5 | 2.9 | 5.6 | | | | | 2.5 | 2.8 |
| 40 | | | | 12.5 | 5.3 | 2.0 | 3.7 | 7.1 | | 1.0 | | | 3.2 | 3.7 |
| 45 | | | | | 6.6 | 2.5 | 4.6 | 8.9 | | 1.2 | | | 4.0 | 4.6 |
| 50 | | | | | 8.1 | 3.0 | 5.6 | 10.9 | | 1.5 | | | 4.9 | 5.6 |
| 55 | | | | | 9.7 | 3.6 | 6.7 | 13.0 | | 1.8 | | | 5.9 | 6.8 |
| 60 | | | | | 11.5 | 4.3 | 7.9 | | 1.1 | 2.1 | | | 7.0 | 8.0 |
| 70 | | | | | | 5.7 | 10.6 | | 1.4 | 2.8 | | | 9.4 | 10.7 |
| 80 | | | | | | 7.3 | 13.6 | | 1.9 | 3.6 | | | 12.1 | 13.9 |
| 90 | | | | | | 9.2 | | | 2.3 | 4.5 | | | | |
| 100 | | | | | | 11.2 | | | 2.8 | 5.5 | | | | |
| 120 | | | | | | | | | 4.0 | 7.7 | | | | |
| 140 | | | | | | | | | 5.4 | 10.3 | | | | |
| 160 | | | | | | | | | 6.9 | 13.3 | | | | |
| 180 | | | | | | | | | 8.7 | | | | | |
| 200 | | | | | | | | | 10.6 | | | | | |
| 220 | | | | | | | | | 12.7 | | | | | |

Based on 95 psig air pressure at hose inlet, includes normal couplings (quick connect couplings will increase pressure losses materially). Hose is assumed to be smooth. Air is clean and dry. If an airline lubricator is upstream from the hose pressure loss will be considerably higher. Pressure loss varies inversely as the absolute pressure (approximately). Probable accuracy is believed to be ±10%. Selections should be made from above the heavy lines for best economy.

Note 1 psi × 6.9 = kPa

Note 2 cfm × .47 = l/s

5. Allowable pressure drops for entire system, including piping and conditioning equipment
6. Altitude, temperature, and contaminant removal corrections
7. Location of air compressor and all ancillary equipment

Having completed the above work, first design the inlet piping system if necessary. Since air-compressor performance depends on inlet conditions, this system deserves special care. The air intake should provide a supply of air to the compressor that is as clean, cool, and dry as possible. The proposed location should be studied for the presence of any type of airborne contamination, and positioned to avoid the probability of contaminated intake.

Whenever reasonable, use outside air because it is colder. For an external installation, the inlet should have a rain cap and a screen. An inlet filter should always be provided inside the building. If the manufacturer of the selected compressor indicates that noise may be a problem, a silencer shall be installed. Each compressor (if a duplex) should have an independent air intake.

The pressure loss of air through the intake piping should be held to a minimum. Velocity of intake air should be limited to about 1000 ft/min (310 m/min) to avoid noise problems, and friction loss limited to about 4 in (100 mm) of water. Table C15.18 gives a recommended inlet pipe size. Inlet louver velocity should also be low enough to avoid drawing in rainwater. In general, if air requirements are less than 14 scmm (500 scfm), the intake can be indoors. If indoor air temperature is usually higher than 100°F (38°C) the intake should be outdoors. Provide an automatic drain on the line leading to the compressor, and pitch the intake piping to the drain point.

**TABLE C15.18** Inlet Pipe Size

| Maximum cfm free-air capacity l/s | | Minimum size | |
|---|---|---|---|
| | | NPS | DN |
| 50 | 25 | 2½ | 65 |
| 110 | 55 | 3 | 80 |
| 210 | 105 | 4 | 100 |
| 400 | 200 | 5 | 125 |
| 800 | 400 | 6 | 150 |

***Source:*** James Church

Uncontrolled piping pulsations can harm inlet piping, damage the building structure, and affect compressor performance. Air flow into a reciprocating compressor pulsates because of the cyclic intake of air into the compressor cylinder. The variable pressure causes the air column in the pipe to vibrate, which creates a traveling wave in the pipe moving at the speed of sound. The inlet pipe itself vibrates at some natural frequency depending on its length. If the air column vibrates at or near the same frequency as the length of pipe, the system is said to be *resonant*. Large pressures could result when this occurs. Resonant pipe lengths can be calculated by the compressor manufacturers, and the critical length given to the engineer. As an example, with a 600 RPM compressor, avoid a length of pipe 3.2 to 12.5 ft, (1 to 3.8 m) 5.2 to 8.1 m (16.8 to 26.2 ft and (8.1 m), 32.3 to 41.5 ft, 10.0 to 12.8 m. A surge chamber can also be used to eliminate this problem.

Many different factors are involved in selection of compressor type:

1. Space limitations
2. Noise limitations
3. Compressor pressure capability
4. Maximum flow rate
5. Availability, cost, and quality of cooling water
6. Need for oil-free air
7. Electrical power limitations
8. Costs—both initial and long-term

The following reasons should be considered when in doubt as to the selection of a duplex unit rather than a simplex unit.

1. The cost of downtime. The owner may request two 100% capacity machines to eliminate the possibility of a shutdown.
2. Where a facility has a steady requirement (called a *base load*) and in addition there are substantial variations due to periodic or intermittent use.
3. When electrical starting requirements would overload the system. Two units starting at different times will eliminate the problem.
4. Where floor space is not available for one large compressor and ancillary equipment.
5. Where widely separated concentrations of heavy use exist, two compressors or possibly two sets of compressors are a good idea.

Experience has shown that a properly sized, constantly working compressor usually requires less maintenance than one running intermittently.

A schematic detail of a typical air compressor assembly is shown in Fig. C15.10.

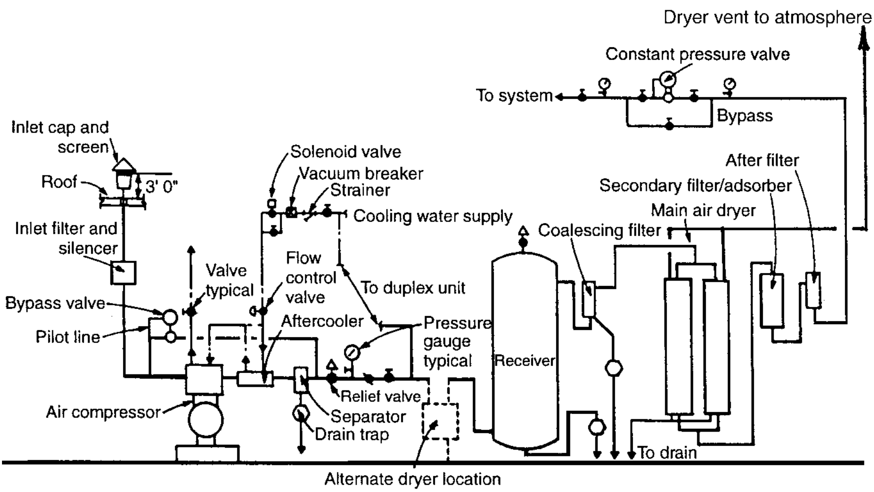



**FIGURE C15.10** Typical air compressor assembly.

Most of the power input to a compressor is rejected through the various cooling systems into the space where the compressor is located. This information must be relayed to the HVAC systems engineer for space-conditioning if necessary. Good ventilation is mandatory in the area where the compressor is installed.

Vibration isolation is achieved by the proper selection of resilient devices between the pump base and the building structure. This is accomplished by placing isolators between the pump and the floor, flexible connections on all piping from the compressor, and spring-type hangers on the piping around the compressor for a distance of about 20 ft (6 m).

## INSTRUMENT AIR

*Instrument air* is a general term used to describe compressed air used to operate pneumatic controllers, valves, actuators, pressure transmitters, and other similar devices. Instrument air also operates automatic temperature control (ATC) systems and associated heating, ventilating, and air-conditioning (HVAC) devices used to control and condition air for comfort in facilities. The largest volume of instrument air in a manufacturing facility is used to operate valve actuators.

### Instrument Air System Codes and Standards

The Instrument Society of America (ISA) is the major organization writing and issuing standards for instrument air. The principal standards concerning the creation and use of instrument air are:

1. ANSI/ISA S7.3 Quality Standard for Instrument Air
2. RP S7.7 Recommended Practice for Producing Quality Instrument Air

Based upon the type of facility and its location, the applicable code may be one of the sections of the ASME Pressure Piping Code or the ASME Boiler and Pressure Vessel Code. For example, an instrument air system in a fossil-fueled power plant would have to comply with the requirements of the ASME B31.1 Power Piping Code, whereas a similar system in a chemical or refinery facility will be constructed in accordance with the ASME B31.3 Process Piping Code.

### Instrument Air Quality Standards

There are four elements of quality that must be considered in instrument air piping: (1) moisture content, (2) oil content, (3) particulate size, and (4) other toxic contamination.

If any instrument air lines are located outside a building, the maximum allowable moisture content that will permit instruments to continuously function satisfactorily is to have a dew point 18°F (10°C) below the lowest temperature that any part of the instrument air system will be exposed to. When the instrument air system is completely indoors, the dew point shall not exceed 35°F (2°C).

The oil content in instrument air systems shall be as close to zero as possible, with the maximum allowable content of 1 ppm under normal operating conditions. This requires that an oil-free compressor be used to generate the compressed air rather than trying to use filters to reduce the oil content from another type of compressor.

The maximum allowable particulate size shall be $3\mu$.

The intake shall be free from all corrosive, flammable, and toxic contaminants. If the intake cannot be located in an area free from this kind of contamination, these impurities shall be removed before entering the compressor.

The instrument Society of America has established the following general requirements:

1. Pressure Dew Point: Maximum 35°F, (2°C), or 20°F (12°C) below the lowest winter ambient temperature expected anywhere (inside or outside) the instrument air lines will be installed at the facility.
2. Particulate size: Maximum 3 microns.
3. Oil Content: Maximum 1 PPM but as close to zero as possible.
4. Misc. contaminants: No corrosive or hazardous gases.
5. Pressures required are generally in the 15 to 50 psi (103 to 345 kPa) range.

## Instrument Air Pressure Requirements

The pressure normally required for actuation devices is 100 psig (690 kPag). Since the exact, final number of devices connected is rarely known during the design phase of a project, it is common practice to provide an instrument air header of sufficient size to satisfy the anticipated load. To allow connections to the header, a valved branch line should be provided every 10.0, or 20.0 ft, (3 or 6 m), based on the information received from the process engineers as to the proposed number and location of devices.

There are two ranges of pressures used in pneumatic pressure transmission for building control purposes. The preferred nominal pressure is 12 psig (80kPa), with an operating range (span) of between 3 and 15 psig (20 and 100 kPa). The air supplied to this system shall have a range of between 19 and 22 psig (130 and 150 kPa). Another commonly used nominal working pressure is 24 psig (166 kPa), with an operating range of between 6 and 30 psig (40 and 210 kPa). The air pressure supplied to this system is in the range of between 38 and 44 psig (260 and 300 kPa).

## Generation of Instrument Air

Instrument air can be generated by means of a dedicated air compressor assembly or obtained from an air compressor serving other purposes. When obtained from other than dedicated sources, the supply air pressure must be adjusted to system requirements and the air stream further conditioned as necessary to achieve the required purity requirements. It is highly recommended that instrument air be produced by dedicated compressors. In order for the actuators to have the ability to go their fail-safe position if power fails, it is recommended that the instrument air receiver have a minimum of a five-minute reserve of air available for shut-down purposes if the compressor is not on emergency power.

To calculate the capacity of the compressor and piping system, generally accepted practice for preliminary calculations is to use 3 scfm (1.5 nl/s) for each device and an average 30 percent use factor for the system. This figure is only an approximation and must be verified. Approximate general usage is 35 scfh for each diaphram device and 180 scfh for piston-operated devices.

## Instrument Air Pipe, Fittings, and Joints

There are several materials that could be used for instrument air system pipe, tubing, fittings, and joints. Material selection must be based on the quality of air, type of compressor, and overall quality requirements for the service, in addition to the design requirements for the system. Use of pipe or tubing, and the type of joints, depends on the location of the system, underground or above ground. For example, it is advisable to use pipe with brazed joints for underground applications. On the other hand, use of tubing with solder joints is customary for aboveground service.

For instrument air systems, copper tubing complying with ASTM B 819 is recommended because this standard copper tube is factory-cleaned and shipped capped. This eliminates any particulates and grease that may be found in other copper tubing or pipe. However, if due precautions and necessary steps are taken to assure that the copper tubing is clean for instrument air application, ASTM B 88 tubing may be used for industrial applications. Copper fittings conforming to ASME B16.22, Wrought Copper and Copper Alloy Solder Joint Fittings, are to be used. These fittings contain phosphorus and do not require flux. Joints are usually brazed with no added flux, and the joint purged with nitrogen to prevent the buildup of copper oxide. Pressure-sensing branch lines are usually PE tubing and fittings. PE tubing is available in long lengths, minimizing joints. Sizes are ¼ in (6.3 mm) and ⅜ in (10 mm) diameters. Also used are copper, aluminum, and PE clad copper. When multiple lines of PE are used, they are often bundled together. When they must be protected, it is common practice to have them run in metallic conduit. Pneumatic lines serving smoke dampers shall be rigid copper or aluminum tubing.

The soldered joints between copper tubing and fittings shall be made by using ordinary solder. Joints for underground copper pipe, conforming to ASTM B42, and fittings conforming to ASTM B61 or B62 shall be brazed joints. Copper pipe can be used above ground also.

Sometimes stainless steel pipe, ASTM A312, Gr. 304L, or 316L along with stainless steel fittings A403, Gr. WP304L, or WP316L and A182 TP 304L or 316L, are used for instrument air system piping, especially when air is expected to contain moisture. Refer to App. E5 and App. E6 for piping and tubing material specifications. In general, NPS 2-½ (DN 65) and larger piping is joined together using butt-welding joints, and NPS 2 (DN 50) and smaller piping is welded by using socket welds. Threaded joints may be used only when permitted by the applicable code. Other types of joints have been developed and qualified for air systems and other services. Refer to Chap. A9 for a stainless steel piping system called Pressfit, which is suitable for air applications.

At times when the quality of air is not a concern, the piping could be constructed by utilizing carbon steel pipe, ASTM A106, Gr. B or A53, Gr. B and carbon steel fittings per A105 and A234, Gr. WPB or WPBW. Galvanized carbon steel piping may be considered when measures for filtering Zinc flakes are incorporated.

It is cautioned that some industry codes and standards do not permit use of certain plastic pipe and fittings for air services. Compliance to applicable code requirements and the safety considerations must take precedence over cost-related considerations of installed piping system.

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