CHAPTER 14

COMPRESSED GAS SYSTEMS

This chapter describes design criteria, production, storage, and central piping distribution methods for various compressed gas systems. Because of the diverse uses and different design criteria for each, this chapter is divided into the following separate sections: utility compressed air for light industrial use, compressed air for instruments and control, specialty gases for laboratories, compressed gases for health care facilities, dental compressed air, and large-scale specialty gas systems for industrial purposes. For purposes of this handbook, a compressed gas is any gas at a pressure higher than atmospheric pressure.

Some of the gases to be discussed could be stored as cryogenic liquids and converted to a gas at the storage location. The storage and vaporization of these gases are discussed in Chap. 19, ''Cryogenic Systems.'' Compressed air used to supply breathing apparatus is discussed in Chap. 18. Ultrapure gases, such as those used by the electronics industry for the manufacture of computer chips and other similar products, are regarded as process gases and are therefore outside the scope of this book.

FUNDAMENTALS

GENERAL

Air is a fluid as compared to a solid. Two kinds of fluids are liquids and gases. In a gas, the molecular structure does not have a lattice type of arrangement, and the cohesive forces that bind the molecules together are not as strong as those for a solid. This means that the molecules are quite mobile and will take the shape of their container. This mobility also allows a gas to expand through space and mix with other gases present.

The actual solid volume that the gas atomic structure occupies in relation to the total volume of a gas molecule is quite small, and 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.

For most purposes, air is compressed by the adiabatic process, whereby the heat of compression helps raise the pressure. Because of this, more horsepower is required to obtain the same outlet pressure than that produced under ideal isothermal conditions. Therefore, manufacturers use different methods to reduce power consumption. The use of intercoolers to reduce the temperature during the compression process is the most common.

DEFINITIONS AND PRESSURE MEASUREMENTS

Definition of Compressed Gases

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

Definition of Basic Compressed Air Processes

Isobaric Process. This process takes place under constant pressure.

Isochoric Process. This process takes place under constant volume.

Isothermal Process. This process takes place under constant temperature.

Polytropic Process. A generalized expression for all of the three above processes when variations in pressure, temperature, or volume are allowed to occur during the compression cycle.

Adiabatic Process. This process of compression allows a gas to gain temperature. This process is the most commonly used in facility compressed air production.

Units of Measurement

Pressure measurements are made using force acting upon an area. The most common method of measuring pressure in IP units is in pounds per square inch (psi). In SI units it is in kilograms per square centimeter (kg/cm^2) and kilopascals (kPa). Another common unit of measurement for low-pressure systems is in inches of water column (in wc). To convert in wc to psig refer to Table 13.9.

Standard Reference Points and Measurement

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, expressed as psig. If the reference pressure level is measured from a perfect vacuum, the term used is absolute pressure, expressed as psia. 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. Theoretical standard atmospheric pressure at sea level is equal to 14.696 psia, 101.4 kPa, 0 psig, 760 mmHg and 29.92 inHg. A perfect vacuum has a value of 0 psia, 0 kPa, and 0 inHg. Refer to Fig. 14.1 for the relationship between various methods of measuring air pressure. Pressure expressed only as psi is incomplete.

Theoretical standard atmospheric temperature is 60°F (15.6°C).

For ease of calculations, 14.7 psig is often adjusted to 15 psig and 29.92 inHg is often adjusted to 30 inHg. These minor deviations yield results well within the accuracy required for most engineering calculations.

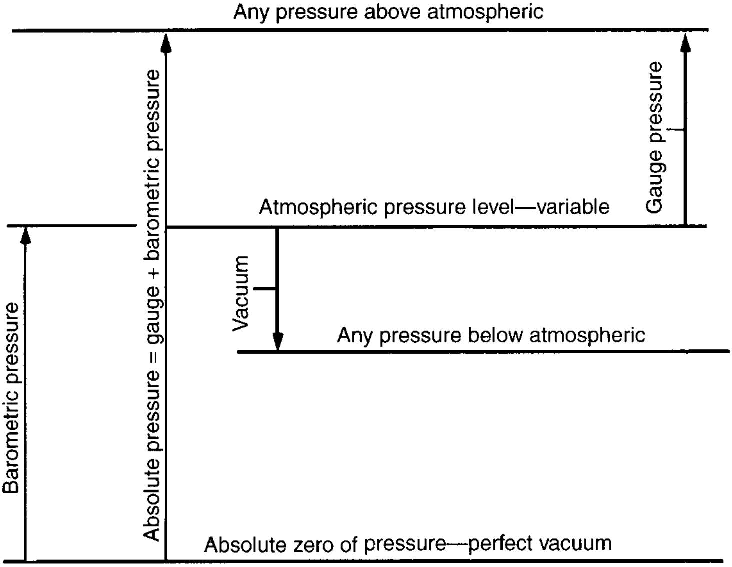


FIGURE 14.1 Relationship between gauge and absolute pressure.

Standard Air. Standard air is dry air with a relative humidity of 0.0 percent, a temperature of 60°F (15.6°C), and a pressure of 14.7 psig (101.4 kPa).

Free Air. Ambient air at a specific location. Temperature, barometric pressure, and moisture content may be different from standard air. The description of free air at a location is not complete unless the ambient temperature, humidity, and barometric pressure conditions at the compressor location are stated.

Flow Rate

The most common measurement of flow rate in IP units is cubic feet per minute (cfm). If the flow rate is low, it is commonly expressed in cubic feet per hour (cfh). For SI units liters per minute (Lpm) and liters per second (Lps) are used. Flow rate must reference standard or actual air.

Standard Cubic Feet (liters) per Minute (scfm), (sLpm). This is a volume measurement of air at standard conditions. One cubic foot of standard air weighs 0.764 lb.

Actual Cubic Feet (liters) per Minute (acfm) (aLpm). This is a volume measurement of standard air after being compressed. To find the acfm equivalent of scfm at pressure, refer to Fig. 14.18. The acfm measurement is not complete unless the pressure is stated.

Inlet Cubic Feet per Minute (icfm). The actual flow rate of free air entering the inlet flange of the compressor, not considering losses through any installed inlet devices or piping. An icfm measurement is not complete unless the ambient temperature, humidity, and barometric pressure conditions at the compressor location are stated.

Free Air Delivered (FAD). The actual volume rate of free air produced at the outlet flange of the compressor when referenced to icfm.

PHYSICAL PROPERTIES OF AIR

Air is the atmosphere surrounding the earth. It is a mixture of many elements and compounds. The composition of dry air is listed in Table 14.1. Pure air is odorless and tasteless unless some foreign matter is suspended in the mixture. The air pressure exerted at the earth's surface is due to the weight of the column of air above that point and is measured barometrically.

Because free air is less dense at higher elevations, a correction factor must be used to determine the equivalent volume of standard air at the higher elevation. The elevation correction factors are given in Table 14.2. By multiplying the volume of air by the correction factor, the actual quantity of standard air will be found.

Temperature is also a consideration. Because an equal volume of free air at a higher temperature will exert a higher pressure than the same volume of standard air at a lower temperature, a correction factor must be used to determine the equiv-

TABLE 14.1 General Composition of Dry Air

Component	Percent by volume	Percent by mass
Nitrogen	78.09	75.51
Oxygen	20.95	23.15
Argon	0.93	1.28
Carbon dioxide	0.03	0.046
Neon	0.0018	0.00125
Helium	0.00052	0.000072
Methane	0.00015	0.000094
Krypton	0.0001	0.00029
Carbon monoxide	0.00001	0.00002
Nitrous oxide	0.00005	0.00008
Hydrogen	0.00005	0.0000035
Ozone	0.00004	0.000007
Xenon	0.000008	0.000036
Nitrogen dioxide	0.0000001	0.0000002
Iodine	2×10^{-11}	1×10^{-10}
Radon	6×10^{-18}	5×10^{-17}

TABLE 14.2 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

alent volume of air at different temperatures. The temperature correction factors are given in Table 14.3. By multiplying the volume of air by the correction factor, the actual quantity of standard air will be found.

WATER VAPOR IN AIR

Both temperature and pressure can affect the ability of air to hold moisture. When a given volume of air is compressed, an increase in temperature occurs. Increased temperature results in an increased ability of air to retain moisture. Conversely, an increase in pressure results in a decreased ability to hold water. With each 20°F increase in temperature, the ability of air to accept water vapor doubles. When air is compressed, the rise in temperature is more critical than the pressure rise. Be-

TABLE 14.3 Temperature Correction Factor

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

cause of the high temperature rise during the compression cycle, no water will precipitate inside the compressor; but water may, however, precipitate after the cycle has been completed.

Air contains varying amounts of water vapor depending on its temperature and pressure. There are various methods of expressing the amount present.

Saturated Air and Dry Air

Saturated air contains the maximum amount of water vapor possible based on its temperature and pressure. Dry air contains no water vapor. To determine the moisture content of saturated air based on its temperature, refer to Fig. 14.2.

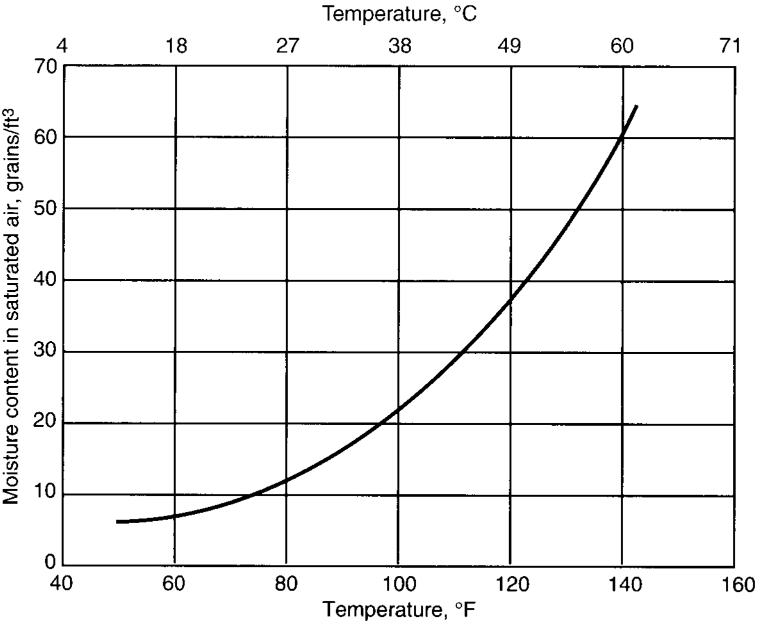


FIGURE 14.2 Moisture content of saturated air.

Relative Humidity

Relative humidity is the amount of water vapor actually present in air expressed as a percent of the total amount capable of being present when the air is saturated. Relative humidity is dependent on pressure and temperature.

Dew Point

The dew point is that temperature at which water in the air will start to condense on a surface, and it is used to express the dryness of the compressed air. 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.* There is a different dew point for air at different pressures. To find the dew point of air at various pressures

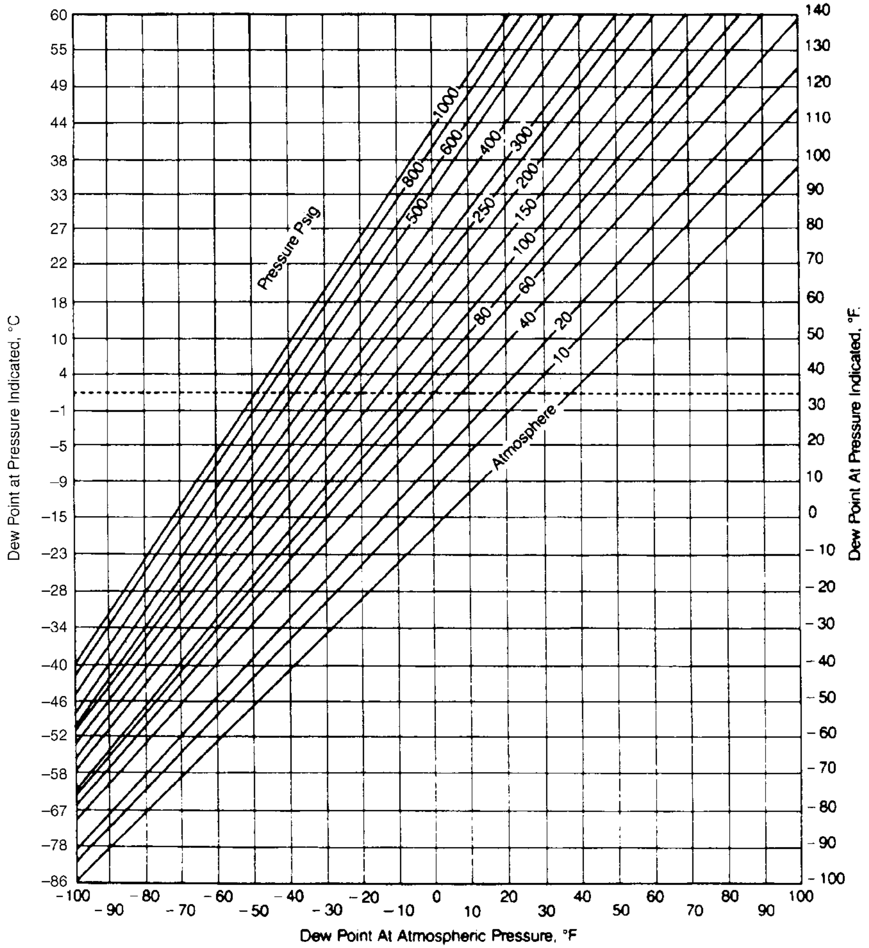


FIGURE 14.3 Dew point conversion chart. (*Courtesy Hankison Corp.*)

and temperatures, refer to the dew point conversion chart in Fig. 14.3. Dew point is the preferred method of expressing the moisture content of compressed air.

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 Fig. 14.3.
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.

Weight of Water Vapor in Air

The relationship of the dew point to weight of water per cubic 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 14.4 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, refer to Table 14.5.

IMPURITIES AND CONTAMINATION

A knowledge of the various pollutants in the air is necessary when deciding on what equipment is required to effectively reduce or remove them. The required level of protection from the various contaminants depends upon the purpose for

TABLE 14.4 Weight of Water Vapor in Air

(*Grains of moisture per pound of air at standard barometric pressure*)

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
8	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		

TABLE 14.5 Moisture Content of Air at One Atmosphere*

°C	Dew point, °F	Grains moisture per lb air	Pounds moisture per lb air	Grains moisture per ft^3 air	ppm	Vol. percent
−15	0					
			0.0006	0.4	600	0.1
		4				
−23	−10					
			0.0004		400	0.06
		2		0.2		
−28	−20					0.04
			0.0002		200	
−34	−30	1		0.1		
		0.8		0.08		0.02
		0.6	0.0001	0.06	100	
−40			0.00008	0.06	100	
			0.00006		80	
				0.04	60	0.01
						0.008
−46	−50		0.00004		40	
		0.2		0.02		0.006
						0.004
−52	−60					
			0.00002	0.01	20	
		0.1		0.008		
		0.08				0.002
−58	−70		0.00001		10	
		0.06	0.000008	0.006	8	
		0.04	0.000006	0.004	6	0.001
						0.0008
−67	−80					0.0008
			0.000004		4	0.0006
		0.02		0.002		0.0004
−78	−90					
			0.000002		2	
		0.01		0.001		0.0002
−86	−100	0.008				
			0.000001	0.0008	1	

*There are many ways of expressing moisture content of air. The accompanying chart provides a quick comparison of the more frequently used methods. Read straight across to find equivalent moisture contents at one atmospheric pressure.

The relationship of dewpoint to grains per cubic foot does not change much with pressure in the range of 0 to 300 psig. Consequently, grains per cubic foot for elevated pressures can also be read directly from the chart, remembering that actual cubic feet are used.

TABLE 14.5 Moisture Content of Air at One Atmosphere* (*Continued*)

°C	Dew point, °F	Grains moisture per lb air	Pounds moisture per lb air	Grains moisture per ft^3 air	ppm	Vol. percent
44	100		0.0600		60,000	
		400		25		9
			0.0500		50,000	8
						7
38	100	300		20		
			0.00400		40,000	
						6
				15		
33	90					5
			0.0300			
		200				
27	80		0.0200			
		150		10	20,000	3
				9		
22	70		0.0150	8		
		100			15,000	2
		90		7		
		80		6		
18	60				10,000	
			0.0100		9,000	
		70	0.0090		8,000	1.5
		60	0.0080			
10	50					
		50	0.0070		7,000	1
		40	0.0060	3	6,000	0.9
4	40				5,000	
			0.0050		4,000	0.8
		30	0.0040	2		0.7
						0.6
−1	30					
		20	0.0030	1.5	3,000	0.5
						0.4
−5	20					
			0.0020	1	2,000	0.3
		10		0.8		
−9	10					
		8	0.0010	0.6	1,000	0.2
		6	0.0008		800	

A pressure correction is necessary for all other measurements listed. For a convenient means of converting dewpoints measured at atmospheric pressure to those measured at an elevated pressure, refer to Fig. 14.3. Use the latter dewpoint on the moisture content chart to read grains per pound, pound per pound, ppm, and volume percent. On the other hand, if moisture content is expressed in these units, read the expanded dewpoint from the moisture content chart and refer to Fig. 14.3 to convert the dewpoint reading to elevated pressure.

Source: Courtesy of Hankison Corp.

which the air will be used. 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 contaminants:

1. Liquids (oil and water)
2. Vapor (oil, water, and hydrocarbons)
3. Gases
4. Particulates

Liquids

Water enters a system with the intake air, passes through the compressor as a vapor, and condenses afterward into liquid droplets. Most liquid oil contamination originates at the intake location or in an oil lubricated compressor. As the droplets are swept through the system at velocities approaching 4000 fpm (feet per minute) (1200 M/M [meters per minute]) they gradually erode obstructions in their path by repeated collisions. When water settles on pipes, corrosion begins, ultimately ruining machinery and tools, causing 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 that they clog orifices or passages of, for example, tools at the end use points. These particulates include metal fines, carbon and Teflon particles, pollen, dust, rust, and scale. Bacteria enter through the inlet and reproduce in a moist warm environment.

1. There is no safe level of liquids in the airstream. They should be removed as completely as practical.

2. The level of acceptable water vapor varies with end use requirements. A dew point of −30°F (−34°C) is required to minimize corrosion in pipelines. For critical applications a dew point of −100°F (−86°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 particles in a typical system are between 10 and 0.01 μm in diameter.

When selecting appropriate and specific air purification components, remember there is no single type of equipment or device that can accomplish the complete job of removing them all. Objective performance criteria must be used to accomplish the desired reduction level. Such criteria must include pressure drop, efficiency, dependability, service life, energy efficiency, and ease of maintenance. There will be further discussion of the contaminant removal processes under individual components.

SYSTEM COMPONENTS

Air Compressors

The selection of an air compressor for any specific application depends primarily upon a knowledge of its performance characteristics as applied to the particular system being designed. Cost, space requirements, and efficiency are other considerations. Increasing attention to energy costs also requires evaluation of total operating costs and ease of maintenance for an extended period of time. A carefully selected air compressor will satisfy systems design and performance criteria while operating in the most cost-efficient manner.

Air Compressor Types. Air compressors are divided into two general categories: displacement and dynamic. Refer to Fig. 14.4 for a listing of various types of compressors according to general categories.

Displacement compressors can be further separated into reciprocating and rotary machines. Typical reciprocating compressors include piston and diaphragm types. Rotary includes such types as sliding vane, liquid ring (or liquid piston), and screw. The most widely used types of dynamic compressors include centrifugal and axial flow.

Piston compressors use a piston within a cylinder to compress the air. When air is compressed in only one direction, it is called *single acting.* Units that compress air in both directions are called *double acting.* See Fig. 14.5. Although these machines are fixed capacity units, the output can be varied. The speed can be lowered, the intake volume can be reduced (by providing adjustable internal clearance that can be selectively cut in or out), cylinder valves can be rendered inoperative to adjust capacity, or a portion of the discarded air can be blown off.

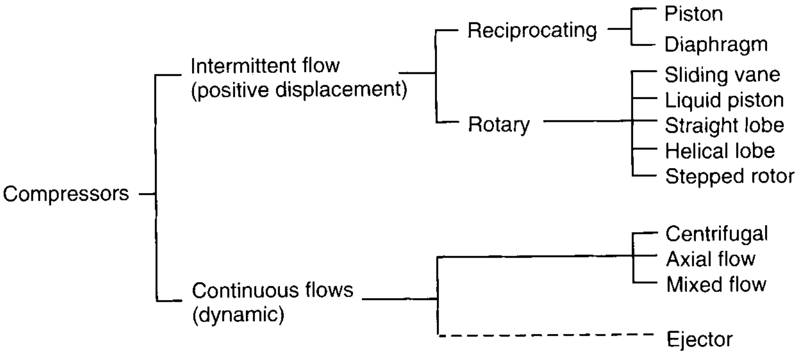


FIGURE 14.4 Air compressor types. Air compressors can be classified by air delivery characteristics as intermittent or continuous flow. Intermittent-flow machines can be distinguished by the type of motion used in the mechanism—reciprocating or rotary. Continuous-flow machines are divided into dynamic types and ejectors.

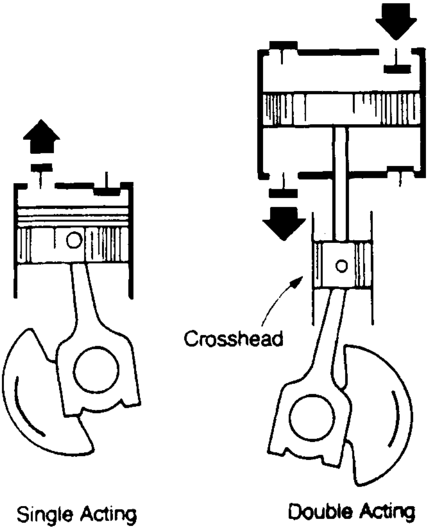


FIGURE 14.5 Piston air compressors.

In general, single-stage compressors are more desirable for pressures of 60 psig (410 kPa) or less, and multistage units are better for pressures of 100 psig or greater. In the 60 to 100 psig (410–690 kPa) range, a single stage is generally recommended for capacities of less than 300 scfm, and multistage for 300 scfm or more.

Piston compressors are also available for oil-free operation by using carbon or Teflon wearing parts that come in contact with the airstream. These parts require no oil due to the low friction.

A water-cooled unit is generally more efficient than an air-cooled one. It has a lower power consumption, but its initial cost is higher. A two-stage piston compressor uses less power than a single-stage unit for equivalent output. Piston compressors are available in an extremely wide selection of capacities and pressures.

Diaphragm compressors use a flexible diaphragm to compress air. These types of units are restricted to light-duty, low scfm, and low-pressure uses where economy is a factor, generally in the range of 50 psig and 25 scfm. A diaphragm compressor is illustrated in Fig. 14.6.

In a sliding vane compressor, the vanes are mounted eccentrically in a cylindrical rotor and 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. See Fig. 14.7.

These are compact units, well suited for direct connection to a relatively high-speed motor. Their efficiency is usually less than an equivalent piston unit. They are best used where small, low-capacity compressors are required, generally in the range of 100 scfm and up to 75 psig (3 m^3/min & 500 kPa).

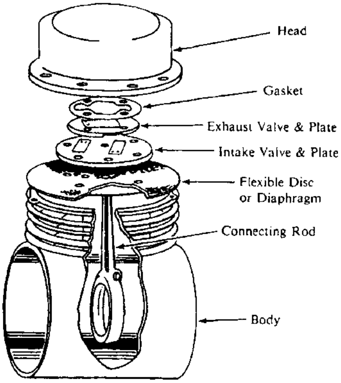


FIGURE 14.6 Detail of diaphragm air compressor.

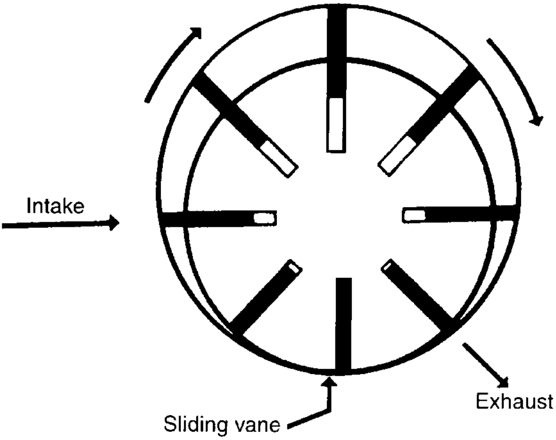


FIGURE 14.7 Detail of sliding vane air compressor.

Liquid ring compressors, sometimes referred to as *liquid piston compressors,* 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. See Fig. 14.8.

The resulting air is completely oil free. This type of compressor will also handle wet, corrosive, or explosive gases. Different liquids can be used that are compatible with any specific gas to be compressed. This unit is also very well suited for hospital and laboratory use. A practical limitation of 100 psig exists, and there is a higher power consumption than there is for piston units of a similar rating.

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. This air is then discharged, using the existing pressure in the system to additionally increase pressure. See Fig. 14.9. In general, this type of compressor has very low operating pressures (around 15 psi or 100 kPa).

Helical lobe, rotary screw, or spiral lobe 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, which increases the pressure. Designs are available to produce oil-free air. A rotary screw compressor is illustrated in Fig. 14.10.

Varying capacity is obtained by adjusting the speed of the driving motor, reducing the amount of inlet air, or returning a portion of the compressed air discharged back into the inlet. A check valve must be provided on the outlet pipe to prevent air from escaping through the compressor, after the compressor has stopped. Because of its rotary operation, the discharge is almost continuous. This type of compressor is best suited for higher-pressure applications, where, in general, capacities are available from 30 to 26,000 scfm (1 to 780 m^3/min) at pressures ranging from 125 to 250 psig (875 to 1750 kPa).

Stepped rotor compressors use two pairs of intermeshing rotors to trap air and reduce its volume. This compressor does not require liquid lubricants in the compressor chamber, thereby producing oil-free air. Clearance between rotors is not

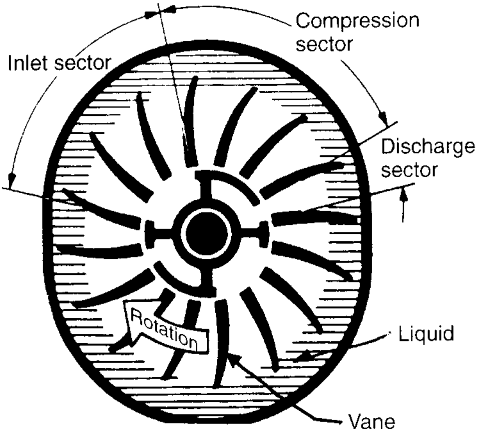


FIGURE 14.8 Detail of liquid ring air compressor.

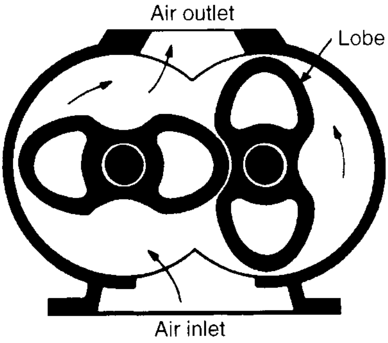


FIGURE 14.9 Straight lobe air compressor.

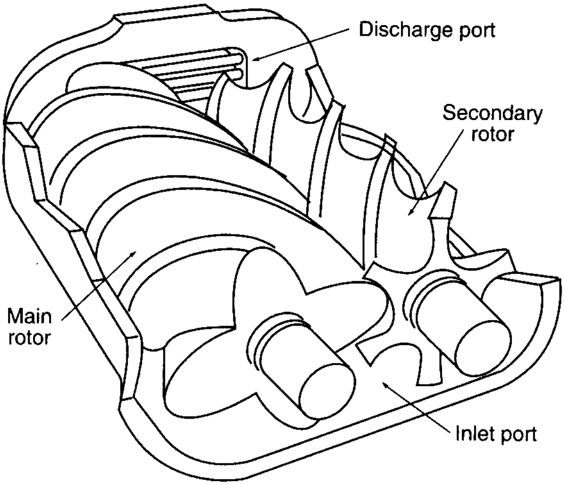


FIGURE 14.10 Rotary screw air compressor.

critical. These units find little application in plumbing system design due to their very limited volume capacities.

Centrifugal compressors use rotating blades or impellers to give velocity (energy) to the air, which is converted to increased pressure inside the pump casing. This classification does not apply to machines developing less than 1 psig, which are usually designated as fans. See Fig. 14.11.

This type of compressor is best suited for high rates at a relatively low pressure. Units are available in capacities of 400 to 170,000 scfm (12 to 5100 m^3/min) and pressures of up to about 125 psig (875 kPa). Since these units cannot develop pressures higher than their maximum design value, no pressure relief is necessary. Centrifugal compressors are smaller than similar reciprocating units, but they use more power. The air delivered is oil free.

Axial flow compressors are continuous flow machines that use two rows of blades, one rotating and one stationary. As the air is given velocity by the moving

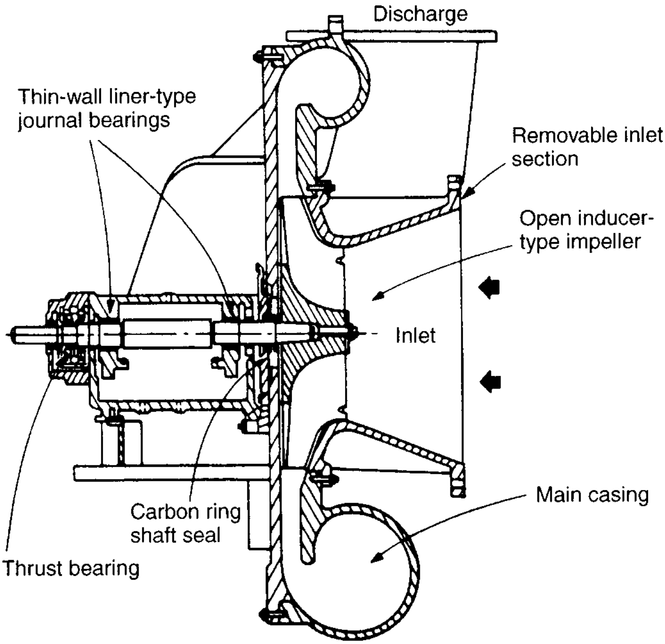


FIGURE 14.11 Centrifugal air compressor.

blades, it passes over the stationary blades, increasing pressure. Many stages are required, with 20 not uncommon. These compressors are well suited for large volumes of air, and they operate best at or near full capacity. Units are available from 10,000 to 800,000 (300 to 24,000 m^3/min) scfm at pressures to 125 psig. Selecting between centrifugal or axial compressors depends upon efficiency, size, weight, and initial cost, since their ranges overlap.

Mixed flow compressors use rotating impeller design, combining certain characteristics of both centrifugal and axial units to achieve capacity and pressure requirements. These units find little application in typical plumbing systems.

Ejectors are continuous flow units that use a moving liquid stream across a venturi to draw in and entrap air for later conversion to higher pressures in the ejector housing.

Silencers

When sound becomes too loud, it turns into noise. This noise, depending upon location and circumstances, can be very objectionable. 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 cps (cycles per second), which is most often found on reciprocating compressors. The absorptive silencer is often used on centrifugal and screw compressors where frequencies are above 500 cps. There is no practical limit in scfm for either type.

The selection of a silencer should be made in conjunction with the manufacturer. It will be necessary for the engineer to determine two things: the sound power level of the compressor (which must be obtained from the compressor manufacturer) and the highest level of sound permitted by 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.

In general, OSHA has established maximum acceptable sound levels to prevent hearing loss. These levels are generally regarded as excessive. In fact, that noise level, if accepted, will usually disturb adjacent facility workers and the surrounding areas. A level of 85 db has been generally accepted.

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.

Aftercoolers

An aftercooler is a device, often an integral part of the compressor, used to lower the temperature of compressed air immediately after the compression process. In doing so, large amounts of water are liberated. The primary function of an aftercooler is to remove water vapor rather than to lower the temperature of the compressed airstream.

Air leaving the compressor is very hot. It is desirable to reduce the temperature of air discharged to a range of between 70 and 110°F (21 and 43°C). Refer to Table 14.6 for the average temperature of compressed air leaving the compressor after the compression cycle is completed. A primary reason the temperature is lowered is to remove moisture that would otherwise condense elsewhere in the system as the air cools to ambient conditions. Therefore, it is considered good practice to install a cooling unit as close to the compressor discharge as practical for that reason. Such a unit is called an *aftercooler.* 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

TABLE 14.6 Temperature of Air Compressor Discharge

Type of compressor	Temperature rise °F over ambient	°C
Piston 1 stage	200	110
Piston 2 stage	250	137.5
Liquid piston	50	27.5
Rotary screw	150	82.5
Centrifugal	150	82.5

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 scfm 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.

Air-cooled units are less efficient than water-cooled units. They are selected on the basis of maximum inlet compressed air temperature, highest ambient air temperature, approach temperature desired, and maximum flow in scfm of compressed air. Typical cooling capacity will bring the compressed air to within 20 to 30°F (12 to 18°C) of the air used for cooling.

A refrigerant type of aftercooler is rarely used. If, due to job conditions, one is required, consult the 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 usually provided. The separator could be either an integral part of the aftercooler or a separate unit. A typical aftercooler and separator is illustrated in Fig. 14.12.

Additional factors to be considered when selecting an aftercooler are pressure drop through units, space requirements, operation costs, and maintenance.

Filters

The purpose of any filter is to reduce or remove impurities or contaminants in the airstream to an acceptable, predetermined level.

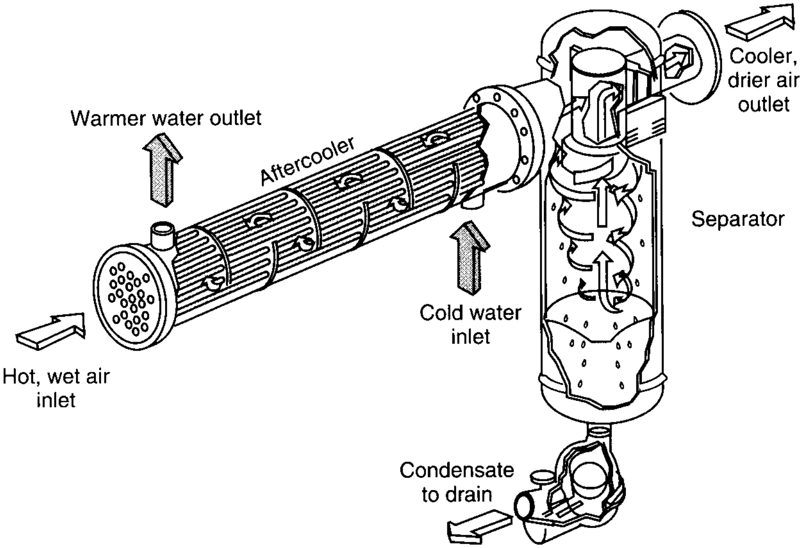


FIGURE 14.12 Typical aftercooler and moisture separator.

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 purpose intended. The following is a brief discussion in general terms of various types of filters:

> Inlet filters remove large amounts of contaminants at the inlet to the air compressor.
>
> Prefilters are generally used before air enters a dryer 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 a prefilter removes. 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 tool or individual piece of equipment that requires additional removal of particulates to a greater extent than an afterfilter.
>
> Oil removal filters are special filters used only to remove an 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 small particulates too small to be removed by coalescing.

Contamination Removal. Contaminants are removed by mechanical separation (interception), coalescence, adsorption, or a combination of these.

Mechanical Separation. Mechanical separation is used to remove solid particles from the airstream. The filter element is a thin sheet or membrane whose passages are smaller than the particles to be retained. They intercept and hold dirt, scale, dust, and other solid particles 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 medium that causes them to randomly collide and merge into larger droplets 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. This medium has 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 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. Mechanical and structural strength. Filters must be capable of withstanding any possible air pressure surge as well as resisting 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 is not recommended for inlet air temperatures greater than 150°F 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 either compressed air or washed according to the manufacturer's instructions. Recommended for oil-free air and other compressors of any capacity.

3. *Oil-wetted labyrinth filters.* These are reusable and are of metal construction. They work based on the principle of separating particulates by rapid changes of direction, causing particles to adhere on surfaces wetted by a film of oil. These filters require careful maintenance to ensure that the oil surface has not dried out or become saturated. These filters are recommended for small-capacity units (up to about 100 scfm) 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 a large capacity for 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 are recommended where large amounts of particulates are present at the inlet.

For most installations, the design engineer would select the inlet location and investigate known and potential pollutants. 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 been taken by some authorities such as state or federal EPA or a health department. In actual practice, during the design phase of a project, tests could be taken and analyzed. 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 types of filters capable of meeting the established criteria. The filter best suited for the system under design would then be selected.

For outdoor installations, provide a weatherproof rain cap and an insect screen around and over the actual inlet. Do not locate the filter close to any exhausts or vent pipes. The inlet should be mounted no less than 3 ft, 0 in (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 airstream. Often, oil and water form an emulsion inside the compressor and are discharged together. Since suspended liquids are present in the airstream leaving the aftercooler or compressor, the most common location is at that point. General design of these units should allow for removal of between 90 and 99 percent by weight, of liquids.

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

The purpose of an oil separator is to remove oil present in the airstream, 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 must be provided.

Oil and moisture separators should never be considered similar types of units, as their functions are quite different.

Filter Selection. Just as the degree of contamination in compressed air varies, so do the requirements for purity of the system 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 should be considered:

1. Maximum flow rate expected
2. Desired pressure drop across filter
3. Temperature of airstream
4. Contaminants to be removed (requirement for filter type and housing material)
5. Pressure rating (ASME stamp requirement)
6. Drain trap requirement (automatic type preferable)
7. Sampling port requirement
8. Filter efficiency

Filter Selection Procedure

1. Calculate the expected maximum flow rate of air. This figure should be expressed in the manufacturer's rating units, usually in scfm.
2. Determine the highest and lowest pressures that the filter can be expected to operate with during operation. This pressure must be used in conjunction with the pressure drop 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. Average conditions use a range of between 6 and 10 psig.

5. Will monitoring of the filter element for replacement be required, such as a color change or pressure drop?
6. Select the appropriate filter from a manufacturer's catalog.

Drain Traps

Separators and aftercoolers are not capable of directly discharging any water or oil removed from compressed air to drains. The purpose of a drain trap is to allow for the collection and removal of liquids that have separated from the airstream, with little or no loss of line pressure or compressed air.

Drain traps fall into two general categories: manual and automatic. Automatic traps are by far the more common. Manual traps are simply a drip leg on piping, with a valve that is opened by hand to drain the liquid that has accumulated in the length of pipe making up the drip leg.

Automatic drains fall into three categories:

1. Float
2. Bucket
3. Electronic

Float traps operate on the principle of a sealed float connected to a valve that opens when the float rises and reaches a predetermined level. Bucket traps use an unsealed bucket that moves due to the displacement of water either in or around the bucket. This opens a valve to allow the accumulated liquid to discharge. The electronic trap is a solenoid valve set to open at predetermined programmable intervals for a programmable period of open time. Float and bucket traps are illustrated in Chap. 11.

Selection of an automatic drain valve is based on line pressure, quantity of liquid stored, consistency of stored liquid, and rate of liquid discharge required. We will discuss how to determine the amount of liquid separated later in this section.

Float traps generally allow for higher discharge rates and greater contamination of stored liquid with oil sludge and solid particles than do bucket traps. Bucket traps are usually tighter sealing and can be used for high-pressure applications. They also cost less than float traps. Some facilities have a preference for using a particular type of trap. If traps must be placed outdoors with a potential for freezing, integral heaters are available to keep the stored liquid above freezing. Some traps require a small equalization line from the trap to the compressed-air piping to allow for reliable float operation.

Compressed Air Dryers

Air dryers are devices used to remove water vapor from the airstream. Large volumes of water consisting of droplets are removed 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 four methods generally used:

1. High pressurization of the compressed air
2. Condensation
3. Absorption

4. Adsorption
5. Heat of compression

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

Condensation. Condensation 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 then condenses out of the air onto the coils of the dryer. A moisture separator removes the condensate. The cooling medium in the coil could be chilled water, brine, or a refrigerant. The most common type uses a refrigerant and is called a *refrigerated dryer.* A schematic diagram of a refrigerated air dryer is shown in Fig. 14.13.

The greatest limitation is that they cannot practically produce a pressure dew point lower than 35°F. Otherwise, the condensed moisture could freeze on the coils. The advantages are that they have the lowest operating cost, and they do not introduce impurities into the airstream. The initial cost is midrange of the different dryer types. General pressure loss through a refrigerated dryer is approximately 5 psig. To achieve the rated moisture removal, a minimum of 20 percent of rated flow is required.

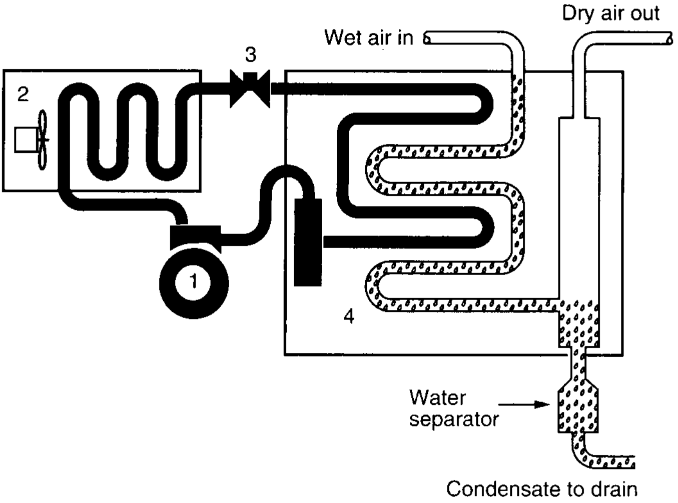


FIGURE 14.13 Refrigerated air dryer. There are four major components. (1) *Refrigeration compressor.* A hermetically sealed motor-driven compressor operates continuously. It generates a high-pressure refrigerant gas. (2) *Hot gas condenser.* The high-pressure refrigerant gas enters an air-cooled condenser 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. (*Courtesy Arrow Pneumatics.*)

Absorption. Absorption dryers use either a solid or liquid medium and operate on the principle of having the airstream pass through or over a deliquescent material. This medium changes state in the presence of water. The 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. Refer to Fig. 14.14 for a system schematic.

The liquid absorber is usually a glycol compound. The airstream passes over the liquid, and the water combines with the glycol. The glycol-water solution must be regenerated by having the water distilled off. Refer to Fig. 14.15 for a system schematic.

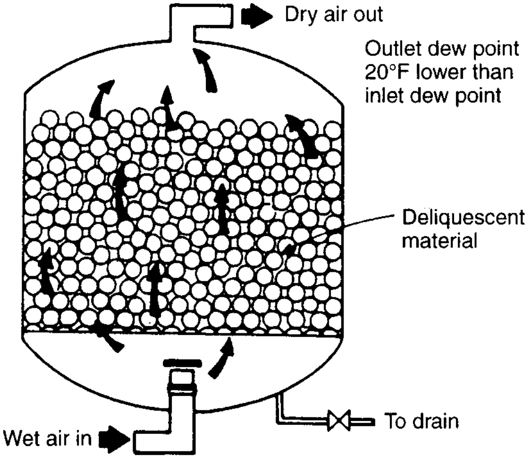


FIGURE 14.14 Absorption (deliquescent) dryer, solid medium.

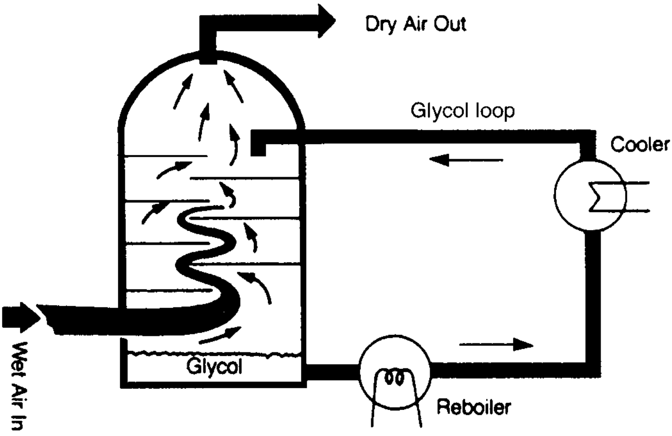


FIGURE 14.15 Absorption (deliquescent) dryer, liquid medium.

This system will produce a 20°F dew point reduction below the inlet air temperature as a general rule. The greatest advantage of this type of dryer is that no external connections of any kind are required for this system to operate except a drain. It has the least initial cost. It is generally used for intermittent flows where a high degree of drying is not required. Disadvantages are that some material used as a medium may be corrosive to the vessel, special treatment of the disposed liquid may be necessary, there is a limited dew point reduction, and since a small amount of glycol is lost in this process, some replacement is periodically required.

Adsorption. Adsorption dryers use a porous, nonconsumable material that causes water vapor to condense as a very thin film on the surface of the material. This material is called a *desiccant.* There is no chemical interaction, and the adsorption process is reversible. For a system schematic, see Fig. 14.16. Desiccant dryers are

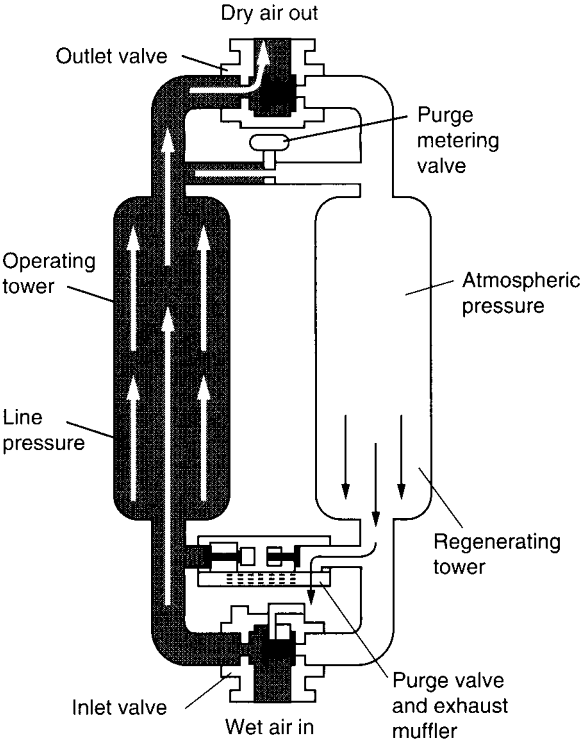


FIGURE 14.16 Absorption (desiccant) dryer. Two vessels filled with desiccant are interconnected by piping and valves that control airflow direction. One tower receives wet air where desiccant collects moisture and dries the air. Simultaneously, desiccant in the second tower is regenerated. Collected moisture is driven off by internal heaters or by dry air from the operating tower. Redirecting the airflow regenerates the first tower while the second dries the main airstream. (*Courtesy Van Air Systems.*)

capable of producing a pressure dew points as low as −100°F. The method of regeneration is the primary way of distinguishing between types of desiccant dryers.

Desiccant materials include silica gel, activated alumina, and aluminosilicate (molecular sieve). Each material can also be applied in the 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, particularly by oils. If adequate protection is not provided, the material may have to be replaced, although, if the contamination is not extensive, it might be brought back by removal of the impurities.

The three general types of regeneration methods for desiccant dryers are: pressure swing (heatless), heat activated (internal or external heaters), and heat of compression.

Pressure swing systems regenerate the material by using a portion of dry air from the system to flow in a reverse direction, thus purging the desiccant bed of water. This operation is completed in a short period of time, usually no longer then 10 min. This purge air must be discharged to the atmosphere and thus is lost. This requires that the compressor be oversized in order to accommodate the additional air required for drying.

Thermal swing regeneration using internal heaters is commonly used for units up to 1000 scfm and 100 psig. Purge air from the system is directed to flow in a reverse direction through the unit, with the purge air heated by internal heating elements. Average purge air requirements may be as much as 15 percent of air compressor capacity.

External heat regeneration uses a purge blower, atmospheric air, and an external heater to fulfill regeneration process requirements. The use of system air is not necessary. Because of the external heater, larger units can be selected for faster regeneration time.

In general, pressure swing dryers are lowest in initial cost, among the lowest in operating cost, and produce the most consistent dew point. In addition, they are more efficient in systems where high contamination may be a problem. Both adsorption and absorption dryers require an afterfilter to trap particles (fines) that escape from the dryer into the piping network.

Heat of compression dryers use hot air piped directly from the compressor to dry the desiccant material on a continuous basis. The air is returned to the discharge of the compressor.

Dryer Selection Procedure. The single most important requirement in the selection process is to determine the lowest required pressure dew point for the intended application. This may eliminate some types of dryers. An excessive regeneration flow rate may eliminate other dryer types. The economics of initial and operating costs between various units will be another determining factor.

The following information should 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 or aftercooler manufacturer the temperature of the air at the inlet of the dryer. Refer to Table 14.6 when no aftercooler is used.
3. Determine the minimum and maximum system pressure.
4. Determine the minimum and maximum flow rate for the system.

5. Determine whether the required electrical power and drainage are available where the dryer is to be installed.
6. Refer to a manufacturer's catalog to select the required dryer capable of meeting these requirements. Consideration should be given to initial and operating costs.

Lubricators

Lubricators are used to lubricate individual pieces of equipment when operating. There are three basic methods of lubrication, each for unique applications: fixed feed, demand feed, and positive displacement.

Fixed-feed lubricators are used for individual tools only and provide oil at a fixed rate (drops per minute). The amount is controlled by air velocity. This type of lubricator must be adjusted while the tool is running. Any filter and/or regulator must be compatible with the individual installation. This system is best used where there are long operating periods with constant airflow.

Demand feed systems use a wick saturated with oil. As the airstream passes the wick, lubricant is carried into the air. This type of lubricator should not be used where either low air velocity or volume exist.

Positive displacement lubricators use a pneumatic piston to force lubricant to the point of application whenever there is flow. This type is regarded as the most accurate and dependable, but it is the most costly. This system is best used for equipment with short operating cycles.

Air Compressor Drives

Electric motors are the predominant motive force for air compressors. Other methods of powering compressors are diesel, gasoline, or steam engines. Since electric motors are used predominantly, the discussion is limited only to that type. The two most common types of motors are induction and synchronous. Smaller compressors are generally driven by squirrel cage induction motors, with larger units having synchronous motors.

Motors are coupled to compressors either by belt drive, direct coupling, adjustable speed couplings, flexible coupling, or flange coupling. Belt drives are the most common for typical systems. Belt drive couplings lose approximately 4 percent of their power through the drive connection.

Starters used for electric drives are based on the type and size of motor. Magnetic, across-the-line starters are the most commonly used. When an across-the-line starter is used with an induction motor, a starting inrush of current is 5½ times the running current. If this is too much current, and you wish to reduce the initial load, a step starter (reduced voltage) can be used. This type has a series of taps or steps to reduce voltage (and therefore current) to the motor. Care must be taken to select a reduced voltage starter that provides the necessary torque to start the compressor, which is usually 110 percent of running torque. Consult an electrical engineer and manufacturer to check correct selection. The synchronous motor has a starting inrush of 3½ times the running current. Make sure all necessary overload protection is provided to prevent damage to the motor in case the compressor fails to start.

The power factor, which is a charge a utility company makes for peak energy demand, may be a deciding criterion in the selection of an appropriate type of drive motor for larger sizes. The synchronous motor has a lower power factor than an induction motor.

Compressor Regulation

If the total system demand for both air pressure and volume exactly matches the compressor output for as long as the compressor operates, no regulation would be required. Since this does not usually happen, whenever system demand varies, it will be necessary to regulate the compressor. Some manner must be found to adjust output to match the variable demands of the system. The ideal method would be to have an infinitely variable compressor to provide the exact volume and pressure required to satisfy all demands. Again, this is not realistic. We will now discuss the commonly used methods to achieve varying volume of air while maintaining adequate system pressure.

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 by controlling 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 either *unloading* or *blowoff* and is wasteful of energy. Finally, the internals of a compressor can be altered to be less efficient by adjusting valves, clearances, and so on. The last method is the least desirable of all because the correct speed and the internal adjustment of the compressor can be determined and accomplished only by the manufacturer for specific projects. This makes it almost impossible for maintenance personnel to repair in the field. Blowoff, however, has several alternatives.

In general, unloading is best used when the compressor operates more than 50 percent of the time or where continuous operation of a motor is desirable. For applications requiring constant compressor speeds, a pilot unloader, pressure-sensing device, or trigger valves would be used. The pilot unloader can operate in one of three ways—it may adjust compressor cylinder suction valves, close valves on the compressor inlet line, or open a bypass in the main discharge line. To summarize, a constant compressor speed unloader operates when upper pressure is reached but the motor continues to run. At the lower pressure limit, the pilot stops working and allows air to be delivered. Of course, the motor is still running.

Discontinuous regulation is the most common method of controlling compressor capacity for relatively small systems. This is accomplished by using a pressure-regulating device (either mechanical or electromechanical) arranged to stop the compressor at a preset high pressure and start it again at 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. Receivers will be discussed later.

There are circumstances when both kinds of regulation may prove beneficial. It is possible to have both types acting together. This is referred to as *dual regulation* or *control.*

Speaking in general terms about continuous regulation, the reciprocating compressor uses the inlet suction valve most often. It is possible to obtain this type of unloader in from one to three gradually increasing stages of operation. Sliding vane and screw compressors commonly use the modulating suction valve, with dual control and a receiver if demand permits. Centrifugal compressors should not be run outside their range, and so a blowoff to atmosphere is used.

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 still under pressure in 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 allow the compressor to start under no load. This is done with a starting unloader, of which there are two types: centrifugal and pressure switch. The pressure switch operates by using a separate switch to open a valve-type mechanism installed in the cylinder head. The centrifugal unloader is an integral part of the compressor and is activated through a connection to the camshaft. The centrifugal unloader is generally preferred because it is more reliable.

Compressed Air Receivers

The primary purpose of a receiver is to store air. 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 blowoff, 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, and 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. Stores air
2. Equalizes 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 inside the tank before being discharged.

Receivers should be ASME stamped for unfired pressure vessels. Refer to Table 14.7 for standard receiver sizes. Receivers should be sized on the basis of system

TABLE 14.7 Standard ASME Receiver Dimensions

Diameter, in	Length, ft	Volume, ft^3
14	4	4½
13	6	11
24	6	19
30	7	34
36	8	57
42	10	96
48	12	151
54	14	223
60	16	314
66	18	428

$\frac{1\text{ in} = 25.4\text{ mm}}{1\text{ ft}^3 = 0.03\text{ m}^3}$ 1 ft = .3 m.

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 that the receiver is an integral part of the system that must function in respect to load conditions, amount of storage, and pressure differential.

Cooling Water

Water is used to cool air compressor jackets and also to cool the air passing through intercoolers and aftercoolers. When used to cool compressors, it will result in a lower horsepower motor than similar capacity air-cooled units. Water may also be used to cool the oil used for compressor lubrication.

It is no longer acceptable to waste the water used for cooling. One reason is that in most cases, this water may be fairly expensive if it has been treated. Another is that the wastewater must also be treated. If river water is used with only filtering, it can be discharged back into the source if doing so is acceptable to the local authorities. The use of cooled or chilled water is preferred.

Water temperature is an important consideration. The coldest water should go to the intercooler and aftercooler first because the lower the cooling water temperature, the more efficient that stage will be. If the cooling water supplied to a reciprocating compressor jacket is too cold, it may cause water vapor to condense inside the cylinders and thus wash away some lubrication. This will accelerate wear of pistons, rings, and cylinder walls. A good rule to remember is that water should be the same temperature as the desired discharged air or slightly higher. In general, water over 110°F should not be considered for cooling purposes. A 10°F (6°C) rise inside the compressor is a common average temperature rise. The following should be considered when providing cooling water:

1. Generally, a 5 psig pressure drop can be expected when cooling compressor jackets.
2. A strainer on the water supply to compressor jackets should be provided.
3. A minimum supply pressure of 10 psig should be available.
4. A solenoid valve to start water flow only when compressor starts should be provided.
5. Thermometers should be provided on the inlet and outlet to facilitate troubleshooting.
6. A sight glass or drain funnel should be provided to monitor actual flow.
7. A figure of ½ gpm/hp is the average requirement for supplying cooling water to an air compressor.

The amount of cooling water required for all purposes may be determined from the following formula.

$$\text{gpm} = \frac{\text{BHP} \times H}{T \times 8.33} \tag{14.1}$$

where BHP = brake horsepower of compressor
H = heat dissipation, Btu/h
T = selected temperature rise of cooling water (usually 10°F)

TABLE 14.8 Selection of Supply Hose Size

Air inlet port NPT, in	⅛	¼	⅜	½
Supply hose size I.D., in	¼	⅜	½	¾

1 in = 25.4 mm.

Hose and Fittings

Most tools use flexible hose for connection to the piping system. The hose used is usually larger than the air inlet port on the tool it serves. Table 14.8 indicates generally accepted practice for the selection of supply hoses based on the size of the inlet ports. Where the length of hose may extend beyond 20 ft, hose one size larger than normal should be used to compensate for additional line friction loss. It is good practice to limit friction loss of hose to 5 psig. Refer to Table 14.21 for pressure loss through various sizes and lengths of hose.

UTILITY (LIGHT INDUSTRIAL) COMPRESSED AIR

SYSTEM 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 at any outlet during the period of heaviest use. 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 be necessary as the design progresses.

The entire system will be separated into three individual systems:

1. Air compressor, including regulation, intake, and receiver
2. Compressed air conditioning equipment
3. Piping distribution network

Design Sequence

1. Locate and identify each process, workstation, or piece of equipment using compressed air. These components should be located on a plan, and a complete list should be made to simplify record keeping.
2. Determine the volume of air to be used at each location.
3. Determine the pressure range required at each location.
4. Determine the conditioning requirements for each item, such as the 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 1-min period of time. This is referred to as the *duty cycle.*
6. Establish the maximum number of locations that may be used simultaneously on each branch and 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 location, and air inlet, making sure that either scfm or acfm is consistently used for both the system and compressor capacity rating.
11. Produce a final piping layout, and size the piping network.

Project Air Consuming Device Location. This speaks for itself. In order to accomplish this task, it is recommended that the location of all air consuming devices and their requirements be marked on a plan in order to facilitate the branch piping layout. Prepare a list for future reference of all devices noted on the plans, as well as their location and actual flow rate.

Pressure and Volume Requirement. The information relative to pressure and volume parameters for individual equipment and tools is usually obtained from the tool manufacturer, end user, facility planner, or owner. It is quite common for these facts 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 14.9 lists general air requirements for various tools.

TABLE 14.9 General Air Requirements for Tools

Tools or equipment	Size or type	Air pressure, psig	Air consumed, scfm
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	6	70–90	4
Grinders	2-in wheel	70–90	50
Grinders	4-in wheel	70–90	20
Paint sprayers	Production gun	40–70	20
Spring oilers		40–70	4
Paint sprayers	Small hand	70–90	2–10
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
Carbon removers		70–100	3
Sand blasters	Wide variation	90	6–400

1 psi = 6.9 kPa.
1 cfm = 0.03 m^3/min.

All tools use air either through an orifice to do work or to drive a piston. Table 14.10 gives the amount of air in scfm passing through an orifice at various pressures. Table 14.11 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, due to the wide variation in requirements of similar air consuming devices from different manufacturers.

Compressed Air Conditioning. The selection of conditioning equipment depends upon end use requirements, usually obtained when items 2, 3, and 4 are received. 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. Table 14.12 gives general performance specifications of types of air dryers. If a very low dew point is required, the only selection possible is a desiccant dryer. If, however, a high dew point is acceptable, several different types of dryers can be considered.

Deliquescent Dryer. The deliquescent dryer is the least efficient, 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 affect the quality of air. For example, a salt material normally reduces 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 the dryer to remove any chemical carryover (fines) into the system.

Refrigerated Dryers. The most often used type of dryer is the refrigerated type. Refrigerated dryers will produce pressure dew points as low as 33°F (1°C), but for practical purposes, a general figure of about 38°F (3°C) has been used. General operating cost is moderate. External requirements are floor drains and electric power. These dryers are sensitive to changes in flow rate and pressure of the airstream. The initial cost is moderate.

TABLE 14.10 Air Volume Passing through an Orifice, CFM

Gauge pressure, psi	Orifice size, inches diameter							
	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 psi × 6.9 = kPa.
1 cfm = 0.03 m^3/min.

TABLE 14.11 Air Volume Requirements for Single-Acting Piston in Cubic Feet

Piston dia., in	Length of stroke, in*											
	1	2	3	4	5	6	7	8	9	10	11	12
1¼	0.00139	0.00278	0.00416	0.00555	0.00694	0.00832	0.00972	0.0111	0.0125	0.0139	0.0153	0.01665
1⅞	0.00158	0.00316	0.00474	0.00632	0.0079	0.00948	0.01105	0.01262	0.0142	0.0158	0.0174	0.01895
2	0.00182	0.00364	0.00545	0.00727	0.0091	0.0109	0.127	0.0145	0.01636	0.0182	0.020	0.0218
2⅛	0.00205	0.0041	0.00615	0.0082	0.0103	0.0123	0.0144	0.0164	0.0185	0.0205	0.0226	0.0244
2¼	0.0023	0.0046	0.0069	0.0092	0.0115	0.0138	0.0161	0.0184	0.0207	0.0230	0.0253	0.0276
2⅜	0.00256	0.00512	0.00768	0.01025	0.0128	0.01535	0.01792	0.02044	0.0230	0.0256	0.0282	0.0308
2½	0.00284	0.00568	0.00852	0.01137	0.0142	0.0171	0.0199	0.0228	0.0256	0.0284	0.0312	0.0343
2⅝	0.00313	0.00626	0.0094	0.01254	0.01568	0.0188	0.0219	0.0251	0.0282	0.0313	0.0345	0.0376
2¾	0.00343	0.00686	0.0106	0.0137	0.0171	0.0206	0.0240	0.0272	0.0308	0.0343	0.0378	0.0412
2⅞	0.00376	0.00752	0.0113	0.01503	0.01877	0.0226	0.0263	0.0301	0.0338	0.0376	0.0413	0.045
3	0.00409	0.00818	0.0123	0.0164	0.0204	0.0246	0.0286	0.0327	0.0368	0.0409	0.0450	0.049
3⅛	0.00443	0.00886	0.0133	0.0177	0.0222	0.0266	0.0310	0.0354	0.0399	0.0443	0.0488	0.0532
3¼	0.0048	0.0096	0.0144	0.0192	0.024	0.0288	0.0336	0.0384	0.0432	0.0480	0.0529	0.0575
3⅜	0.00518	0.01036	0.0155	0.0207	0.0259	0.031	0.0362	0.0415	0.0465	0.0518	0.037	0.062
3½	0.00555	0.0112	0.0167	0.0222	0.0278	0.0333	0.0389	0.0445	0.050	0.0556	0.061	0.0644
3⅝	0.00595	0.0119	0.0179	0.0238	0.0298	0.0357	0.0416	0.0477	0.0536	0.0595	0.0655	0.0715
3¾	0.0064	0.0128	0.0192	0.0256	0.032	0.0384	0.0447	0.0512	0.0575	0.064	0.0702	0.0766
3⅞	0.0068	0.01362	0.0205	0.0273	0.0341	0.041	0.0477	0.0545	0.0614	0.068	0.075	0.082
4	0.00725	0.0145	0.0218	0.029	0.0363	0.435	0.0508	0.058	0.0653	0.0725	0.0798	0.087
4⅛	0.00773	0.01547	0.0232	0.0309	0.0386	0.0464	0.0541	0.0618	0.0695	0.0773	0.0851	0.092
4¼	0.0082	0.0164	0.0246	0.0328	0.041	0.0492	0.0574	0.0655	0.0738	0.082	0.0903	0.0985
4⅜	0.0087	0.0174	0.0261	0.0348	0.0435	0.0522	0.0608	0.0694	0.0782	0.087	0.0958	0.1042
4½	0.0092	0.0184	0.0276	0.0368	0.046	0.0552	0.0643	0.0735	0.0828	0.092	0.101	0.1105

TABLE 14.11 Air Volume Requirements for Single-Acting Piston in Cubic Feet (Continued)

Piston dia., in	Length of stroke, in*											
	1	2	3	4	5	6	7	8	9	10	11	12
4⅝	0.0097	0.0194	0.0291	0.0388	0.0485	0.0582	0.0679	0.0775	0.0873	0.097	0.1068	0.1163
4¾	0.01025	0.0205	0.0308	0.041	0.0512	0.0615	0.0717	0.0818	0.0922	0.1025	0.1125	0.123
4⅞	0.0108	0.0216	0.0324	0.0431	0.054	0.0647	0.0755	0.0862	0.097	0.108	0.1185	0.1295
5	0.0114	0.0228	0.0341	0.0455	0.0568	0.0681	0.0795	0.091	0.1023	0.114	0.125	0.136
5⅛	0.01193	0.0239	0.0358	0.0479	0.0598	0.0716	0.0837	0.0955	0.1073	0.1193	0.1315	0.1435
5¼	0.0125	0.0251	0.0376	0.0502	0.0627	0.0753	0.0878	0.100	0.1128	0.125	0.138	0.151
5⅜	0.0131	0.0263	0.0394	0.0525	0.0656	0.0788	0.092	0.105	0.118	0.131	0.144	0.158
5½	0.01375	0.0275	0.0412	0.055	0.0687	0.0825	0.0962	0.110	0.1235	0.1375	0.151	0.165
5⅝	0.0144	0.0288	0.0432	0.0575	0.072	0.0865	0.101	0.115	0.1295	0.144	0.1585	0.173
5¾	0.015	0.030	0.045	0.060	0.075	0.090	0.105	0.120	0.135	0.150	0.165	0.180
5⅞	0.0157	0.0314	0.047	0.0628	0.0785	0.094	0.110	0.1254	0.142	0.157	0.1725	0.188
6	0.0164	0.032	0.492	0.0655	0.082	0.963	0.1145	0.131	0.147	0.164	0.180	0.197

Note: in = 25.4 mm, 1 cf = 0.0283 m^3.

*These volumes are for single-acting cylinders. For double-acting cylinders, multiply by 2 and subtract the volume of the piston rod.

TABLE 14.12 General Performance of Different Types of Air Dryers

	Inlet air capacity at 100°F				Outlet air at 100°F ambient						
Dryer type	Flow, scfm	Press., psig	Max. temp., °F	Moisture, % RH	Pressure, psig	Moisture, °F pdp	Cooling	Power required	Prefilter	Afterfilter	Installation
Deliquescent	5–30,000	100	100	Saturated	95	80	None	None (requires replenishment of drying medium)	Recommended	Required*	Indoor and outdoor
Refrigerated	5–25,000†	100	130	Saturated	95	35 to 50	Air at 100°F, or water at 85°F	Electrical‡	Recommended	Not required	Indoor
Desiccant, regenerative	1–20,000	100	120	Saturated	95	−40 to −100	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 increased. 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.

All cycling refrigerated air dryer ratings and capacity are based on National Fluid Power Association recommended Standard T/3.27.2 with saturated entering inlet air at 100°F (37.8°C) and 100 psig (690 kPa), with a 100°F (37.8°C) ambient air temperature. At these standard conditions, the dryer must be capable of producing outlet air with a dewpoint in a range of between 33 and 39°F and a pressure drop of 5 psig (35 kPa) or less. To select a dryer based on pressure drop and rated flow, refer to Fig. 14.17, entering with the actual pressure at the dryer inlet. For correction factors based on temperatures other than 100°F (37.8°C), inlet air temperatures other than 100°F (37.8°C), and ambient air temperatures other than 100°F (37.8°C), refer to Table 14.13. Dew point is also effected by low flow rates.

Desiccant Dryer. The desiccant dryer will produce the lowest dew points. They are the highest in initial cost and the highest in operating cost. Of the three purging methods used, the vacuum type is the most energy efficient. The unheated 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 dryer installations because it is an economical way to reduce the moisture content of air, and it should be selected in conjunction with the dryer. The aftercooler adds cost to the project and is not often used.

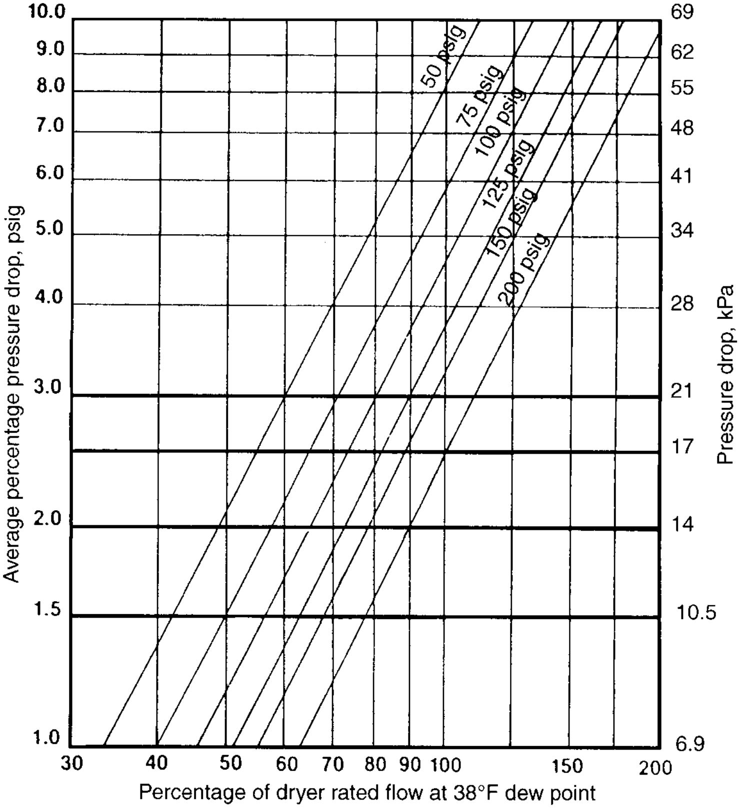


FIGURE 14.17 Pressure loss through refrigerated air dryers.
psi × 6.9 = kPa.

TABLE 14.13 Correction Factors for Refrigerated Air Dryers

	Inlet air pressure		Inlet air temperature		Ambient air temperature	
kPa	Pressure, psig	Correction factor	Temperature, °F/°C	Correction factor	Temperature, °F/°C	Correction factor
345	50	1.19	80/27	0.66	80/27	0.92
518	75	1.06	90/32	0.82	90/32	0.95
690	100	1.00	100/38	1.00	100/38	1.00
1035	150	0.95	110/43	1.21	110/43	1.07
1207	175	0.94				
1552	255	0.92	120/49	1.42	120/49	1.16

There are two factors that will be used to select a filter: effectiveness and pressure drop. Do not specify a filter that will produce cleaner air than is 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 70 kPa) pressure drop when dirty. If the actual figure proves to be too much, it would be a good idea to oversize the filter to cut down the pressure drop. In most cases, it would be more economical to pay the added initial cost of a larger filter than to increase energy requirements to compress air to a higher pressure for the life of the system.

It is considered good practice to provide pressure gauges on either side of main filters in order to determine filter condition. Lubricators are selected based on the manufacturer's requirements for tool operation. They must be consulted for type. Pressure regulators are selected using flow rate and pressure drop ratings.

Duty Cycle. In order to determine the duty cycle, the user should be consulted, for in most cases, they are the only authority capable of discussing the length of time air is in use. 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. Experience has shown that it is almost impossible to accurately determine a simultaneous 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. The exceptions are for classrooms, some research facilities, and some areas within hospitals, where the use factor may be quite high. See Table 14.14 and Fig. 14.29 for use factors applicable to typical laboratory projects.

Allowable Leakage. There is no method to accurately determine a reasonable figure. Leakage is a function of the number and type of connections, the age of the system, and quality of pipe assembly. Many smaller tools and operations will generally have a greater leakage of air than a few larger use points. A well-maintained system will have a leakage of about 2 to 5 percent. Average conditions will incur a 10 percent leakage. Poorly maintained systems have been known to have a 25 percent leakage factor. The facility maintenance department should be consulted when selecting a value.

TABLE 14.14 Laboratory Outlet Use Factors

No. of outlets	Percent use factor
1–2	100
3–5	80
6–10	66
11–20	40
21–50	30
Over 50	20

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

Soot Blowers. Air may be used in large boilers for removing interior soot and dirt. Flow may be either pulsating or steady. Design pressure would range between 100 and 120 psig (700 and 840 kPa) at about 50 scfm (1.5 m^2/mh). Check with manufacturer for exact requirements.

Ship Service. When a ship is berthed, air is used to supply pressure for pneumatic controls and some air tools. Expected flow would generally be 100 scfm at 100 psig (3 m^3 at 700 kPa). Larger ships may require additional scfm.

Aircraft Starting. Air is used to start jet engines. Pressures range from 45 to 75 psig (315 to 520 kPa) with a maximum flow of 1200 scfm (3.5 m^3/min). Air is stored in a receiver at a high pressure. A compressor should fill the receiver in 3 min.

Piping System Design

Piping layout on the plans will now be reasonably complete, with checking for space, clearances, interferences, and securely anchored drops to equipment. 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 using the following sequence:

1. In order to use pressure drop tables, it is necessary to find the equivalent length to run from the compressor to the farthest point in the piping system. The reason is that the various pipe sizing tables are based on a pressure drop developed 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 create an obstruction to the flow of air. This degree of obstruction has been converted to an equivalent length of pipe in order to make calculations easy. Table 14.15 has been developed to indicate the equivalent pipe length for fittings and valves that should be added to the actual measured run, to establish a total equivalent run. For preliminary calculation purposes, the addition of 50 percent of the actual measured run will give a conservative approximation of the total equivalent run and therefore the means to select a preliminary pipe size, if necessary, before final calculations are made.

2. Determine the actual pressure drop that will occur only in the piping system. Generally accepted practice is to allow 10 percent of the proposed system pressure for pipe friction loss. So, for a 125 psig (860 kPa) system, a figure of 10 to 12 psig (85 to 90 kPa) will be allowed. 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 the original design.

3. Size the piping using the appropriate charts for system pressure. 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) (30 m), it will be necessary to arrive at the required value for the chart you are using. Tables 14.16 through 14.19 present friction loss of air through Schedule 40 steel pipe in psig for a 100-ft (30 m) length of pipe, at from 50 to 125 psig (345 to 860 kPa) line pressure. Use the highest system working pressure to determine pipe size. The temperature used to calculate the friction loss is 60°F (15.6°C). For 100°F (37.8°C), increase pressure drop figures in the tables by 7.7 percent for greater accuracy. For copper pipe, reduce pressure drop figures by 5 percent. Table 14.20 is a suggested form for sizing stacks and mains. A maximum velocity or 4,000 fpm (1200 m/min) is recommended.

The charts were calculated using the following formula using IP units:

$$P = Q\,\frac{FV^2}{2GD} \tag{14.2}$$

where P = pressure loss due to friction, psi per 100 ft of pipe
F = friction loss factor (Use 4000 as an average figure.)
V = velocity, ft/s
G = acceleration due to gravity, 32.2 ft/s
D = pipe diameter, ft
Q = specific weight of air, lb/ft^3

The following general design parameters can be used for miscellaneous devices as a guide when calculating the total pressure drop of the piping system:

1. Equipment drop leg: 2 psig loss (1 psig if possible)
2. Hose allowance: 2 to 5 psig loss
3. Quick disconnect coupling: 4 psig loss
4. Lubricator: 1 to 4 psig loss
5. Point-of-use filter: ½ to 2 psig loss

Table 14.21 gives the friction loss of air through hose that would be used to connect tools to the main piping system.

TABLE 14.15 Equivalent Pressure Loss through Valves and Fittings in Feet of Pipe

Nominal pipe size, in	Actual inside diameter, in	Gate valve	Long radius, all or on run of standard tee	Standard ell or on run of tee reduced in size 50 percent	Angle valve	Close return bend	Tee through side outlet	Globe valve
½	0.622	0.36	0.62	1.55	8.65	3.47	3.10	17.3
¾	0.824	0.48	0.82	2.06	11.4	4.60	4.12	22.9
1	1.049	0.61	1.05	2.62	14.6	5.82	5.24	29.1
1¼	1.380	0.81	1.38	3.45	19.1	7.66	6.90	38.3
1½	1.610	0.94	1.61	4.02	22.4	8.95	8.04	44.7
2	2.067	1.21	2.07	5.17	28.7	11.5	10.3	57.4
2½	2.469	1.44	2.47	6.16	34.3	13.7	12.3	68.5
3	3.068	1.79	3.07	6.16	42.6	17.1	15.3	85.2
4	4.026	2.35	4.03	7.67	56.0	22.4	20.2	112.0
5	5.047	2.94	5.05	10.1	70.0	28.0	25.2	140.0
6	6.065	3.54	6.07	15.2	84.1	33.8	30.4	168.0
8	7.981	4.65	7.96	20.0	111.0	44.6	40.0	222.0
10	10.020	5.85	10.00	25.0	139.0	55.7	50.0	278.0
12	11.940	6.96	11.00	29.8	166.00	66.3	59.6	332.0

1 ft = 0.3 m.
1 in = 25.4 mm.

TABLE 14.16 Pressure Drop of Air (in psi through 100 ft) through Steel Pipe, 50 psig and 60°F Temperature (350 kPa and 18°C)

	Pipe diam., in										
scfm	½	¾	1	1¼	1½	2	2½	3	4	5	6
2	0.024	0.006									
3	0.055	0.012									
4	0.098	0.022	0.006								
5	0.153	0.034	0.009								
6	0.220	0.050	0.013								
8	0.391	0.088	0.023	0.006							
10	0.611	0.138	0.036	0.009							
15	1.374	0.310	0.082	0.020	0.009						
20	2.443	0.551	0.146	0.035	0.016						
25	3.617	0.861	0.227	0.055	0.024	0.007					
30	5.497	1.240	0.328	0.079	0.035	0.010					
35	—	1.688	0.446	0.108	0.047	0.013	0.005				
40	—	2.205	0.582	0.141	0.062	0.017	0.007				
45	—	2.791	0.737	0.178	0.078	0.021	0.009				
50	—	3.445	0.910	0.220	0.097	0.026	0.011				
60	—	4.961	1.310	0.317	0.140	0.038	0.016	0.005			
70	—	—	1.783	0.432	0.190	0.052	0.021	0.007			
80	—	—	2.329	0.564	0.248	0.068	0.028	0.009			
90	—	—	2.948	0.713	0.314	0.086	0.035	0.011			
100	—	—	3.639	0.881	0.388	0.106	0.044	0.014			
125	—	—	5.686	1.376	0.606	0.165	0.068	0.022			
150	—	—	—	1.982	0.872	0.238	0.098	0.031	0.007		
175	—	—	—	2.697	1.187	0.324	0.133	0.043	0.010		
200	—	—	—	3.523	1.550	0.423	0.174	0.056	0.013		
225	—	—	—	4.459	1.962	0.536	0.220	0.070	0.016		
250	—	—	—	5.505	2.423	0.662	0.272	0.087	0.020	0.006	
275	—	—	—	—	2.931	0.801	0.329	0.105	0.024	0.007	

1 in = 25.4 mm.

TABLE 14.16 Pressure Drop of Air (in psi through 100 ft) through Steel Pipe, 50 psig and 60°F Temperature (350 kPa and 18°C) (Continued)

	Pipe diam., in									
scfm	½	¾	1	1¼	1½	2	2½	3	4	5	6
300	—	—	—	—	3.489	0.953	0.392	0.125	0.029	0.009	
325	—	—	—	—	4.094	1.118	0.460	0.147	0.034	0.010	
350	—	—	—	—	4.748	1.297	0.533	0.170	0.039	0.012	
375	—	—	—	—	5.451	1.489	0.612	0.195	0.045	0.014	0.005
400	—	—	—	—	6.202	1.694	0.696	0.222	0.051	0.015	0.006
425	—	—	—	—	—	1.912	0.786	0.251	0.057	0.017	0.007
450	—	—	—	—	—	2.144	0.881	0.281	0.064	0.019	0.006
475	—	—	—	—	—	2.388	0.982	0.313	0.072	0.022	0.009
500	—	—	—	—	—	2.646	1.068	0.347	0.079	0.024	0.010
550	—	—	—	—	—	3.202	1.317	0.420	0.096	0.029	0.012
600	—	—	—	—	—	3.811	1.567	0.500	0.114	0.035	0.014
650	—	—	—	—	—	4.473	1.839	0.587	0.134	0.041	0.016

TABLE 14.17 Pressure Drop of Air (in psi per 100 ft) through Schedule 40 Steel Pipe, 75 psig

(Cubic feet of free air at 60°F, 14.7 psia 18°C and 100 kPa)

	Pipe diam., in										
scfm	½	¾	1	1¼	1½	2	2½	3	4	5	6
2	0.018										
3	0.040	0.009									
4	0.070	0.016									
5	0.110	0.025									
6	0.159	0.036	0.009								
8	0.282	0.064	0.017								
10	0.441	0.099	0.026								
15	0.991	0.224	0.059	0.014							
20	1.762	0.398	0.105	0.025	0.011						
25	2.753	0.621	0.164	0.040	0.017						
30	3.965	0.895	0.236	0.057	0.025						
35	5.396	1.218	0.322	0.078	0.034	0.009					
40	7.048	1.590	0.420	0.102	0.045	0.012					
45	8.921	2.013	0.532	0.129	0.057	0.015					
50	—	2.485	0.656	0.159	0.070	0.019	0.008				
60	—	3.579	0.945	0.229	0.101	0.027	0.011				
70	—	4.871	1.286	0.311	0.137	0.037	0.015				
80	—	6.362	1.680	0.407	0.179	0.049	0.020				
90	—	8.052	2.126	0.515	0.226	0.062	0.025	0.008			
100	—	—	2.625	0.635	0.280	0.076	0.031	0.010			
125	—	—	4.101	0.993	0.437	0.119	0.049	0.016			
150	—	—	5.906	1.429	0.629	0.172	0.071	0.023			
175	—	—	8.039	1.946	0.856	0.234	0.096	0.031			
200	—	—	—	2.541	1.118	0.305	0.126	0.040	0.009		
225	—	—	—	3.216	1.415	0.387	0.159	0.051	0.012		
250	—	—	—	3.971	1.747	0.477	0.196	0.063	0.014		
275	—	—	—	4.804	2.114	0.577	0.237	0.076	0.017		

1 in = 25.4 mm.

TABLE 14.17 Pressure Drop of Air (in psi per 100 ft) through Schedule 40 Steel Pipe, 75 psig (Continued)

(Cubic feet of free air at 60°F, 14.7 psia 18°C and 100 kPa)

	Pipe diam., in										
scfm	½	¾	1	1¼	1½	2	2½	3	4	5	6
300	—	—	—	5.718	2.516	0.687	0.283	0.090	0.021		
325	—	—	—	6.710	2.953	0.807	0.332	0.106	0.024		
350	—	—	—	7.782	3.425	0.935	0.385	0.123	0.028	0.008	
375	—	—	—	8.934	3.932	1.074	0.441	0.141	0.032	0.010	
400	—	—	—	—	4.473	1.222	0.502	0.160	0.037	0.011	
425	—	—	—	—	5.050	1.379	0.567	0.181	0.041	0.013	
450	—	—	—	—	5.662	1.546	0.636	0.203	0.046	0.014	
475	—	—	—	—	6.308	1.723	0.706	0.226	0.052	0.016	
500	—	—	—	—	6.990	1.909	0.785	0.251	0.057	0.017	
550	—	—	—	—	8.458	2.310	0.950	0.303	0.069	0.021	0.008
600	—	—	—	—	—	2.749	1.130	0.361	0.082	0.025	0.010
650	—	—	—	—	—	3.226	1.326	0.423	0.097	0.029	0.012

TABLE 14.18 Pressure Drop of Air (in psi per 100 ft) through Schedule 40 Steel Pipe, 100 psig (700 kPa)

(Cubic feet of free air at 60°F, 14.7 psia)

	Pipe diam., in										
scfm	½	¾	1	1¼	1½	2	2½	3	4	5	6
2	0.014										
3	0.031										
4	0.055	0.012									
5	0.086	0.019									
6	0.124	0.028									
8	0.220	0.050	0.013								
10	0.345	0.078	0.021								
15	0.775	0.175	0.046	0.011							
20	1.378	0.311	0.082	0.020							
25	2.153	0.486	0.128	0.031	0.014						
30	3.101	0.700	0.185	0.045	0.020						
35	4.220	0.952	0.251	0.061	0.027						
40	5.512	1.244	0.328	0.079	0.035						
45	6.976	1.574	0.416	0.101	0.044	0.012					
50	8.613	1.943	0.513	0.124	0.055	0.015					
60	12.402	2.799	0.739	0.179	0.079	0.021					
70	—	3.809	1.006	0.243	0.107	0.029	0.012				
80	—	4.975	1.314	0.318	0.140	0.038	0.016				
90	—	6.297	1.663	0.402	0.177	0.048	0.020				
100	—	7.774	2.053	0.497	0.219	0.060	0.025				
125	—	12.147	3.207	0.776	0.342	0.093	0.038	0.012			
150	—	—	4.619	1.118	0.492	0.134	0.055	0.018			
175	—	—	6.287	1.522	0.670	0.183	0.075	0.024			
200	—	—	8.211	1.987	0.875	0.239	0.098	0.031			
225	—	—	10.392	2.515	1.107	0.302	0.124	0.040			
250	—	—	12.830	3.105	1.367	0.373	0.153	0.049	0.011		
275	—	—	—	3.757	1.654	0.452	0.186	0.059	0.014		

TABLE 14.18 Pressure Drop of Air (in psi per 100 ft) through Schedule 40 Steel Pipe, 100 psig (700 kPa) (Continued)

(Cubic feet of free air at 60°F, 14.7 psia)

	Pipe diam., in										
scfm	½	¾	1	1¼	1½	2	2½	3	4	5	6
300	—	—	—	4.471	1.968	0.537	0.221	0.071	0.016		
325	—	—	—	5.248	2.309	0.631	0.259	0.083	0.019		
350	—	—	—	6.086	2.678	0.731	0.301	0.096	0.022		
375	—	—	—	6.987	3.075	0.840	0.345	0.110	0.025		
400	—	—	—	7.949	3.498	0.955	0.393	0.125	0.029		
425	—	—	—	8.974	3.949	1.079	0.443	0.142	0.032		
450	—	—	—	10.061	4.428	1.209	0.497	0.159	0.036	0.011	
475	—	—	—	11.210	4.933	1.347	0.554	0.177	0.040	0.012	
500	—	—	—	12.421	5.466	1.493	0.614	0.196	0.045	0.014	
550	—	—	—	—	6.614	1.806	0.743	0.237	0.054	0.016	
600	—	—	—	—	7.871	2.150	0.884	0.282	0.064	0.020	
650	—	—	—	—	9.238	2.523	1.037	0.331	0.076	0.023	

TABLE 14.19 Pressure Drop of Air (in psi per 100 ft) through Schedule 40 Steel Pipe, 125 psig

(Cubic feet of free air at 60°F, 14.7 psia)

	Pipe diam., in									
scfm	½	¾	1	1¼	1½	2	2½	3	4	5
3	0.025									
4	0.045									
5	0.071	0.016								
6	0.102	0.023								
8	0.181	0.041								
10	0.283	0.064	0.017							
15	0.636	0.144	0.038							
20	1.131	0.255	0.067	0.016						
25	1.768	0.399	0.105	0.025						
30	2.546	0.574	0.152	0.037	0.016					
35	3.465	0.782	0.206	0.050	0.022					
40	4.526	1.021	0.270	0.065	0.029					
45	5.728	1.292	0.341	0.083	0.036					
50	7.071	1.596	0.421	0.102	0.045					
60	10.183	2.298	0.607	0.147	0.065	0.018				
70	13.860	3.128	0.826	0.200	0.088	0.024				
80	—	4.085	1.079	0.261	0.115	0.031	0.013			
90	—	5.170	1.365	0.330	0.145	0.040	0.016			
100	—	6.383	1.685	0.408	0.180	0.049	0.020			
125	—	9.973	2.633	0.637	0.281	0.077	0.031			
150	—	14.361	3.792	0.918	0.404	0.110	0.045	0.014		
175	—	—	5.162	1.249	0.550	0.150	0.062	0.020		
200	—	—	6.742	1.632	0.718	0.196	0.081	0.026		
225	—	—	8.533	2.065	0.909	0.248	0.102	0.033		
250	—	—	10.534	2.550	1.122	0.306	0.126	0.040		
275	—	—	12.746	3.085	1.358	0.371	0.152	0.049		

TABLE 14.19 Pressure Drop of Air (in psi per 100 ft) through Schedule 40 Steel Pipe, 125 psig (Continued)

(Cubic feet of free air at 60°F, 14.7 psia)

	Pipe diam., in									
scfm	½	¾	1	1¼	1½	2	2½	3	4	5
300	—	—	15.169	3.671	1.616	0.441	0.181	0.058	0.013	
325	—	—	—	4.309	1.896	0.518	0.213	0.068	0.016	
350	—	—	—	4.997	2.199	0.601	0.247	0.079	0.018	
375	—	—	—	5.736	2.525	0.689	0.283	0.090	0.021	
400	—	—	—	6.527	2.872	0.784	0.323	0.103	0.024	
425	—	—	—	7.368	3.243	0.886	0.364	0.115	0.027	
450	—	—	—	8.260	3.635	0.993	0.408	0.130	0.030	
475	—	—	—	9.204	4.050	1.106	0.455	0.145	0.033	
500	—	—	—	10.198	4.488	1.226	0.504	0.161	0.037	
550	—	—	—	12.340	5.430	1.483	0.610	0.195	0.044	0.013
600	—	—	—	14.685	6.463	1.765	0.726	0.232	0.053	0.016
650	—	—	—	—	7.585	2.071	0.852	0.272	0.062	0.019

TABLE 14.20 Suggested System Sizing Forms

Compressed air sizing main

Stack	Size stack	Conn. scfm stack no.	Total conn. scfm main	Use factor main	Total scfm main	Size main	Conn. scfm BR	Use factor BR	BR total scfm	Size BR

Compressed air sizing stack

Floor	Conn. scfm	Use factor branch	scfm branch	Size branch	Total conn. scfm stack	Stack use factor	Total scfm	Size stack

Air-Conditioning Equipment Selection

Specific performance characteristics of various dryer types have previously been given. All other equipment in this network will now be discussed.

The selection of a cooling medium for aftercoolers has been discussed previously. There are, however, additional points to be considered. Some aftercoolers have a high pressure drop at rated flow. Consider oversizing the unit. Some dryers require inlet air at a low maximum temperature. Selection must be made with this in mind. Provide a bypass around the aftercooler for ease of servicing.

Moisture separators are designed for specific flow conditions and so should be selected based on the actual design of the system. If marginal conditions are encountered, go to the next larger sized unit, but be sure the specified unit is compatible with actual volume. The pressure drop through a properly sized unit is about 3 psig.

The filter selection guidelines have been discussed earlier in this section under design. The sizing parameters must include maximum oil content of the air, maximum particulate size, and total scfm the filters must handle. Pressure loads are also a prime consideration. The magnitude of contaminants depends on the following:

1. Choice of air compressor
2. Presence or absence of an aftercooler
3. Type of dryer used
4. Quality of inlet air

Valves are an often overlooked component of a compressed air system. The selection of valve type and material is important to efficiency and operating life. The following should be considered when selecting valves:

1. The most important valve feature is minimum flow restriction (pressure drop) when the valve is open full. Ball, gate, and plug valves have the lowest pressure drop. It is extremely rare to use a valve for flow restriction; therefore, this is not a consideration.
2. The pressure rating should be suitable for the maximum pressure of compressor.
3. The valve body and seat materials must be compatible with the expected trace gases and contaminants.

TABLE 14.21 Friction Loss for Hose, in psi

Free air flow, scfm	6 ft, ⅛ in	8 ft, 5⁄32 in	8 ft, ¼ in	8 ft, 5⁄16 in	8 ft, ⅜ in	12.5 ft, ½ in	25 ft, ½ in	50 ft, ½ in	25 ft, ¾ in	50 ft, ¾ in	8 ft, 5⁄32 in 25 ft, ½ in	8 ft, ¼ in 50 ft, ½ in	12.5 ft, ½ in 25 ft, ¾ in	12.5 ft, ½ in 50 ft, ¾ 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	9.3	—	—	—	—	—	—	—	—	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					

Note: 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 percent. Use one half of indicated value for air at 50 psig.

4. There must be positive shutoff.
5. There should be minimum leakage through the valve stem.
6. The valves used should have been designed for compressed air service. Be careful to examine valve specifications for airway ports or openings smaller than the nominal size indicated or expected.

Selecting the Air Compressor Assembly

There is now enough information to size the compressor assembly. The assembly will include the intake system, compressor and compressor installation, and receiver. To start, the following information must be available:

1. Total connected scfm of all air using devices including flow to the air dryer system if applicable
2. Maximum pressure the assembly devices require
3. Duty and use factors giving maximum expected use of air by devices
4. scfm leakage and future expansion allowance
5. Allowable pressure drops for the 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. 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 possible, use outside air.

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. See Table 14.22 for characteristics of air inlet filters.

Uncontrolled piping pulsations can harm inlet piping, damage the building structure, and affect compressor performance. Airflow 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.’’ High 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, 16.8 to 26.2 ft, and 32.3 to 41.5 ft. A surge chamber can also be used to eliminate this problem.

The pressure loss of air through the intake piping should be held to a minimum. Suggested inlet pipe size is given in Table 14.23. Velocity of intake air should be limited to about 1000 fpm (300 m/min) to avoid noise problems, and friction loss limited to about 4 in of water. Inlet louver velocity should also be low enough to avoid drawing in rainwater. Standard round duct charts can also be used for sizing.

TABLE 14.22 Inlet Air Filter Characteristics

Filter type	Filtration efficiency, %	Particle size, μm	Maximum drop when clean, in WC	Comments (see key)
Dry	100	10	3–8	(1)
	99	5		
	98	3		
Viscous impingement (oil wetted)	100		¼–2	(2) (3)
	95	20		
	85	10		
Oil bath	98	10	6–10 = nominal	(2) (3) (4)
	90	3	2 = low drop	
Dry with silencer	100	10	5 (5)	
	99	5	7 (6)	
	98	3		

Key to comments:

(1) Recommended for nonlubricated compressors and for rotary vane compressors in a high dust environment.

(2) Not recommended for dusty areas or for nonlubricated compressors.

(3) Performance requires that oil is suitable for both warm and cold weather operation.

(4) Recommended for rotary vane compressors in normal service.

(5) Full flow capacity up to 1600 scfm.

(6) Full flow capacity from 1600 to 6500 scfm.

TABLE 14.23 Recommended Air Inlet Pipe Size

Maximum scfm free air capacity	Minimum size, in
50	2½
110	3
210	4
400	5
800	6

1 cfm = 0.03 m^3/min.

Source: Courtesy James Church.

In general, if air requirements are less than 500 scfm (15 m^3/min), the intake can be indoors. Provide an automatic drain on the line leading to the compressor, and pitch the intake piping to the drain point. If indoor air temperature is usually higher than 100°F (37.8°C), the intake should be outdoors.

Many different factors are involved in selection of compressor type:

1. Space limitations
2. Noise limitations
3. Compressor pressure capability
4. Capacity

5. Availability, cost, and quality of cooling water
6. Need for oil-free air
7. Electrical power limitations
8. Cost, both initial and long term

In the following circumstances, a duplex unit should be considered instead of a simplex unit:

1. When the cost of downtime is high. The owner may request two 100 percent capacity machines to eliminate the possibility of a shutdown.
2. Where a facility has a steady flow rate (called a *base load*) and in addition, where there are substantial additional requirements due to periodic or intermittent use.
3. When electrical starting requirements would overload a simplex system. Two units starting at different times would 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.

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

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 of the compressor.

The selection of the proper type of pump foundation and mounting depends upon the lowest frequency and magnitude of pump vibration and the load bearing requirement of the slab upon which the compressor rests. Metal, rubber, coils, and spring materials are available for use as isolators. The manufacturers of isolators should be consulted to confirm the proper type for the purpose and conditions expected.

Vibration isolation is achieved by the proper selection of resilient devices between the pump base and the building structure. This isolation 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). To illustrate the information presented, a typical design problem is presented below.

PROJECT DESIGN EXAMPLE

The project is located in Denver, Colorado, with the following values established:

1. Actual elevation: 5000 ft (1500 m) above sea level
2. Highest inlet air temperature: 90°F (32.2°C)
3. Highest average relative humidity expected: 90 percent
4. Established maximum system volume requirement: 800 scfm free air

5. Maximum required system pressure: 125 psi (860 kPa)

6. The selected air compressor rating units: at scfm 60°F (18°C), dry air at sea level

Adjustment of Required Intake Volume

After calculating the required volume of air that the compressor will have to deliver at pressure, it is time to find the actual compressor requirement for air intake in order to deliver the scfm required for use. As we will see, the required compressor intake volume must be adjusted in order to deliver the necessary volume. The reason adjustment is necessary is that the compressors are rated in scfm, and we have free air at the intake. Since standard air is at 60°F (18°C), dry (0 percent RH) and pressure at sea level. Since all three values from the Denver location do not match standard conditions, all three must be adjusted.

1. Altitude correction. From Table 14.2,

Opposite 5000 ft, read 1.17.

800 scfm × 1.17 factor = <u>136 scfm</u>

2. Temperature adjustment. From Table 14.3,

Opposite 90°F, read	1.038
Opposite 60°F, read	<u>0.981</u>
Total correction difference	0.057

800 scfm × 0.057 factor = <u>46 scfm</u>

3. Find the actual volume that the moisture in the inlet air occupies. Since this water will be removed, additional air must replace this water vapor.

a. From Table 14.4, 90 percent RH and 90°F, read 195 gr/lb of air

b. From Table 14.5, 195 gr/lb, read 4 percent volume:

800 scfm × 4 percent = <u>32 scfm</u>

Adding all adjustments together,

136 scfm—altitude

46 scfm—temperature

<u>32 scfm</u>—removal of water vapor

214 scfm say, 220 scfm

Therefore, the actual inlet volume would be 1020 scfm free air at the inlet (800 + 220) for a compressor to deliver 800 scfm free air. If some requirements are given in air actually compressed (acfm), see Fig. 14.18 to determine the free air equivalent of compressed air at pressure.

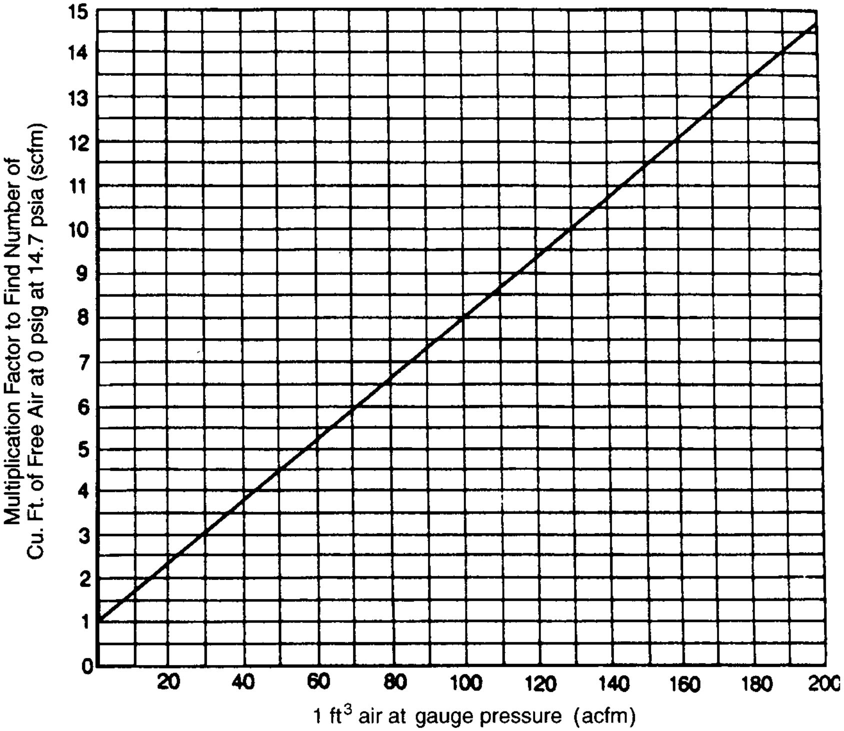


FIGURE 14.18 Ratio of free air to compressed air. To find the free air equivalent for 1 acfm at 130 psig pressure, find 130 at the bottom, go up to the diagonal, then horizontal to the left, to find the multiplier of 9.8. Then 1 acfm will equal 9.8 scfm.
1 psig × 7 = kPa.
1 cfm × 0.03 = m^3/min.

Sizing Moisture Separators and Traps

Water vapor enters the system through the air intake. The amount depends upon the temperature and relative humidity of the intake air. After compression and cooling, the air will not hold the same amount of water.

In order to determine the separator size and drain trap required to discharge the water condensed out of the air (either by intercooler or aftercooler) immediately after the compression process, the following is required:

1. Find the amount of water at intake based on the maximum values of temperature and relative humidity at the intake location.
2. Find the amount of water compressed air will hold at pressure and discharge temperature. The aftercooler must be selected and the discharge temperature (approach) known in order to find the correct values.

First, to find the amount of water in the air before compression at the intake, refer to Table 14.4, and at 90°F and 90 percent RH, read 195 gr/lb air. If the air is saturated, use Fig. 14.19. Next, determine the amount of water vapor remaining

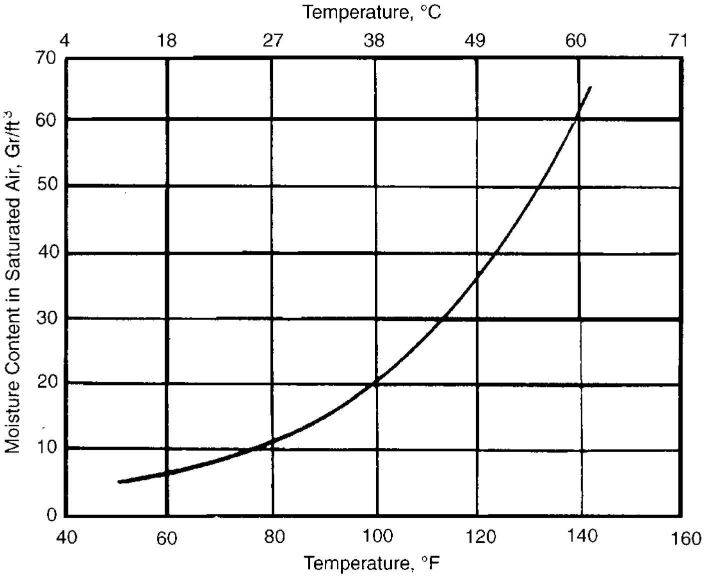


FIGURE 14.19 Moisture content of saturated air at atmospheric pressure.

in the air after compression, and after the aftercooler has cooled the air. The air leaving an aftercooler is saturated with water vapor. The design assumes that the temperature of air at this point is 100°F. Using Fig. 14.20, at the junction of the 125 psig curve and 100°F, read 0.29 lb/1000 cf.

To subtract one from the other, convert 195 gr/lb into gr/cf. Using Table 14.5, 195 gr/lb is 13 gr/cf. To convert 0.29 lb/1000 cf, use the conversion factor of 7000 gr in 1 lb. Therefore, $0.29 \times 7000 = 2100$ grains per 1000 cubic feet, or 2.1 grains per cubic foot. Therefore, the discharge rate is $13 = 2.1 - 10.9/\text{WFF} \times 1020$ scfm $= 11{,}118$ gr, or 1.7 gpm. Size the drain trap accordingly.

The air leaving the aftercooler has been established as having 2.1 gr/cf moisture; using Fig. 14.3, this figure translates to a dew point of +32°F. If a lower dew point is needed, a dryer will be required.

To size the drain trap at the dryer, use Table 14.5 and Fig. 14.3 to determine the amount of moisture lost between +32°F dew point and the actual dew point selected.

Sizing Receivers

Air receivers are used to keep compressors from working continuously. They store air at a higher pressure, allowing the compressor to shut down until the volume used causes the pressure to drop. Then the compressor starts the cycle again.

Air receivers should be placed as close as practical to the compressor. A flexible connection should be used to isolate the vibration of the compressor from the receiver. The size of the receiver is a function of time and pressure. One formula commonly used is:

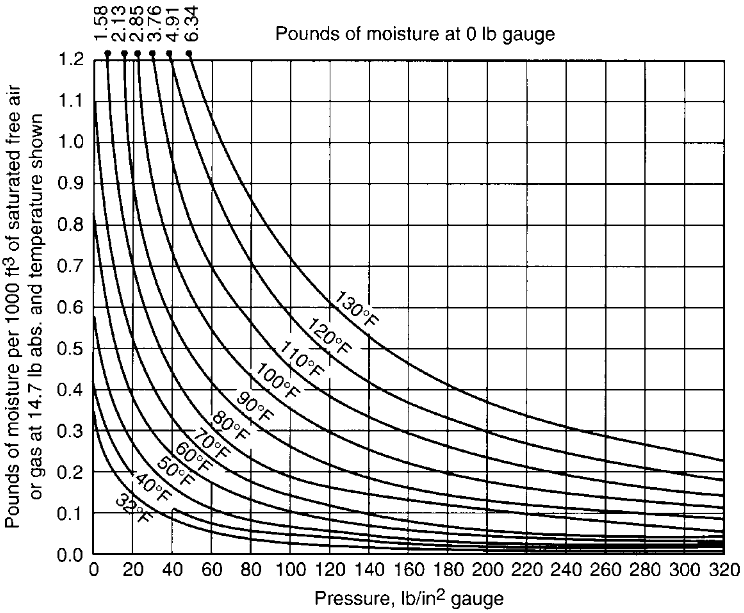


FIGURE 14.20 Moisture remaining in saturated air after compression. 1 psi × 4.9 = kg/m^2.

$$T = \frac{V(P_1 - P_2)}{CP} \tag{14.3}$$

where T = Time receiver will supply air from upper pressure to lower pressure, min
V = volume of receiver under design, ft^3
P_1 = upper pressure of air in receiver, psia
P_2 = lower pressure of air in receiver, psia
C = system air requirements, scfm
P = atmospheric pressure at receiver location, psia

Use the average value of T, which should be about 10 min. Then solve for the volume, selecting a standard tank as listed in Table 14.7. If the calculated size is too large, use a smaller T and consult the manufacturer. The receiver should be provided with an automatic drain trap and a pressure relief valve.

Instrumentation

Pressure and temperature gauges located in the system can help identify problems and signal the need for maintenance. Put temperature gauges on the discharge of both the aftercooler and fryer and on the cooling water inlet and outlet. Pressure gauges on each side of the filters and dryers and on the compressor discharge are useful for determining buildup and deposits.

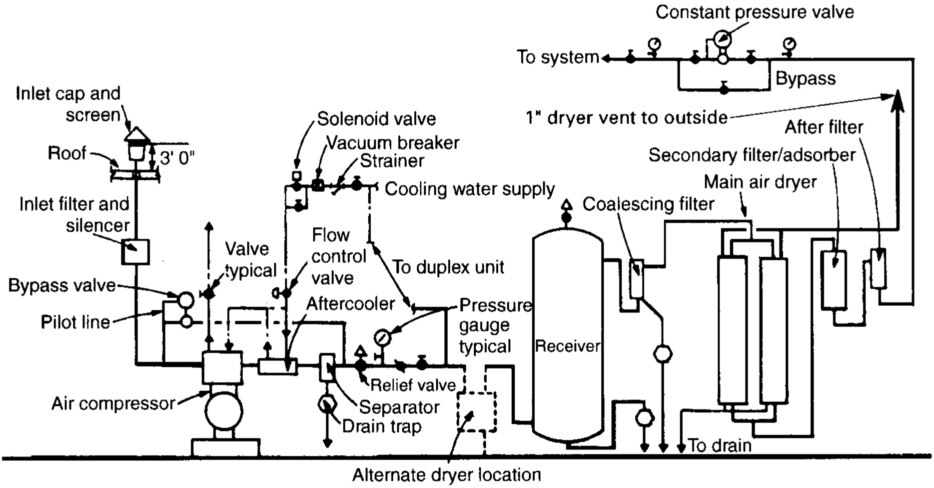


FIGURE 14.21 Typical detail of industrial air compressor assembly.

System Design Considerations

1. Provide for thermal expansion of pipe due to possibility of air reaching a temperature of 350°F.
2. Take all branch connections from top of mains.
3. Pitch pipe in direction of flow. When not possible, increase pipe one size to allow for water obstruction. With the flow, pitch pipe 3 in/100 ft (75 mm/33 m). Opposite flow, use 6 in per 100-ft (150 mm per 33 m) run.
4. Where pressure is over 100 psig, support piping on spring-loaded hangers around the compressor.
5. When quick disconnect fittings are used, provide extra stiff and rigid support (particularly at a ceiling drop). This type of fitting is often subjected to repeated force used in the connecting and disconnecting of hoses.

A detail of a typical industrial compressed air system is given in Fig. 14.21. This illustration shows the location of all equipment; however, not all the equipment shown is used for all installations.

INSTRUMENT AND CONTROL AIR

GENERAL

This subsection will discuss compressed air requirements for pneumatic instruments and control purposes. Instrument air is compressed air used to operate pneumatic controllers, pressure transmitters, pneumatic information transmission systems, pressure transducers, and other similar devices. Control air 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. This section will describe instrument air quality, production methods of air for use in pneumatic instruments.

CODES AND STANDARDS

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

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

AIR QUALITY STANDARDS

There are four elements of quality that must be considered: moisture content, oil content, particulate size, and other toxic contamination.

If any instrument air lines are located outside a building, then the maximum allowable dew point at which the instruments will continuously function satisfactorily is 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 shall be as close to zero as possible, with the maximum allowable content of 1 ppm under normal operating conditions. This requires the use of an oil-free compressor to generate the compressed air rather than the type of compressor that relies on filters to reduce the oil content.

The maximum allowable particulate size shall be 3 μm. The intake shall be free of 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 135°F (2°C)
2. Particulate size: Maximum 3 μm
3. Oil content: Maximum 1 ppm but as close to zero as possible
4. Miscellaneous contaminants: No corrosive or hazardous gases
5. Pressures required: Generally in the 15 to 50 psig (100 to 345 kPa) range

AIR PRESSURE REQUIREMENTS

There are two ranges of pressures used in pneumatic pressure transmission. The preferred nominal pressure is 12 psig (80 kPa), with an operating range (span) of between 3 psig (20 kPa) and 15 psig (100 kPa). The air supplied to this system shall have a range of between 19 psig (130 kPa) and 22 psig (150 kPa).

Another commonly used nominal working pressure is 24 psig (160 kPa), with an operating range of between 6 psig (40 kPa) and 30 psig (200 kPa). The air pressure supplied to this system is in the range of between 38 psig (260 kPa) and 44 psig (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 airstream further purified if necessary to achieve the required purity requirements. It is highly recommended that instrument air be produced by dedicated compressors.

PIPE AND FITTINGS

The most often used material for branch instrument air and pressure sensing lines is PE tubing and fittings. PE tubing is available in long lengths, minimizing joints. Sizes are ¼ and ⅜-in diameter. 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 of rigid copper or aluminum tubing.

PE should not be used where the ambient temperatures are greater than 175°F (80°C). PE is also subject to deterioration by solvents and by ultraviolet light.

SPECIALTY GASES FOR LABORATORIES

GENERAL

This subsection will describe various specialty compressed air and gas systems typically used for organic and inorganic chemistry, physics, and biological laboratories, and those used for research and development purposes. The gases used in these types of facilities are characterized by low delivery pressure, low and intermittent volume, and high purity requirements of the gas and of the delivery system. It is extremely rare that the quantity of pure gases used for laboratory and research purposes would justify large bulk storage. For this reason, this section will concentrate on cylinder supply, smaller cryogenic bulk storage tanks, and the generation of such gases. Larger bulk supply and storage systems will be discussed in the specialty industrial gas section of this chapter where production and other uses require large storage volumes.

CODES AND STANDARDS

The building codes and standards impacting the design and installation of the various laboratory gas systems have been put in place to protect the safety and health of operating personnel and building occupants, as have the building code requirements concerning fire and structural consequences of accidents. There are no mandated code requirements concerned with sizing or purity.

Minimum purity requirements are listed in the Compressed Gas Association (CGA) standards for various gases called ‘‘Commodity Standards.’’ Often, the actual, onsite purity requirements are higher than those listed in the standards and will be determined by the proposed use of the gas and the standards of the user. The CGA also has material and dimensional standards for pipe connections to terminals. For the gases not covered by the National Fire Protection Association (NFPA) and the CGA, good engineering practice is used to adequately locate the tanks and piping systems.

The NFPA has standards for the storage of flammable gases both inside and outside a building. NFPA-50 covers bulk oxygen at consumer sites, and NFPA-50A and 50B cover the storage of hydrogen. There are also standards for acetylene. NFPA-99 lists the requirements for the storage of flammable and nonflammable gases in cylinders.

Compressed gas systems within any type of facility are often required to conform to requirements of NFPA-99, health care facilities. The decision to adhere to provisions of this standard is dependent on the client, requirements of the client’s insurance carrier, and authorities having jurisdiction.

There are EPA health hazard classifications, fire hazard classifications, and sudden release of pressure hazard classifications. All of these ratings are available from a Material Safety and Data Sheet (MSDS). There are gases that fall under a classification of ‘‘Reactive Hazard,’’ and these must be kept separate from each other. This is usually done with walls, nonpermanent solid separators available from the supplier of the gas, or gas cabinets. There are also EPA threshold limit values for the degree of concentration of any particular gas in air for breathing purposes.

CLASSIFICATION OF SPECIALTY GASES

Compressed gases are classified into the following general categories:

1. *Oxidizers.* These gases are nonflammable but support combustion. No oil or grease is permitted to be used with any device associated with the use of this gas, and combustibles shall not be stored near these gases. Oxygen is an example.
2. *Inert gases.* These are gases that do not react with other materials. If released into a confined space, they will reduce the oxygen level to a point that asphyxiation could occur. Storerooms should be provided with oxygen monitors and should be well ventilated.
3. *Flammable gases.* These are gases that, when combined with air or oxidizers, will form a mixture that will burn or possibly explode if ignited. Flammable mixtures have a range of concentration below which they are too lean to be ignited and above they are too rich to burn. The most often used figure is the lower explosive level (LEL), which is the minimum percent, by volume, that will form a flammable mixture at normal temperatures and pressures. The high level for alarms is generally one-half of the LEL, with warnings issued at one-tenth of the LEL. The area where flammable gases are stored must be well ventilated, use approved electrical devices suitable for explosive atmospheres, and restrict all ignition sources. Flammability limits for common gases are given in Table 14.24.
4. *Corrosive gases.* These are gases that will attack the surface of rubber, metals, and other substances and also damage human tissue upon contact.
5. *Toxic and poisonous.* These are gases that will harm human tissue by contact or ingestion. Protective clothing and equipment must be used.
6. *Pyrophoric.* These are gases that spontaneously ignite upon contact with air under normal conditions.
7. *Cryogenic.* These gases are stored as extremely cold liquids under moderate pressure and vaporized when used. If the liquid is spilled, bare skin will suffer severe burns, and splashing into the eyes will cause blindness.

The categories and significant values of various gases are given in Table 14.24.

GRADES OF SPECIALTY GASES

There are many grades of pure and mixed gases available. Since there is no industry-recognized standard grade designation for purity, each supplier has its own individual designations. It is possible for the same gas used for different purposes to have a different designation for the same purity. The instrument manufacturer and the end user must be consulted for the maximum acceptable level of the various impurities based on the type of instrument used and the analytical work to be

TABLE 14.24 Specialty Gas Categories

Gas	Compressed gas	Liquefied gas	Oxidant	Inert	Corrosive	Toxic
Acetylene	(1)					
Air	●		●			
Allene		●				
Ammonia		●			●	●
Argon	●				●	
Arsine		●				(3)
Boron trichloride		●			●	●
Boron trifluoride	●		●		●	(3)
1,3-butadiene		●				
Butane		●				
Butenes		●				
Carbon dioxide		●			●	(2)
Carbon monoxide	●					●
Carbonyl sulfide		●			(2)	●
Chlorine		●	●		(2)	(3)
Cyanogen		●				(3)
Cyclopropane		●				
Deuterium	●					
Diborane	●					(3)
Dimethylamine		●			●	(3)
Dimethyl ether		●				
Ethane		●				
Ethyl acetylene		●				
Ethyl chloride		●				
Ethylene	●					
Ethylene oxide		●				(4)
Fluorine	●		●			(3)
Germane	●					(3)
Helium	●				●	
Hydrogen	●					
Hydrogen bromide		●			(2)	(3)
Hydrogen chloride		●			(2)	(3)
Hydrogen fluoride		●			●	(3)
Hydrogen sulfide		●				(3)
Isobutane		●				
Isobutylene		●				
Krypton	●				●	
Methane	●					
Methyl chloride		●				●
Methyl mercaptan		●				(3)
Monoethylamine		●				(3)
Monomethylamine		●			●	(3)
Neon	●				●	
Nitric oxide	●		●		(2)	(3)

(*Continued*)

TABLE 14.24 Specialty Gas Categories (*Continued*)

Gas	Compresses gas	Liquefied gas	Oxidant	Inert	Corrosive	Toxic
Nitrogen	●				●	
Nitrogen dioxide		●	●		(2)	(3)
Nitrogen trioxide		●	●		(2)	(3)
Nitrosyl chloride		●	●		(2)	(3)
Nitrous oxide		●		●		
Oxygen	●			●		
Phosgene		●				(3)
Phosphine		●				(3)
Propane		●				
Propylene		●				(3)
Halocarbon-12 (dichlorodifluoromethane)		●		●		(3)
Halocarbon-13 (chlorotrifluoromethane)		●			●	
Halocarbon-14 (tetrafluoromethane)	●				●	
Halocarbon-22 (chlorodifluoromethane)		●			●	
Silane	●					(3)
Sulfur dioxide		●			(2)	(3)
Sulfur hexafluoride		●			●	
Sulfur tetrafluoride		●			●	(3)
Trimethylamine		●			●	●
Vinyl bromide		●				●
Vinyl chloride		●				(6)
Xenon	●				●	

Key:
(1) Dissolved in solvent under pressure. Gas may be unstable and explosive above 15 psig.
(2) Corrosive in presence of moisture.
(3) Toxic. It is recommended that the user be thoroughly familiar with the toxicity and other properties of this gas.
(4) Cancer suspect agent.
(5) Pyrophoric; spontaneously flammable in air.
(6) Recognized human carcinogen.
(7) Flammable. However, limits are not known.

performed. The supplier must then be informed of these requirements in order to determine the grade of gas it will supply that meets or exceeds the allowable level of the various impurities.

The following list, although not complete, covers some manufacturers' designations for different grades of gases available. There are additional grades for specific instruments, such as ''Hall'' grades of gases.

1. Research grade
2. Carrier grade

3. Zero gas
4. Ultra zero
5. Ultrahigh purity plus
6. Ultrahigh purity
7. Purified
8. USP

STORAGE AND GENERATION OF GASES

Cylinder Storage

Where the anticipated gas usage does not require the installation of a cryogenic bulk supply, it is more convenient and less expensive to have gases compressed and stored in cylinders. Cylinders are available in various pressure ratings, with nomenclature differing between the several manufacturers. The high-pressure cylinder has gas stored at pressures ranging to 6000 psig, with the most common pressures between 2000 and 2500 psig. The low-pressure cylinder has gas pressures up to about 480 psig.

Cylinders do not have a standard designation from one supplier to another. If the actual capacity of any gas must be determined, it can be found using the following formula:

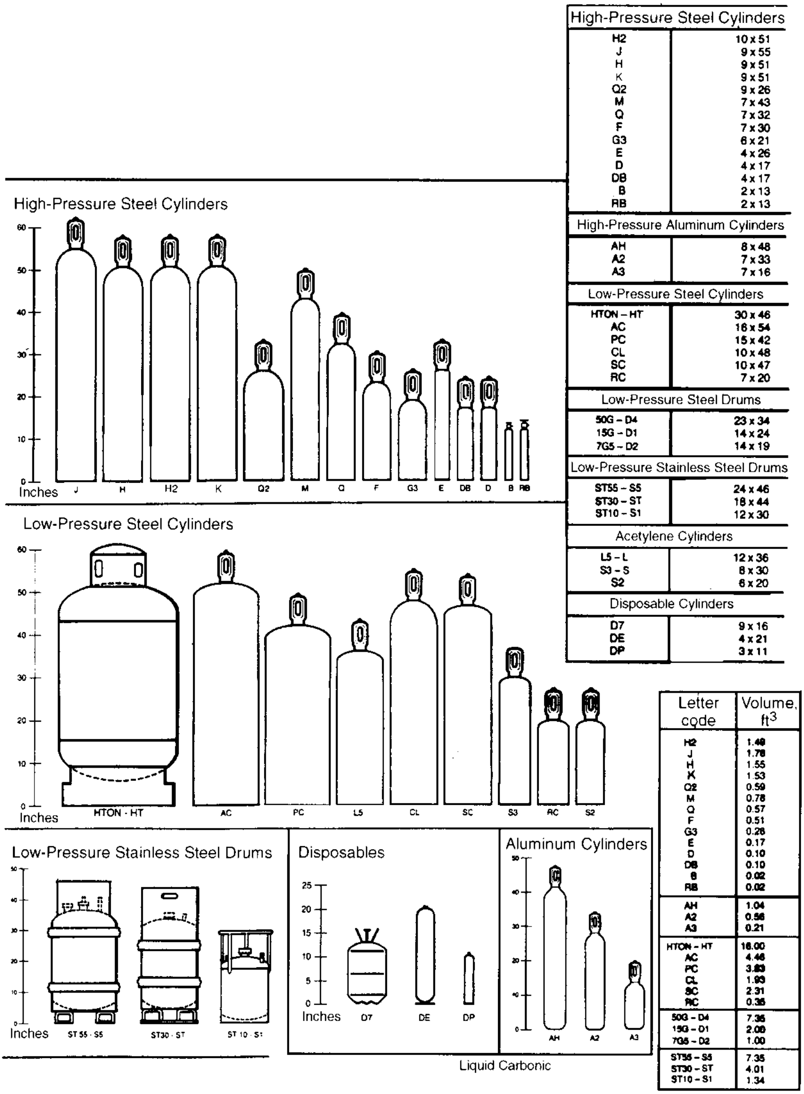
$$\mathrm{VG} = \frac{\mathrm{CP}}{14.7} \times \mathrm{CV} \tag{14.4}$$

where VG = volume of gas at pressure, ft^3
CP = actual cylinder pressure (obtained from the supplier), psi
CV = cylinder volume (obtained from Fig. 14.22), ft^3

As an example, find the number of cubic feet of nitrogen stored in a cylinder with a volume of 1.76 ft^3 and a pressure of 2600 psig.

$$\begin{aligned} \mathrm{VG} &= \frac{2600}{14.7} \times 1.76 \\ &= 176.87 \times 1.76 \\ &= 311\ \mathrm{ft}^3 \end{aligned}$$

Cylinders are available in many sizes and pressure ratings. Figure 14.22 illustrates typical sizes. The cylinders themselves are available in four general categories. The first is the *plain carbon steel tank.* The second is called the *ultraclean tank,* which is made of a slightly different alloy steel and in addition, has been completely cleaned, prepared, and dried to reduce contaminants in the cylinder. The third classification is *aluminum tanks.* The tank interior has been specially prepared and the walls treated to maintain stability and reduce particulates. Aluminum is used for cleanliness and for gases that will react with steel. In many cases, the exterior is also treated in order to be more easily kept clean, such as required for clean room installations. The fourth type of cylinder is made of *stainless steel,* which is often used for ultrapure gases.



High-Pressure Steel Cylinders	
H2	10 x 51
J	9 x 55
H	9 x 51
K	9 x 51
Q2	9 x 26
M	7 x 43
Q	7 x 32
F	7 x 30
G3	6 x 21
E	4 x 26
D	4 x 17
DB	4 x 17
B	2 x 13
RB	2 x 13
High-Pressure Aluminum Cylinders	
AH	8 x 48
A2	7 x 33
A3	7 x 16
Low-Pressure Steel Cylinders	
HTON – HT	30 x 46
AC	16 x 54
PC	15 x 42
CL	10 x 48
SC	10 x 47
RC	7 x 20
Low-Pressure Steel Drums	
50G – D4	23 x 34
15G – D1	14 x 24
7G5 – D2	14 x 19
Low-Pressure Stainless Steel Drums	
ST55 – S5	24 x 46
ST30 – ST	18 x 44
ST10 – S1	12 x 30
Acetylene Cylinders	
L5 – L	12 x 36
S3 – S	8 x 30
S2	6 x 20
Disposable Cylinders	
D7	9 x 16
DE	4 x 21
DP	3 x 11

Letter code	Volume, ft^3
H2	1.49
J	1.78
H	1.55
K	1.53
Q2	0.59
M	0.78
Q	0.57
F	0.51
G3	0.28
E	0.17
D	0.10
DB	0.10
B	0.02
RB	0.02
AH	1.04
A2	0.56
A3	0.21
HTON – HT	16.00
AC	4.46
PC	3.83
CL	1.93
SC	2.31
RC	0.36
50G – D4	7.36
15G – D1	2.00
7G5 – D2	1.00
ST55 – S5	7.35
ST30 – ST	4.01
ST10 – S1	1.34

FIGURE 14.22 Typical cylinder dimensions. (*Courtesy Liquid Carbonic.*)
1 ft^3 = 0.03 m^3.

The following are general recommendations for the installation and storage of cylinders:

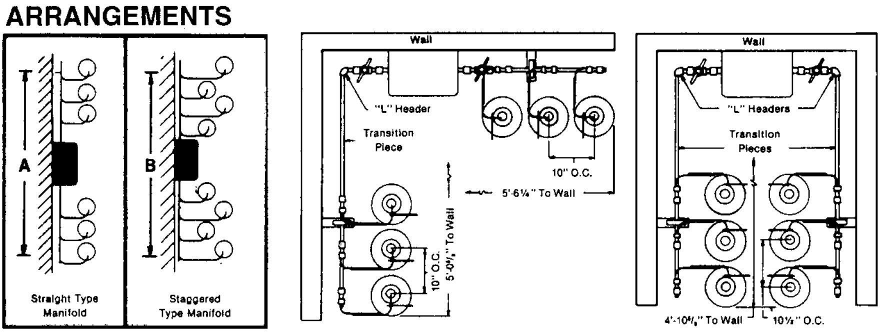
1. The room or area in which cylinders are placed shall have adequate ventilation and be free from combustible material and separated from sources of ignition.
2. Consideration should be given for the storage of additional full and empty cylinders in the same room for convenience.

3. Enough room should be allowed for the easy changing of cylinders. They are brought in on a hand truck or cart, and room should be allowed for their maneuvering.
4. Gas cylinders in active use shall be secured against falling by means of floor stands, wall brackets, or bench brackets. These brackets use straps to attach the cylinder to the bracket. Also available are floor racks and stands that can be provided for the installation and support of cylinders that cannot be located near walls.
5. When toxic or reactive gases are used, the cylinders should be placed in a gas cabinet. The basic purpose of the cabinet is to isolate the cylinder(s) and to contain the gases in the event of a leak and direct those gases away from the immediate vicinity of the cylinder and cylinder storage area to a point outside the building where they are diluted with the outside air. The cabinet could also contain panel-mounted manifolds, purging equipment, and other devices to allow some degree of control of operating parameters. Typical cabinet construction is 11 gauge painted steel or thicker to give a one-half hour fire rating. They could also be provided with vertical and horizontal adjustable cylinder brackets. The following options are available along with the cylinder cabinet:
    - ***a.*** Automatic shutoff of gas in the event of a catastrophic failure (flow limit).
    - ***b.*** Purging of gas lines after cylinder changes.
    - ***c.*** Mechanical cabinet exhaust. A typical system is designed for 13 air changes per minute with the access window open.
    - ***d.*** A sprinkler head for flammable gases. A typical head should be rated at 135°F, with a minimum water pressure of 25 psig.
    - ***e.*** For toxic and reactive gases, a small openable access window could be provided to operate valves without having to open the main door and compromising the exhaust system. A fixed access window is acceptable for inert gases.

When more than one cylinder is used to supply a system, the multiple arrangement is referred to as a *bank of cylinders.* Cylinder banks are classified as primary, secondary, and reserve. They are connected together by a header and controlled by a manifold assembly. The arrangement of the cylinders is chosen by the space available for the installation and the relative ease desired for the changing of cylinders. They can be placed either in a single row, double row, or staggered. The space typically required for various arrangements is shown in Fig. 14.23. Any additional space between banks of cylinders required for specialized devices such as manifold controls, purging devices, filters, and purifiers should be added to the cylinder bank dimensions.

Specialty Gas Generators

In some cases, it is more desirable for a small facility to generate their own high-purity specialty gases rather than having them supplied in cylinders. There are a limited number of gases for which anticipated volume allows this choice in laboratory or research facilities. Among them are nitrogen, hydrogen and helium, and compressed air. The generating units have their own filters and purifiers that can create gases of ultra-high purity. In particular, the use of these units for generation of hydrogen eliminates flammable cylinders in the laboratory or separate storage



DIMENSIONAL DATA

CYLINDERS PER BANK	DIMENSION "A"	DIMENSION "B"
2 Banks Of 2 Each	5'-0"	4'-6"
2 Banks Of 3 Each	6'-8"	5'-8"
2 Banks Of 4 Each	8'-4"	6'-10"
2 Banks Of 5 Each	10'-0"	8'-0"
2 Banks Of 6 Each	11'-8"	9'-2"
2 Banks Of 7 Each	13'-4"	10'-4"
2 Banks Of 8 Each	15'-0"	11'-6"
2 Banks Of 9 Each	16'-8"	12'-8"
2 Banks Of 10 Each	18'-4"	13'-10"
2 Banks Of 12 Each	21'-8"	16'-2"

FIGURE 14.23 Typical arrangements and dimensions of cylinder installations (9-in diameter).

areas and keeps the actual amount of gas stored below that needed for explosion to take place.

Depending upon the type of generator and the type of gas generated (except compressed air), pressures are available to about 60 psig (415 kPa), and flow rates to 300 cc/min are common. Compressed air generators are available that will deliver up to 20 scfm and 100 psig. This type of unit is ideally suited for analytical purposes in widely separated areas of use, where the installation of cylinders is inconvenient and the changing of cylinders may cause disruption of continuing work. The operating cost is low, but the initial cost is high. However, there is a short payback period compared to cylinder supply. Depending on the type of gas generated, many of these units take their air supply from the room they are installed in, and others require a connection to a separate compressed air supply of known purity.

DISTRIBUTION SYSTEM COMPONENTS

Manifolds

A manifold is an assembly used to connect multiple cylinders together. This assembly could also contain regulators, shutoff valves, gauges, and so on. Manifolds can be specified with manual or automatic changeover, and they can be constructed of high-purity and other special materials compatible with any specific gas being used. A header manifold with individual shutoff valves and connecting pigtail is used to physically connect several cylinders to a changeover manifold. The most often used materials for the header manifold, interconnecting pipe, and fittings are brass and stainless steel, with stainless steel flexible connections connecting the cylinders to the header.

When use is intermittent and the demand is low, a manual, single-cylinder (station) supply is appropriate. The cylinder must be changed when the pressure becomes marginally low. This will require an interruption in supply. The same system could also be used for greater demand where a bank of cylinders is used. When an uninterrupted supply is required, some method of automatic changeover must be used.

The simplest and least costly of the automatic types is the semiautomatic or differential type of changeover manifold. For this type of installation, the regulators for each bank of cylinders are manually set at different pressures. Usually, the secondary bank is set 5 psig lower than the primary bank. When the pressure of the primary bank falls below the lower setting of the reserve bank, the secondary bank automatically becomes the primary supply by default, since it has a higher pressure than the primary bank. A low-pressure alarm or low-pressure gauge reading will indicate that the changeover has taken place. In order to change the cylinders, the empty bank must first be manually isolated. Then, the pressures on the respective primary and secondary regulators must be reset to new settings to reflect the 5 psig difference between the former reserve supply, which is now the primary supply and vice versa. In other types of semiautomatic manifolds, the changeover is fully automatic, but a switch must be manually turned from the reserve position to the primary position when changing cylinders.

The fully automatic changeover manifold uses pressure switches or transducers to sense changes in line and supply pressures. This in turn sends an electric signal to a relay that turns off or on appropriate valves that accomplish the changeover with no variation in system delivery pressure. It also changes the secondary operating bank indicator to primary. For critical applications, connection of the power supply to emergency power should be considered.

A typical manifold assembly is illustrated in Fig. 14.24. Exact manifold dimensions vary and should be obtained from the manufacturer.

Regulators

A regulator is a device used to reduce a variable high inlet pressure to a constant lower outlet pressure. There are two broad categories of regulators: line and cylinder. Line regulators are in-line devices used to reduce a higher to a lower pressure and also used on cryogenic tanks to reduce the pressure, generally in the range of 150 to 250 psig, of the vapor above the vaporized liquid. Cylinder pressure regulators are used on high-pressure cylinders to reduce high-pressure gases, generally in the range of 2000 to 6000 psig, to a lower pressure. The regulator is the first device installed in the distribution system. Depending on the purity of the gas, an integral inlet filter should be considered to keep particulates from entering the regulator.

Regulators are available in two types, single and double stage. The single stage is less costly and less accurate. This type should be chosen if fluctuating pressure is not a major factor in system operation. The double stage is more costly and more

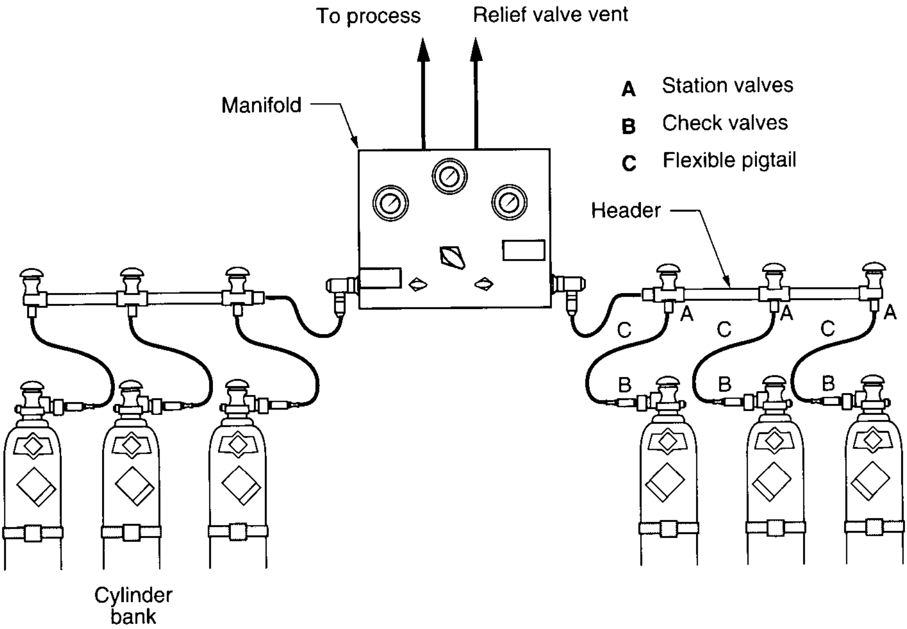


FIGURE 14.24 Typical manifold assembly. (*Courtesy Scott.*)

accurate, and able to achieve a constant outlet pressure within a narrow operating range. The accuracy of the regulator is proportional to the inlet pressure and the flow rate. When selecting a regulator for specific accuracy requirements, obtain the accuracy envelope diagrams from the manufacturer to check the device parameters using actual anticipated system design pressures and flow rates. Typical single- and double-stage regulators are illustrated in Fig. 14.25.

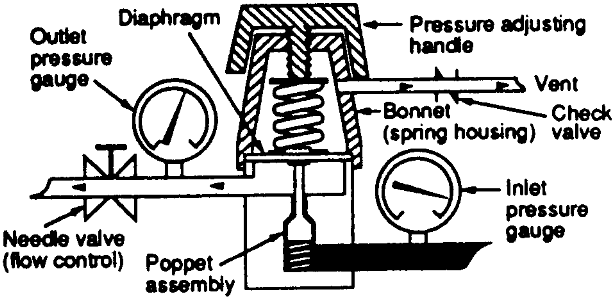
The single-stage regulator reduces pressure in one step. Typical differences in outlet pressure can vary as much as 15 psig when the inlet pressure changes from 2000 to 500 psig. Typical differences in outlet pressure could vary as much as 7 psig from low to high flow rates.

The double-stage regulator reduces the pressure in two steps. Typical differences in outlet pressure can vary as much as 5 psig when the inlet pressure changes from 2000 to 500 psig. Typical differences in outlet pressure could vary as much as 3 psig from low to high flow rates.

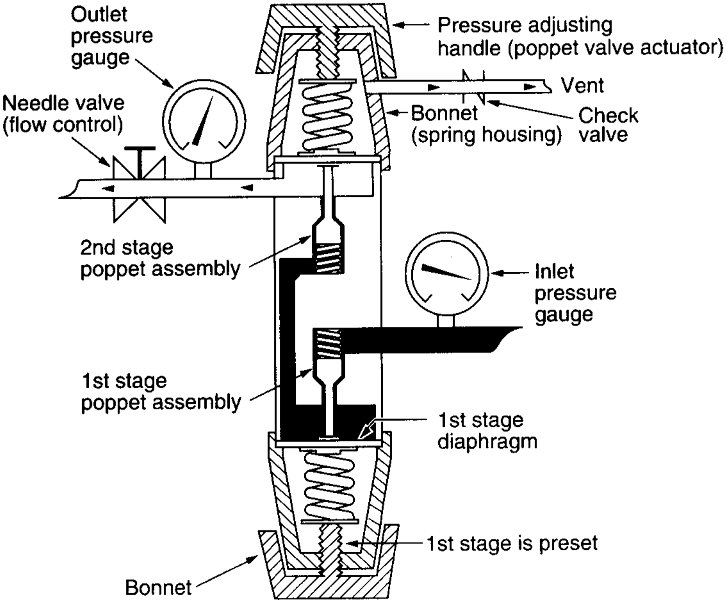
Another parameter that may be important in some installations is regulator creep. This is the rise in delivery pressure due to differences in motion of the internal mechanical components caused by aging. Creep is also caused by foreign material interfering with the mechanical operation of the unit. This is the most common cause of unit failure.

The following are other considerations used in the selection of a regulator:

1. The regulator should have a positive gas vent.
2. The regulator must be rated for the highest possible working pressure.



Single-stage regulator



Two-stage regulator

FIGURE 14.25 Typical single- and double-stage regulators. (*Courtesy Scott.*)

3. The delivery pressure range must be adequate.
4. The operating temperature must be compatible for the environment in which the valve is located.
5. The valve body and internal materials should be selected for the specific purity of the desired gas, such as being machine welded, having diffusion-resistant materials and packing, low particulate metals, and flexible diaphragms. High-purity regulators shall have little dead space internally and diaphragm seals consistent with the required purity.
6. The pressure range of the gauges must be compatible with the pressures expected. As an ideal, the working pressure should be half the maximum outlet gauge reading.

One feature that should be considered when only gas is to be used from a bulk liquid supply is an internal tank piping arrangement called an *economizer.* Provided as an integral part of the tank, this allows use of the gas available in the vapor space above the liquid in the tank before the liquid itself has to be vaporized. A special type of pressure regulator shall be provided that will switch from the economizer to the liquid line when the pressure in the vapor space falls below a preset level.

Filters and Purifiers

Filters and purifiers are necessary to reduce or eliminate unwanted contaminants and particulates in the gas stream. The most common purifiers are those used to remove oxygen, water vapor, hydrocarbons, and particulates. They are also used to eliminate other unwanted trace elements. There are a number of materials used for filters:

1. The most often used filter removes particulates 0.2 μm and larger.
2. To remove hydrogen, palladium filters are used.
3. Ceramic, fiberglass, sintered metal, and other adsorbent material are used to remove oil, moisture, and other trace contaminants in order to make the main gas as pure as possible. For some filter mediums, colored materials can be added to change color to indicate when it is time to replace the filter medium.
4. Another type of filter material is the molecular sieve. This is a synthetically produced crystalline metal powder that has been activated for adsorption by removing the water of hydration. This material is manufactured with precise and uniform size and dimensions. The size determines what can be filtered out. Sieves are available as powder, pellets, beads, and mesh. Mesh is not used in laboratories.
5. The 0.2-μm filter for removing particulates is the most commonly used in laboratory service. However, the actual requirements of the end user will dictate the filter medium and type. A filter shall be placed before any flow meter.
6. The housing has to be compatible with the gas being filtered and the pressure involved. None of the filters should be subject to pressures much over the 50 psig (345 kPa) normally used in most laboratories unless specified for a higher pressure.

7. Pressure drop through the filter medium is a critical factor in the selection of the material used. For larger installations, pressure gauges on each side of the filters are used to monitor their effectiveness. Usually, a 5 psig (35 kPa) drop means that replacement is required.
8. It is not possible to improve the purity of a gas with the use of purifiers. If a gas of a certain purity is required, a gas of that grade must be used from the outset.

Refer to Fig. 14.26 for a typical system purifier arrangement.

Gauges

Gauges for pressures of up to 10 psig (70 kPa) are usually the diaphragm sensing element type. For pressures over 10 psig (70 kPa), use the bourdon type. They should be cleaned for oxygen service and the materials must be compatible with the intended gas. Provide a small gas cock between the pipe line and the gauge to shut off the flow and allow the gauge to be replaced without having to shut down the system.

Relief Valves

Relief valves are used to protect a system from overpressure. A relief valve must be provided between the regulator and the first shutoff valve in the system, with the discharge independently piped outdoors, The discharges from a single gas service manifold or regulator may be connected together but shall not be connected to any relief discharge from any other system. The discharge pipe should be a minimum size of ¾ in. The relief valve shall be located at the first point in the system that could be subject to full cylinder pressure if the regulator should fail. There shall be no valve between the relief valve and the regulator. The relief valve release point should be set to 50 percent over working pressure. This is a safe figure because the system test pressure is 150 percent over working pressure. Typical relief venting is illustrated in Fig. 14.27.

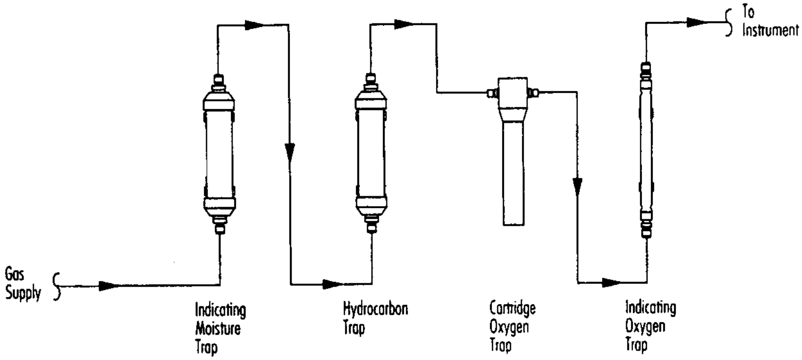


FIGURE 14.26 Typical purifier arrangement.

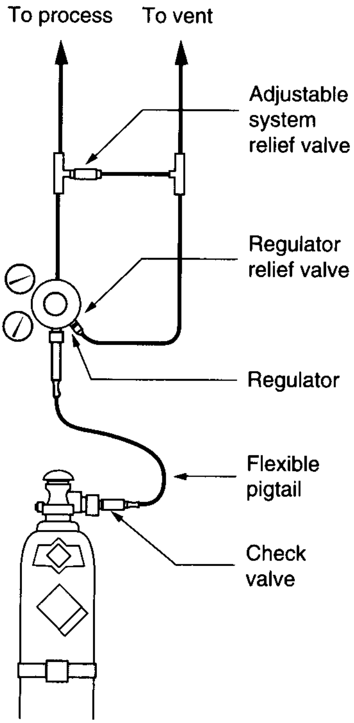


FIGURE 14.27 Typical relief venting. When two-stage regulators are used, a preset first-stage (or interstage) relief valve is sometimes required to protect the second stage from overpressure. Additionally, it is good practice to install an adjustable relief valve on the second stage to protect the system and instruments from damage from excessive pressure. For outdoor installations involving inert gases, the relief valves can exhaust directly to atmosphere. For indoor installations, or any installations involving toxic or flammable gases, the relief valve exhaust should be captured and vented to a safe location. (*Courtesy Scott.*)

Flow Limit Shutoff Valve

A flow limit shutoff valve automatically shuts off the flow from a cylinder if that flow rate exceeds a predetermined limit. That limit is usually about 10 times the highest expected flow rate. This valve must be manually reset after operation. A typical installation detail is shown in Fig. 14.28.

Check Valves

Check valves are used to prevent the reverse flow of gas in the delivery piping system. If there is a possibility that one gas at a higher pressure may force its way

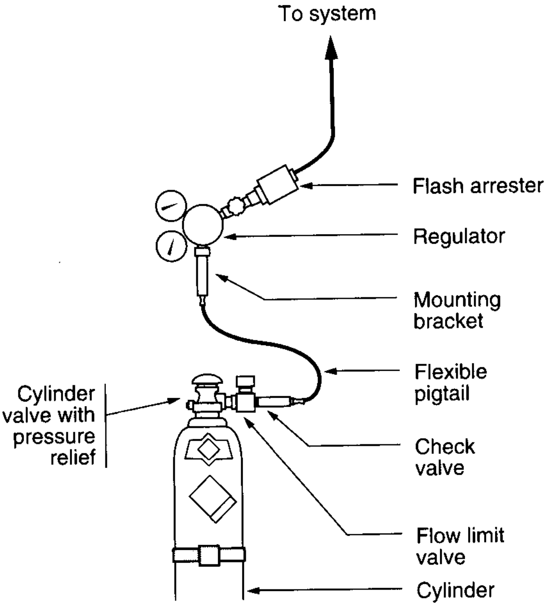


FIGURE 14.28 Typical single-cylinder installation detail.

into another piping system, a check valve shall be installed. A typical single-cylinder installation detail is shown in Fig. 14.28.

Flash Arresters

Flash arresters are required when the gas being used is flammable, particularly hydrogen and acetylene. They are mounted in-line to prevent any flame from going back into the tank in the event that gas in the delivery piping system has ignited. It is standard procedure that a check valve be made an integral part of a flash arrester, although this is not true in all cases. A typical installation detail is shown in Fig. 14.28.

Valves

The most often used shutoff valves are ball valves. Three piece are the most desired because the body can be separated from the end connections when being installed and serviced. For control and modulating purposes, needle valves are used because of the precise level of control permitted. The materials of the valve and seals must be compatible with the gas used.

For specialty applications, there are the diffusion-resistant valves that reduce or eliminate unwanted gases from entering the system through the packing. Where purity is a major consideration, packless and bellows sealed diaphragm valves are available.

Manifold and Regulator Purge Devices

The replacement of cylinders introduces unwanted room air into the piping manifold assembly and the connecting cylinder pigtails. When maintaining a high purity level of the gas is necessary, purge valves are installed to run system gas through the con-taminated parts of the system to replace all such air. The purge valve outlet should be vented outside the building. If the gas is suitable and low enough in volume and the storage room is large enough and well ventilated, it could discharge into the room since the purge volume used is generally quite small. The regulator often requires special purging techniques recommended by the manufacturer.

Flow Measurement

Flow meters can be either of two types: electric or mechanical. The mechanical kind is called a *variable area type* and uses a small ball as an indicator in a variable area vertical tube. The type of mechanical meter most often used has an accuracy of 10 percent full scale. This means that if the flow range is from 1 to 10 scfm, the accuracy is ±1 acfm. There are also more accurate variable area flow meters available.

The mass flow meters are electronically operated, using the difference in temperature that gas creates when flowing over a heated element. The mass flow meter is quite accurate and quite expensive.

Gas Warmers

On occasion, the gas in cylinders is withdrawn so fast that the regulator could ice up because of the change in temperature. If this occurs, an electrically heated gas warmer is available to be installed in-line, and this warmer would heat the gas out of the cylinder before it reached the regulator. The rule of thumb is to consider a warmer if the use of gas exceeds 35 acfm. The actual figure should be based on experience with the specific type of gas being used. Ask the supplier what his or her experience has been. Carbon dioxide is a particular problem.

Low-Temperature Cutoff

On occasion, the temperature of the delivered gas is a critical factor. If low temperature could harm instruments or interfere with procedures being conducted, a low-temperature cutoff should be installed with a solenoid valve to stop the flow of gas. If this happens often, a gas warmer might be required.

Alarms

Alarms are necessary for the user to be made aware of immediate or potential trouble. They could be visible and/or audible. Usual alarms are high system pressure, low system pressure, and reserve in use. In some installations, a normal light is also requested. Other alarms could be provided that will indicate high pressure loss at filters, low gas temperature, purifiers at limit of capacity, and flow limit valve operation. These alarms are usually installed in an alarm panel. The panel could be mounted in the room where the gases are stored, in a constantly occupied location such as a maintenance shop or receptionist area, or in the laboratory itself depending on the availability and level of maintenance. Often multiple locations are desirable if continued supply of gas is critical. Various devices must be placed in the system for these alarms to function, such as pressure switches, transducers, and auxiliary contacts in a manifold assembly to transmit the alarm signal to the alarm panel.

Toxic and Flammable Gas Monitors

If there is a possibility for a toxic flammable gas to accumulate in an enclosed area or room, it is required that a gas monitor be installed to alarm if the gas percentage rises above a predetermined limit that is considered harmful or dangerous. This should be 50 percent of either the lower flammability limit (LFL) or the concentration that may cause ill effects or breathing problems. The oxygen concentration of ambient air should never be allowed to fall below 19.5 percent. In addition, much lower levels should also be alarmed to indicate that a problem exists well before the evacuation of an area is required because of the leak. Refer to Table 14.25 for the flammability limits of some of the more common gases and to the MSDS for gases not listed.

Gas Mixers

For certain applications gas mixers are available to accurately mix different gases together to produce various proportions. The accuracy of the mixture, flow rates of the various gases, and the compatibility of the piping materials and the gases are considerations in the selection of the mixer.

DISTRIBUTION NETWORK

System Pressure

It is generally accepted practice to use a pressure of 50 to 55 psig (345 to 380 kPa) in the piping distribution system. Accepted practice limits the allowable friction loss in the piping system to approximately 10 percent of initial pressure. These figures should be adjusted for specific conditions or special systems when necessary.

Pipe Material Selection

The piping material must be compatible with the specific gas, capable of delivering the desired gas purity for anticipated usage, and capable of being cleaned and/or sterilized often, if required. Table 14.26 gives the compatibility of various piping materials for the most commonly used gases. For materials or gases not listed, refer to the manufacturer or the supplier of the gas for additional information. The allowable pressure ratings for various piping materials are given in Table 14.27.

The pipe most often used to maintain the highest purity is grade 304L or 316L stainless steel tubing conforming to ASTM A-270. The interior should be electropolished, and the exterior could be mill finished in concealed spaces. In exposed

TABLE 14.25 Flammability Limits and Specific Gravity for Common Gases

Gas	Specific gravity	Flammability in air, percent	
		Low	High
Acetylene	0.906	25	100
Air	1.00	—	—
Ammonia	0.560	15	28
Argon	1.38	—	—
Arsine	2.69	5.1	78
Butane	0.600	1.8	8.4
Carbon dioxide	1.52	—	—
Carbon monoxide	0.967	12.5	74
Chlorine	2.49	—	—
Cyclopropane	0.720	2.4	10.4
Ethane	1.05	3.0	12.4
Ethylene	0.570	2.7	36
Ethyl chloride	2.22	3.8	15.4
Fluorine	1.31	—	—
Helium	0.138	—	—
Hydrogen	0.069	4.0	75
Hydrogen sulfide	1.18	4	44
Isobutane	2.01	1.8	9.6
Isopentane	2.48		
Krypton	2.89	—	—
Methane	0.415	5.0	15
Methyl chloride	1.74	10.7	17.4
Natural gas	0.600		
Neon	0.674	—	—
Nitrogen	0.966	—	—
Nitrous oxide	1.53	—	—
Oxygen	1.10	—	—
Phosgene	1.39	—	—
Propane	1.580	2.1	9.5
Silane	1.11	1.5	98
Sulphur dioxide	2.26	—	—
Xenon	4.53	—	—

locations and where pipe exterior will be sterilized or cleaned, the pipe exterior should have a No. 4 finish. The pipe is joined by orbital welding. This tube should have a minimum wall thickness of 0.65 in in order to be welded. Stainless steel pipe is capable of withstanding repeated sterilization by steam and a variety of chemicals. When welding is not required, a tube wall thickness of 0.28 is commonly used. The installed cost often is less than that of copper tube.

In many laboratory applications, maintaining ultrahigh purity of a gas from storage tank to the outlet is not a requirement. For this type of service, copper tube and fittings that have been cleaned for oxygen service and joined by brazing often has the least initial cost and is the material of choice. The following grades of copper pipe have been used:

1. ASTM B-88
2. ASTM B-819

TABLE 14.26 Compatibility of Pipe to Common Specialty Gases

Gases		Metals						Synthetics					
Gas (common name)	Chemical formula	Aluminum	Brass	Copper	Monel	Carbon steel	Stainless steel	Buna-N	Kel-F	Neo-prene	PVC	Teflon	Viton
Acetylene	C_2H_2	Y	Y	N	Y	Y	Y	Y	Y	Y	I	Y	Y
Air	—	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ammonia	NH_3	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N
Argon	Ar	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Arsine	AsH_3	I	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Boron trichloride	BCl_3	I	Y	Y	Y	Y	Y	I	Y	I	Y	Y	I
Boron trifluoride	BF_3	Y	I	Y	Y	Y	Y	Y	I	Y	Y	Y	Y
1,3-butadiene	C_4H_6	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
n-butane	C_4H_{10}	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
1-butene	C_4H_8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
cis-2-butene	C_4H_8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
trans-2-butene	C_4H_8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Carbon dioxide	CO_2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Carbon monoxide	CO	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Chlorine	Cl_2	N	N	N	Y	Y	Y	N	Y	N	Y	Y	Y
Deuterium	D_2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Dichlorosilane	SiH_2Cl_2	I	I	I	Y	Y	Y	Y	Y	I	I	Y	I
Dimethyl ether	$(CH_3)_2O$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Dimethylamine	$(CH_3)_2NH$	N	N	N	I	Y	Y	N	Y	Y	Y	Y	N
Disilane	Si_2H_6	I	Y	Y	Y	Y	Y	I	Y	I	I	Y	Y
Ethane	C_2H_6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ethyl acetylene	C_4H_6	Y	I	N	Y	Y	Y	I	Y	Y	I	Y	Y
Ethyl chloride	C_2H_5Cl	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Ethylene	C_2H_4	Y	Y	Y	Y	Y	Y	Y	Y	Y	I	Y	Y
Ethylene oxide	C_2H_4O	I	I	N	I	Y	Y	N	Y	N	N	Y	N

TABLE 14.26 Compatibility of Pipe to Common Specialty Gases (*Continued*)

Gases		Metals						Synthetics					
Gas (common name)	Chemical formula	Aluminum	Brass	Copper	Monel	Carbon steel	Stainless steel	Buna-N	Kel-F	Neo-prene	PVC	Teflon	Viton
Halocarbon 11	CCl_3F	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 12	CCl_2F_2	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 13	$CClF_3$	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 13B-1	$CBrF_3$	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 14	CF_4	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 21	$CHCl_2F$	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	N
Halocarbon 22	$CHClF_2$	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	N
Halocarbon 23	CHF_3	Y	Y	Y	Y	Y	Y	I	Y	Y	N	Y	I
Halocarbon 113	$C_2Cl_3F_3$	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 114	$C_2Cl_2F_4$	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 115	C_2ClF_5	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 116	C_2F_6	Y	Y	Y	Y	Y	Y	I	Y	Y	N	Y	I
Halocarbon 500	$C_2H_4F_2/CCl_2F_2$	Y	I	I	Y	Y	Y	Y	Y	Y	N	Y	Y
Halocarbon 502	$CHClF_2/C_2ClF_5$	Y	I	I	Y	Y	Y	Y	Y	Y	N	Y	Y
Helium	He	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Hydrogen	H_2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Hydrogen bromide	HBr	I	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y
Hydrogen chloride	HCl	I	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y
Hydrogen fluoride	HF	I	I	I	Y	Y	Y	N	Y	N	Y	Y	N
Hydrogen sulfide	H_2S	Y	N	I	Y	I	Y	Y	Y	Y	Y	Y	N
Isobutane	C_4H_{10}	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Isobutylene	C_4H_8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Methane	CH_4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Methyl bromide	CH_3Br	N	Y	Y	I	Y	Y	Y	Y	N	I	Y	Y
Methyl chloride	CH_3Cl	N	Y	Y	Y	Y	Y	Y	Y	N	I	Y	Y
Neon	Ne	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Nitric oxide	NO	Y	Y	Y	Y	Y	Y	I	Y	Y	Y	Y	I
Nitrogen	N_2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Nitrogen dioxide	NO_2	I	I	Y	Y	Y	Y	N	Y	Y	N	Y	N
Nitrous oxide	N_2O	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

(*Continued*)

TABLE 14.26 Compatibility of Pipe to Common Specialty Gases (*Continued*)

Gases		Metals						Synthetics					
Gas (common name)	Chemical formula	Aluminum	Brass	Copper	Monel	Carbon steel	Stainless steel	Buna-N	Kel-F	Neo-prene	PVC	Teflon	Viton
Oxygen	O_2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Phosgene	$COCl_2$	Y	I	N	Y	Y	Y	I	Y	I	I	Y	I
Phosphine	PH_3	Y	I	I	Y	Y	Y	I	Y	I	I	Y	I
Phosphorous pentafluoride	PF_5	I	I	I	Y	Y	Y	I	Y	I	I	Y	I
Propane	C_3H_8	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y
Propylene	C_3H_6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Silane	SiH_4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Silicon tetrachloride	$SiCl_4$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Silicon tetrafluoride	SiF_4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sulfur dioxide	SO_2	Y	N	N	Y	Y	Y	N	Y	N	Y	Y	N
Sulfur hexafluoride	SF_6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Trichlorosilane	$SiHCl_3$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Trimethylamine	$(CH_3)_3N$	N	N	N	Y	Y	Y	N	Y	Y	N	Y	N
Xenon	Xe	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Note: Prior to using a gas mixture or a gas that is not listed in the gas compatibility guide, it is strongly recommended that you contact a specialty gas laboratory for information.

Y = Yes, suitable for use with intended gas.

N = No, not suitable for use with intended gas.

I = Insufficient data available to determine compatibility with intended gas.

3. ASTM B-75

4. ASTM B-280

Another pipe material often used for noncritical applications is aluminum tubing ASTM B-210, alloy 6061, T4 or T6 tempers. This pipe is most commonly joined using the patented flare joint.

Maintaining Cleanliness and Purity during Construction

Copper fittings and various valve types can be purchased from the manufacturer specifically cleaned for oxygen service and delivered to the job site capped and bagged to maintain cleanliness. If a fitting becomes dirty prior to being installed, it should be cleaned in accordance with NFPA-99 requirements before being made part of the system. During construction, the greatest threat to cleanliness is dirt and dust entering the pipe because it has not been capped to keep it out.

When brazing joints, the cleanliness of the copper piping system shall be maintained by not using flux and having the joint continuously purged with oil-free, dry

TABLE 14.27 Allowable Pressure Ratings of Pipe and Tube

A. All pressures are calculated from equations in ANSI Code for Pressure Piping ASME/ANSI B31.3.

B. All calculations are based on maximum O.D. and minimum wall thickness.

Example: *½-in O.D. × 0.035-in wall stainless steel tubing purchased to ASTM A269:*

O.D. tolerance ±0.005 in/wall thickness tolerance ±15 percent

Calculations are based on a 0.505 in O.D. × 0.0298-in wall tubing.

C. No allowance is made for corrosion or erosion.

TABLE 14.27*a* Aluminum tubing, psig

[Based on ultimate tensile strength 42,000 psig (289,400 kPa). For metal temperatures −20° to 100°F (−29° to 37°C). Allowable working pressure loads calculated from S values (14,000 psi—96,500 kPa) as specified by ANSI B31.3 code.]

Tube O.D., in	Tube wall thickness, in				
	0.035	0.049	0.065	0.083	0.095
⅛	8600				
3⁄16	5600	8000			
¼	4000	5900			
5⁄16	3100	4600			
⅜	2600	3700			
½	1900	2700	3700		
⅝	1500	2100	2900		
¾		1700	2400	3100	
⅞		1500	2000		
1		1300	1700	2300	2700

Suggested ordering information: High-quality aluminum-alloy seamless tubing ASTM B-210 or equivalent. (Values shown are for alloy 6061-T6.)

TABLE 14.27*b* Copper Tubing, psig

[Based on ultimate strength 30,000 psig (206,700 kPa). For metal temperatures −20° to 100°F (−29° to 37°C). Allowable working pressure loads calculated from S values (6000 psi—41,300 kPa) as specified by ANSI B31.3 code.]

Tube O.D., in	Tube wall thickness, in							
	0.028	0.035	0.049	0.065	0.083	0.095	0.109	0.120
⅛	2700	3600						
3⁄16	1800	2300	3400					
¼	1300	1600	2500	3500				
5⁄16		1300	1900	2700				
⅜		1000	1600	2200				
½		800	1100	1600	2100			
⅝			900	1200	1600	1900		
¾			700	1000	1300	1500	1800	
⅞			600	800	1100	1300	1500	
1			500	700	900	1100	1300	1500

Suggested ordering information: High-quality soft annealed seamless copper tubing ASTM B-75 or equivalent. Also soft annealed (Temper 0) copper water tube type K or type L to ASTM B-88.

TABLE 14.27*c* Carbon Steel Tubing, psig

[*Soft annealed carbon steel hydraulic tubing ASTM A179 or equivalent. Based on ultimate tensile strength 47,000 psig* (*323,800 kPa*). *For metal temperatures −20° to 100°F* (*−29 to 37°C*). *Allowable working pressure loads calculated from S values* (*15,700 psi—108,200 kPa*) *as specified by ANSI B31.3 code.*]

Tube O.D., in	Tube wall thickness, in												
	0.028	0.035	0.049	0.065	0.083	0.095	0.109	0.128	0.134	0.148	0.165	0.180	0.228
⅛	8000	10200											
3⁄16	5100	6600	9600										
¼	3700	4800	7000	9600									
5⁄16		3700	5500	7500									
⅜		3100	4500	6200									
½		2300	3200	4500	5900								
⅝		1800	2600	3500	4600	5300							
¾			2100	2900	3700	4300	5100						
⅞			1800	2400	3200	3700	4300						
1			1500	2100	2700	3200	3700	4100					
1¼				1600	2100	2500	2900	3200	3600	4000	4600	5000	
1½					1800	2000	2400	2600	2900	3300	3700	4100	5100
2						1500	1700	1900	2100	2400	2700	3000	3700

Suggested ordering information: High-quality soft annealed seamless carbon steel hydraulic tubing ASTM A-179 or equivalent. Hardness Rb72 (HV(VPN)130) or less. Tubing to be free of scratches. Suitable for bending and flaring.

TABLE 14.27*d* Pressure Rating of Stainless Steel Tubing, psig

[Annealed 304 or 316 stainless steel tubing ASTM A269 or equivalent. Based on ultimate tensile strength 75,000 psig (516,700 kPa). For metal temperature from −20° to 100°F (−29° to 37°C). Allowable working pressure loads calculated from S values (20,000 psig—37,800 kPa) as specified by ANSI B31.3 code.]

For Seamless Tubing

Note: For welded and drawn tubing, a derating factor must be applied for weld integrity: For double-welded tubing multiply pressure rating by 0.85—for single-welded tubing, multiply pressure rating by 0.80.

Tube O.D., in	Tube wall thickness, in															
	0.010	0.012	0.014	0.016	0.020	0.028	0.035	0.049	0.065	0.083	0.095	0.109	0.120	0.134	0.156	0.188
1⁄16	5600	6800	8100	9400	12000											
3⁄8						8500	10900									
3⁄16						5400	7000	10200								
1⁄4						4000	5100	7500	10200							
5⁄16							4000	5800	8000							
3⁄8							3300	4800	6500							
1⁄2							2400	3500	4700	6200						
5⁄8								2900	4000	5200	6000					
3⁄4								2400	3300	4200	4900	5800				
7⁄8								2000	2800	3600	4200	4800				
1									2400	3100	3600	4200	4700			
1 1⁄4										2400	2800	3300	3600	4100	4900	
1 1⁄2											2300	2700	3000	3400	4000	4900
2												2000	2200	2500	2900	3600

Suggested ordering information: Fully annealed high quality (Type 304, 316, etc.) (seamless or welded and drawn) stainless steel hydraulic tubing ASTM A200 or A213 or equivalent. Hardness Rb80[HV(VPN)180] or less. Tubing to be free of scratches. Suitable for bending and flaring.

1 psi = 6.9 kPa.

nitrogen, thereby eliminating the formation of copper oxide on the inside of the joint generated by the heat of the brazing process. The flow of purge gas shall be continued until the joint is cool to the touch.

Another consideration in maintaining high purity of the gas is outgasing. This is a phenomenon in which a gas under pressure is absorbed into any porous material. This occurs primarily in elastomers used as gaskets or seals, and to some lesser extent into metallic and plastic pipe and tubing materials. When the pressure is reduced or eliminated, such as when changing cylinder banks or during maintenance, the absorbed gases are spontaneously given off, adding impurities into the gas piping system.

Joints

The most often used joints for copper are brazed. No flux is permitted, and only cast copper fittings should be used, which require no flux. The interior of the joint shall be purged with an inert gas, such as nitrogen type ‘‘NF’’ or argon. For stainless steel pipe, orbital welding leaves the smoothest interior but should be used generally on tubing 0.65 in or thicker. Another type of joint that can be used is the patented flared joint, which is preferable to solder or brazed joints that often leave a residue that contributes particulates into the gas stream. In addition, the flared joint is popular because it can be made up using only a saw and some wrenches. When copper tubing is used with flared joints, the pipe shall not have embossed identification stamped into the pipe because doing so causes leaks at the joint. There is no ASTM designation for the patented flare joints, but they are acceptable for all applications as long as the allowable pressure ratings are not exceeded.

Pipe Sizing

The following is a recommended system sizing procedure:

1. Locate the gas storage area and lay out the cylinders, manifold, and so on.
2. Establish a general layout of the system from the storage area to the farthest outlet or use point. Measure the actual distance along the run of pipe to the most remote terminal, and then add 50 percent of the distance for a fitting allowance. This is the total equivalent run of pipe.
3. Choose all of the filters, purifiers, and so on necessary for system purity in order to establish a combined allowable pressure drop through each of them and the assembly as a whole.
4. Establish the gas pressure required at the farthest outlet, add the pressure required to overcome the drop through the filter-purifier-manifold assembly, and add 10 percent of the supply pressure to allow for friction loss of the gas through the total run of pipe. It is commonly accepted practice for general laboratory use to have a minimum system pressure of 45 to 50 psig (310 to 345 kPa) and to allow 5 psig (35 kPa) as a pressure loss in the pipe. For higher-pressure systems serving specific equipment or tools, start with the actual pressure required.
5. Divide the total run of pipe (in 100s of feet) by the allowable friction loss to calculate the allowable friction loss in psig per 100 ft of pipe, This is to allow the use of the sizing chart provided in this handbook. If other methods are used

to indicate friction loss in the piping system, calculate the loss in that specific method.

6. Determine the total connected flow rate of gas for all parts of the system. For general laboratory use, a figure of 1 scfm (30 Lpm) for each outlet is used. Calculate the scfm (Lpm) of gas through each branch, from the farthest outlet back to the source (or main). For specific equipment, use the flow rate recommended by the manufacturer.
7. Determine the appropriate diversity factor when sizing compressed air pipe in order to allow for the fact that not all outlets will be used at once. This will result in the actual flow rate. A diversity factor for general laboratory use is given in Table 14.14, and a direct reading chart is illustrated in Fig. 14.29. For specific equipment, the diversity factor must be ddetermined from the end user.
8. With all the above information available, the pipe can now be sized. Starting from the most remote point on the branch and then proceeding to the main, calculate the actual flow rate using the diversity factor. Enter Table 14.28 with the actual flow rate and the allowable friction loss. Find the flow rate, and then read across to find a friction loss figure that is equal to or is less than the allowable friction loss. Read up the column to find the size. In some cases, the diversity factor for the next highest range of outlets may result in a smaller-size pipe than the range previously calculated. If this occurs, do not reduce the size of the pipe—keep the larger size previously determined. For equipment using capilary piping, refer to Fig. 14.30 for ⅛ in size, Fig. 14.31 for ¼ in size and Fig. 14.32 for ⅜ in size.

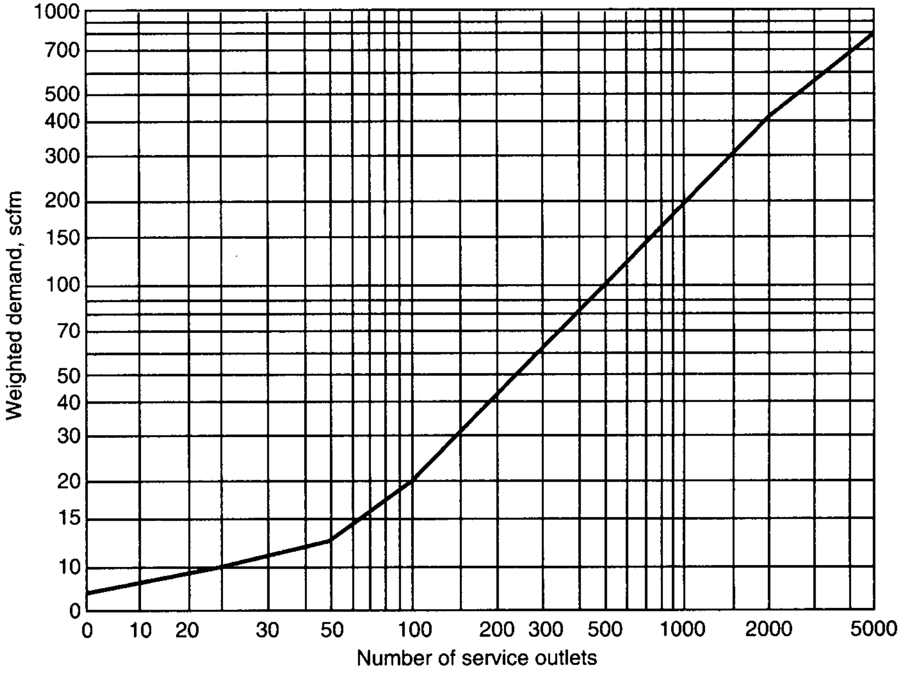


FIGURE 14.29 General laboratory demand for compressed air.

TABLE 14.28 Compressed Air Pipe Sizing Chart

Pressure drop (psi) per 100 ft in 55 psig compressed air system using Darcy's equation with copper tubing

scfm	acfm	½	¾	1	1¼	1½	2	2½	3	4
5	1.1	0.15	0.04	0.01						
10	2.2	0.51	0.13	0.04	0.01					
15	3.3	1.04	0.27	0.09	0.02	0.01				
20	4.3	—	0.45	0.14	0.04	0.02				
25	5.4	—	0.67	0.21	0.06	0.03	0.01			
30	6.5	—	0.93	0.29	0.08	0.04	0.01			
35	7.6	—	—	0.39	0.10	0.05	0.02	0.01		
40	8.7	—	—	0.49	0.13	0.06	0.02	0.01		
45	9.8	—	—	0.60	0.16	0.08	0.02	0.01		
50	10.9	—	—	0.73	0.20	0.09	0.03	0.01		
60	13.0	—	—	1.01	0.27	0.13	0.04	0.02	0.01	
70	15.2	—	—	—	0.36	0.17	0.05	0.02	0.01	
80	17.4	—	—	—	0.45	0.22	0.07	0.03	0.01	
90	19.5	—	—	—	0.56	0.27	0.08	0.03	0.01	
100	21.7	—	—	—	0.68	0.32	0.10	0.04	0.02	0.00
110	23.9	—	—	—	0.81	0.38	0.12	0.05	0.02	0.01
120	26.0	—	—	—	0.94	0.45	0.14	0.06	0.02	0.01
130	28.2	—	—	—	1.09	0.52	0.16	0.07	0.02	0.01
140	30.4	—	—	—	—	0.59	0.18	0.08	0.03	0.01
150	32.6	—	—	—	—	0.67	0.20	0.09	0.03	0.01
175	38.0	—	—	—	—	0.89	0.27	0.11	0.04	0.01
200	43.4	—	—	—	—	1.13	0.34	0.14	0.05	0.01
225	48.8	—	—	—	—	—	0.42	0.18	0.06	0.02
250	54.3	—	—	—	—	—	0.51	0.22	0.08	0.02
275	59.7	—	—	—	—	—	0.60	0.26	0.09	0.02

TABLE 14.28 Compressed Air Pipe Sizing Chart (Continued)

Pressure drop (psi) per 100 ft in 55 psig compressed air system using Darcy's equation with copper tubing

scfm	acfm	½	¾	1	1¼	1½	2	2½	3	4
300	65.1	—	—	—	—	—	0.71	0.30	0.11	0.03
325	70.5	—	—	—	—	—	0.82	0.35	0.12	0.03
350	76.0	—	—	—	—	—	0.94	0.40	0.14	0.04
375	81.4	—	—	—	—	—	1.06	0.45	0.16	0.04
400	86.8	—	—	—	—	—	—	0.51	0.18	0.05
450	97.7	—	—	—	—	—	—	0.63	0.22	0.06
500	108.5	—	—	—	—	—	—	0.76	0.27	0.07
550	119.4	—	—	—	—	—	—	0.90	0.32	0.09
600	130.2	—	—	—	—	—	—	1.06	0.37	0.10
650	141.1	—	—	—	—	—	—	—	0.43	0.12
700	151.9	—	—	—	—	—	—	—	0.49	0.13
750	162.8	—	—	—	—	—	—	—	0.56	0.15
800	173.6	—	—	—	—	—	—	—	0.63	0.17
850	184.5	—	—	—	—	—	—	—	0.70	0.19
900	195.3	—	—	—	—	—	—	—	0.78	0.21
950	206.2	—	—	—	—	—	—	—	—	0.23
1000	217.0	—	—	—	—	—	—	—	—	0.25
1100	238.7	—	—	—	—	—	—	—	—	0.30
1200	260.4	—	—	—	—	—	—	—	—	0.35
1300	282.1	—	—	—	—	—	—	—	—	0.41
1400	303.8	—	—	—	—	—	—	—	—	0.47
1500	325.5	—	—	—	—	—	—	—	—	0.53

Note: Values in the table are for flows not exceeding 4000 fpm vel.

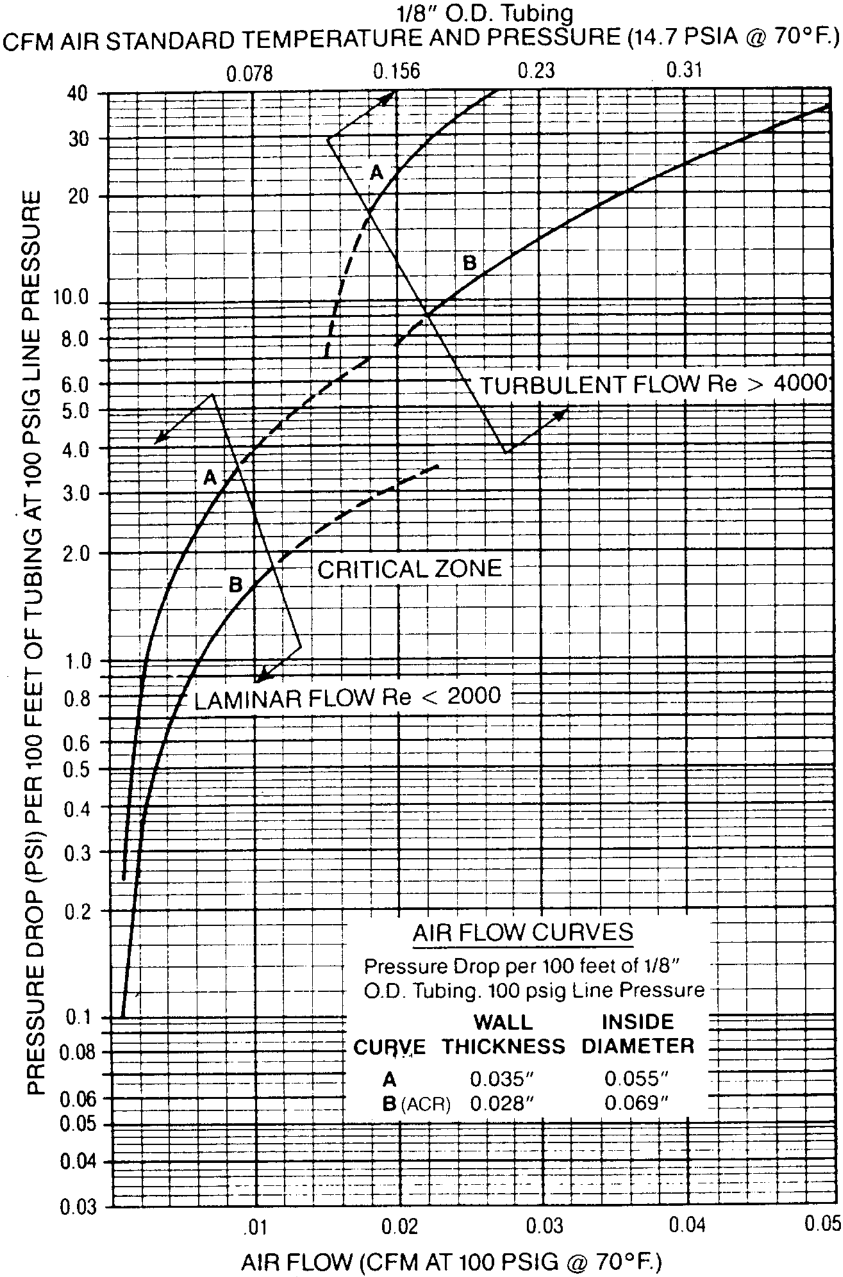
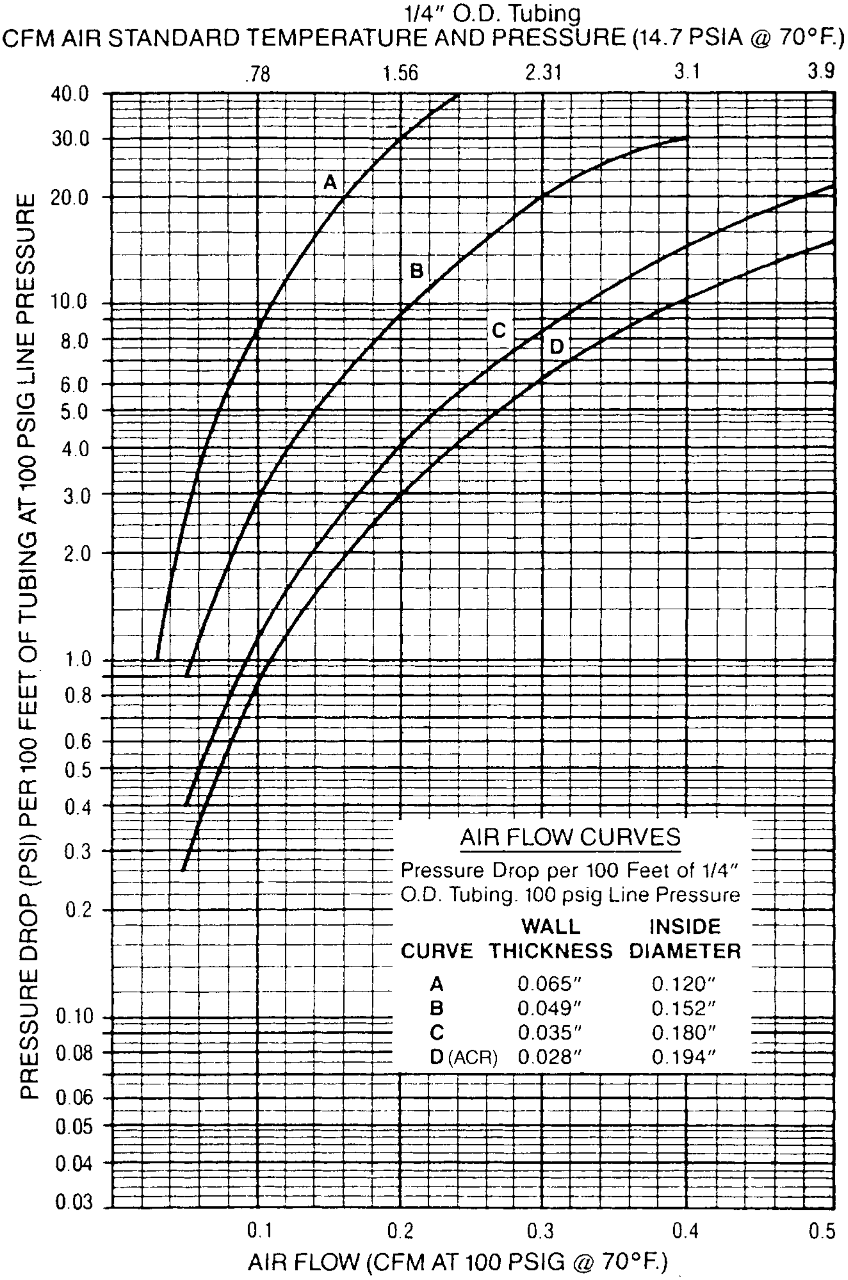


FIGURE 14.30 Compressed air sizing chart ⅛ in (6 mm) copper tubing, 100 psig. (*Courtesy Swagflok.*)



AIR FLOW CURVES

Pressure Drop per 100 Feet of 1/4" O.D. Tubing. 100 psig Line Pressure

CURVE	WALL THICKNESS	INSIDE DIAMETER
A	0.065"	0.120"
B	0.049"	0.152"
C	0.035"	0.180"
D (ACR)	0.028"	0.194"

FIGURE 14.31 Compressed air sizing chart ¼ in (8 mm) copper tube, 100 psig.

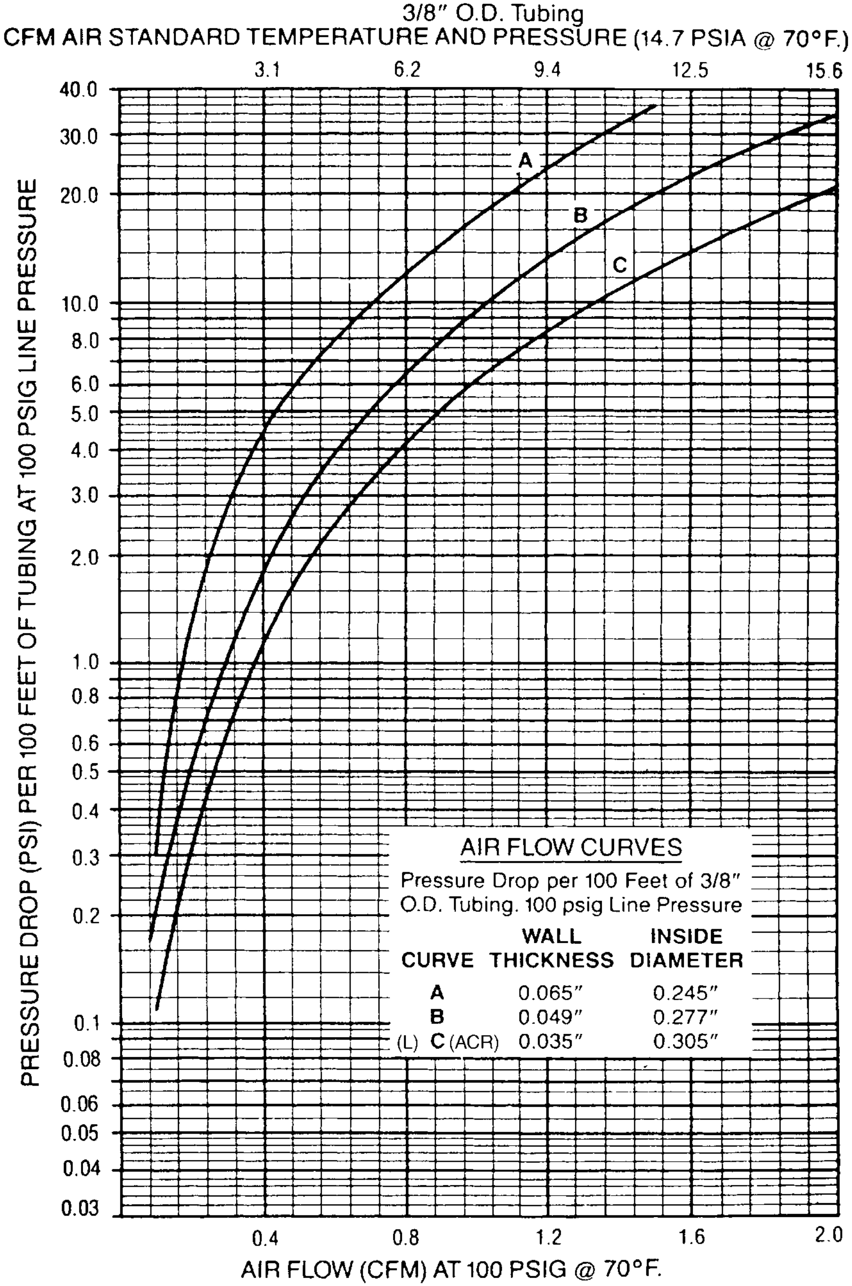


FIGURE 14.32 Compressed air sizing chart ⅜ in (10 mm) copper tubing, 100 psig line pressure.

Discussion:

1. The diversity (or simultaneous use) factor, which determines the maximum number of outlets in use at any one time, has a major influence in the sizing of the piping system. It has no exact method of being determined and is arrived at purely by judgment. Table 14.14 has been developed for general laboratory use and is based on past experience. A direct reading chart for compressed air systems is provided in Fig. 14.29.
2. The sizing chart, Table 14.28, has been calculated specifically for use with compressed air, type L copper pipe, and a pressure of 55 psig. In order to use this chart for other gases, pipe materials, and pressures, the following conversion calculations will be necessary:

   a. When any gas with a specific gravity other than air (1.00) is used, an adjustment to the scfm flow rate will be required. Equation (14.5) shall be used to calculate a factor that will convert scfm in Table 14.28 from compressed air to the equivalent of any other gas or combination of gases. Multiply the calculated factor f by the compressed air flow rate to obtain the new flow rate for the gas in question:

   $$f = \sqrt{\frac{1}{g}} \tag{14.5}$$

   To calculate the specific gravity of any gas, divide the molecular weight of that gas by 29, which is the composite molecular weight of air.

   b. For flow of any compressed gas in steel pipe, use Table 14.16 and Eq. (14.5) to adjust for the type of gas.

   c. For pressures other than 55 psig, use the following formula:

   $$\mathrm{PD}_a = \frac{P1 + 14.7}{P2 + 14.7} \times \mathrm{PD}_r \tag{14.6}$$

   d. For flow of any compressed gas at temperatures other than 60°F, use the following formula to calculate a factor that, when multiplied by the flow rate, will give the flow rate at the new temperature:

   $$f = \frac{460 + t}{520} \tag{14.7}$$

   where $P1$ = 55 (referenced table pressure, psig)
   $P2$ = actual service pressure, psig
   PD_r = reference pressure drop found in chart for flow rate in table, psi/100 ft
   PD_a = adjusted pressure drop for actual pressure, psi/100 ft
   g = specific gravity of gas
   t = temperature under consideration, °F
   f = factor

Another method, applicable only to branch lines with smaller numbers of laboratory outlets used for average purposes, is to use a prepared chart based on the number of outlets with the actual flow of gas not considered. The flow rate and diversity of use is taken into consideration in the sizing chart and assumes that sufficient system pressure is available. When there is a small number of outlets on a branch, this method provides a sufficient degree of accuracy and speed of calculation. Table 14.29 is such a chart for various systems found in a laboratory.

Tests

The bulk storage tanks and dewers are required to be ASME rated and therefore are tested at the factory before shipment. They are not tested after installation. Cylinders are not tested for the same reason. This requires that only the distribution system, from the cylinder valve to the outlets, be subject to pressure tests.

Testing is done by pressurizing the system to the test pressure with an inert, oil-free and dry gas. Nitrogen is often used because of its low cost and availability. For systems with a working pressure up to 200 psig, the entire piping system, including the cylinder manifold, is tested to 300 psig for 1 h with no leakage permitted. If a working pressure higher than 200 psig is required, the system is tested at 150 percent of the system pressure. This pressure testing should be done in increments of 100 psig, starting with 100 psig. This is done to avoid damage due to a catastrophic failure. Leaks are repaired after each increment. After final testing, it is recommended that the piping be left pressurized at system working pressure with system gas if practical.

Flushing, Testing, and Purging the Distribution System

After the system is completely installed and before it is placed in service, the piping system must first be flushed to remove all loose debris, then tested, and finally purged with the intended system gas to assure purity.

TABLE 14.29 Typical Laboratory Branch Sizing Chart

	Pipe diameter, in						
No. of conn.	Cold water, hot water	Air	Gas	Vac.	Oxygen	D.W.	Nitrogen
1	½	½	½	½	½	½	½
2	¾	½	½	½	½	½	½
3	¾	½	½	¾	½	½	½
4	¾	½	½	¾	½	½	½
5	¾	½	¾	¾	½	¾	½
6	¾	½	¾	1	½	¾	½
7	1	½	¾	1	½	¾	½
8	1	½	¾	1	½	1	½
9	1	½	¾	1	½	1	½
10	1	½	¾	1	½	1	½
11–20	1¼	¾	1	1¼	¾	1	¾
21 and over	1½	1	1¼	1½	1 (21–30) 1¼ (31–50) 1½ (over 50)	1	1

1 in = 25.4 mm.

An accepted flushing method is to flow two to five times the volume of the branch or main through each respective part of the system. This is done by connecting the flushing gas under pressure to the piping system and then opening and closing all outlets and valves starting from the closest and working to the most remote.

Tests of the gas at the farthest outlet shall be taken to assure that the gas is the desired purity. This test could be done either by the end user if he or she has the necessary instruments or by an acceptable testing service with the results given to the client to verify that the gas is acceptably pure. A test for particulates is to have the gas flow at a minimum rate of 100 Lpm into a clean white cloth and observe for contamination.

Finally, the system must be capable of providing the desired purity when actually placed in operation. Since flushing and testing leaves the piping system filled with those inert or other gases, they must be removed, or purged. This is accomplished by allowing the system gas to flow through all parts of the piping system, opening all of the valves, and testing the gas purity at various points of the system until the desired purity level is reached.

For high-purity gases, a laboratory specializing in testing for the purity level required shall be used unless the facility is capable of performing the test.

GASES FOR HEALTH CARE FACILITIES

GENERAL

This section will describe centrally distributed oxygen, nitrous oxide, nitrogen, and compressed air systems used specifically in health care facilities. They are used variously for direct patient care, life support, as an anesthetic, or to power medical instruments. These compressed gas systems are characterized by gas purity, pipeline cleanliness, and total system reliability.

The definition of a health care facility includes hospitals, nursing homes, medical and dental offices, clinics, and ambulatory care centers. These facilities fall into two general categories: short-term acute care and long-term care. Short term is considered the typical acute care surgical-medical hospital. Long-term care includes specialty care and nursing home facilities that do not have direct surgical and other specialized capabilities normally associated with hospitals.

The overriding system concept is reliability. The central supply source and piping system shall be designed so that it shall not fail to provide the minimum amount of gas required by the facility no matter how high the demand may be during any condition, even those requiring a much higher than expected usage or experiencing equipment component failure.

The systems consist of a central gas storage or source, the distribution system, station outlets, and alarms.

CODES AND STANDARDS

Building codes that govern building construction and the design and installation of mechanical systems do not have direct provisions for regulating the design of medical gas systems. Such regulation is done by reference to standards that have been so widely accepted throughout the industry and by the various authorities that they have the force of law. These standards are required to be observed for the design, specification, storage, delivery, installation, and testing of the various medical gases. Among them are:

1. NFPA
   - ***a.*** NFPA-99. Health Care Facilities. This has now become the standard for pressurized medical gases in the United States and some countries throughout the world.
   - ***b.*** NFPA-50. Bulk Oxygen Systems at Consumer Sites.
2. CGA
   - ***a.*** C-9.0 Standards for Color Marking of Compressed Gas Cylinders Intended for Medical Use.
   - ***b.*** G-7.0 Compressed Air for Human Respiration.
   - ***c.*** DISS (Diameter Index Safety System) for patient and service outlet connections.

3. *JCAHO Accreditation Manual for Hospitals,* 1994. Conformance with the requirements of this manual is mandatory for accreditation by the JCAHO. Accreditation has become necessary for Medicare and Medicaid reimbursement and other licensing requirements. Accreditation is not desired or obtained by all hospitals. The JCAHO manual also refers to other standards.
4. AIA (American Institute of Architects). *Guidelines for Construction and Equipment of Hospital and Medical Facilities,* 1992–1993.
5. CSA (Canadian Standards Association). Since many medical devices and pieces of equipment are sold in Canada, manufacturers commonly conform to the CSA standards when more stringent than U.S. standards.

DESCRIPTION AND GENERAL USES FOR THE COMMON GASES

Oxygen

Oxygen is a colorless and tasteless gas and is one of the most widely used of the medical gases. Its primary use, either undiluted or as part of a mixture, is for respiratory, inhalation, and anesthesia purposes. Although nonflammable, oxygen supports combustion and is therefore considered an oxidant. Oxygen is normally distributed at a pressure of between 50 and 55 psig (340 and 375 kPa).

NFPA distinguishes between small- and large-size systems. Storage of less than 3000 ft^3 of oxygen is called a *class I system.* Storage of 3000 ft^3 or more is called a *class II system.* Other standards (not NFPA) reference oxygen stored as a gas as *type I,* and when stored as a liquid as *type II.*

Nitrous Oxide

Nitrous oxide is a colorless and tasteless gas that produces a loss of sensitivity to pain when inhaled. Its primary use is in surgical and dental suites as an anesthetic and in far lesser amounts for other specialized applications. Nitrous oxide is nontoxic and nonflammable. It supports combustion to a lesser extent than oxygen but is considered an oxidant. Nitrous oxide is generally stored as a cryogenic liquid in cylinders and normally distributed at a pressure of between 50 and 55 psig (340 and 375 kPa).

Nitrogen

Nitrogen is an inert, colorless, and tasteless gas used primarily to power pneumatic tools in surgical suites. It is also used for inhalation therapy where mixed gases closely matching natural air proportions are desired and rarely for decontamination purposes. When used to power pneumatic tools, nitrogen is distributed at pressures up to 250 psig (1725 kPa) depending on the specific tools used. It is not unusual to have two separate pressure systems in facilities. Some pneumatic power tools require a minimum pressure of 200 psig (1360 kPa) at the tool for proper operation, for which a pressure of 250 psig (1725 kPa) be available at the regulator outlet. Often, a dedicated nitrogen cylinder supply is installed at each location with the required controls and regulator. These tools will operate properly at lower pressures but with reduced efficiency.

Although not directly concerned with health care, nitrogen is also used to test and blow out medical gas piping systems and as a purge to provide an inert atmosphere when brazing copper pipe joints.

Compressed Air

Compressed air is a colorless and tasteless gas. It is separated into three categories depending on specific use with a health care facility: low-pressure surgical-medical compressed air, high-pressure compressed air used to drive dental and other pneumatic tools, and low-pressure compressed air used for other purposes such as laboratories. It is a requirement of NFPA-99 that the compressor used as a source for the surgical-medical air system be a dedicated one and not used for any other purpose.

Medical compressed air is distributed at a pressure of between 50 and 55 psig (345 and 375 kPa) and is used primarily for patient inhalation, anesthesia purposes and to power respirators and ventilators. High-pressure compressed air is distributed at a pressure generally in the range of 160 to 250 psig (1190 to 1725 kPa) and is used to power pneumatic tools. Compressed air for laboratory use is distributed at a pressure of between 50 and 55 psig (340 and 375 kPa) and is used for a variety of general purposes where purified air is not required. For purified laboratory air service, refer to discussions of laboratory compressed air earlier in this chapter.

STORAGE AND GENERATION OF GASES

Oxygen

Bulk oxygen is typically stored as a cryogenic liquid in tanks and as a compressed gas in high-pressure cylinders. Bulk supplies are defined as an assembly of containers, pressure regulators, safety devices, vaporizers, manifolds, and piping that has a storage capacity of 20,000 ft^3 (566,000 L) of gas including unconnected reserves on hand at the same location. The purity of the oxygen must conform to Oxygen USP requirements.

The capacity of commonly used high-pressure cylinders is given in Table 14.30. Typical bulk containers have capacities listed in Table 14.31.

For all but the smallest uses of oxygen, it is recommended that a bulk supply be installed. A generally accepted range of 400 to 600 ft^3 of gas/month/bed (depending on the type of hospital and other specialized treatment activity) is used to find a typical month's usage. If the hospital is in a large city with a large percentage of trauma and surgical patients, or if the hospital is a specialized type that has a large percentage of patients that may require inhalation assistance, use the larger figure. For ‘‘average’’ conditions, use the smaller figure. Consultation with the facility staff regarding past usage and with a potential supplier, along with some judgment, will be necessary to confirm a final decision. The size of the bulk supply tank should allow a minimum of 7 to 10 days between fill cycles, with a longer period if practical.

Because oxygen supports combustion, outdoor storage tanks and cylinders shall be separated from other gases and structures in the event of a fire. Refer to Fig. 14.33 for cylinder and bulk oxygen separation criteria. Indoor storage requires an

TABLE 14.30 Storage Capacity of Typical Medical Gas Cylinders

	Standard cubic feet per cylinder		
Type of gas	H size	G size	Storage mode
Oxygen	244	187	Compressed gas at 2200 psig (15,170 kPa)
Nitrous oxide	558	488	Liquid in cylinder
Air	232	178	Compressed gas at 2200 psig (15,170 kPa)
Carbon dioxide	558	436	Liquid in cylinder
Helium	213	141	Compressed gas at 2200 psig (15,170 kPa)
Argon	244	187	
Xenon	88.8	—	
Nitrogen	226	—	Compressed gas at 2200 psig (15,170 kPa)

TABLE 14.31 Storage Capacity of Typical Bulk Liquid Oxygen Tanks

Gross capacity, gal (L)	Net liquid capacity, gal (L)	Capacity oxygen, scf (10^6 L)	Approximate weight empty vessel, lb (kg)	Approximate weight—vessel loaded with oxygen, lb (kg)
330 (1,249.1)	314 (1,188.5)	36,200 (1.03)	4,000 (1,816)	7,000 (3,178)
575 (2,176.4)	535 (2,025)	61,500 (1.74)	5,800 (2,633.2)	10,900 (4,948.6)
975 (3,690.4)	920 (3,482.2)	105,700 (2.99)	9,300 (4,222.2)	18,100 (8,217.4)
1,625 (6,150.6)	1,533 (5,802.4)	176,100 (4.99)	10,400 (4,721.6)	25,000 (11,350)
3,400 (1,286.9)	3,250 (12,301.3)	374,000 (10.59)	18,500 (8,399)	49,400 (22,427.6)
6.075 (22,993.9)	5,935 (2,246.4)	684,000 (19.37)	27,000 (12,258)	83,500 (37,909)
9,200 (34,822)	8,766 (33,179.3)	1,009,000 (28.57)	34,000 (15,436)	117,500 (53,345)
11,000 (41,635)	10,500 (39,742.5)	1,215,000 (34.41)	40,000 (18,160)	139,750 (63,446.5)

enclosure with a minimum fire rating of 1 h around the cylinders, although a 2-h separation is required by many authorities. Storage of inert gases only are permitted inside this enclosure. A typical schematic diagram of a bulk oxygen supply is illustrated in Fig. 14.33. A typical schematic diagram of a cylinder oxygen supply is illustrated in Fig. 14.34. Liquid oxygen stored in tanks generally requires a vaporizer to convert the liquid to a gas.

Nitrous Oxide

Nitrous oxide is typically stored as a cryogenic liquid in cylinders, with multiple cylinders arranged in banks. The capacity of commonly used storage cylinders is

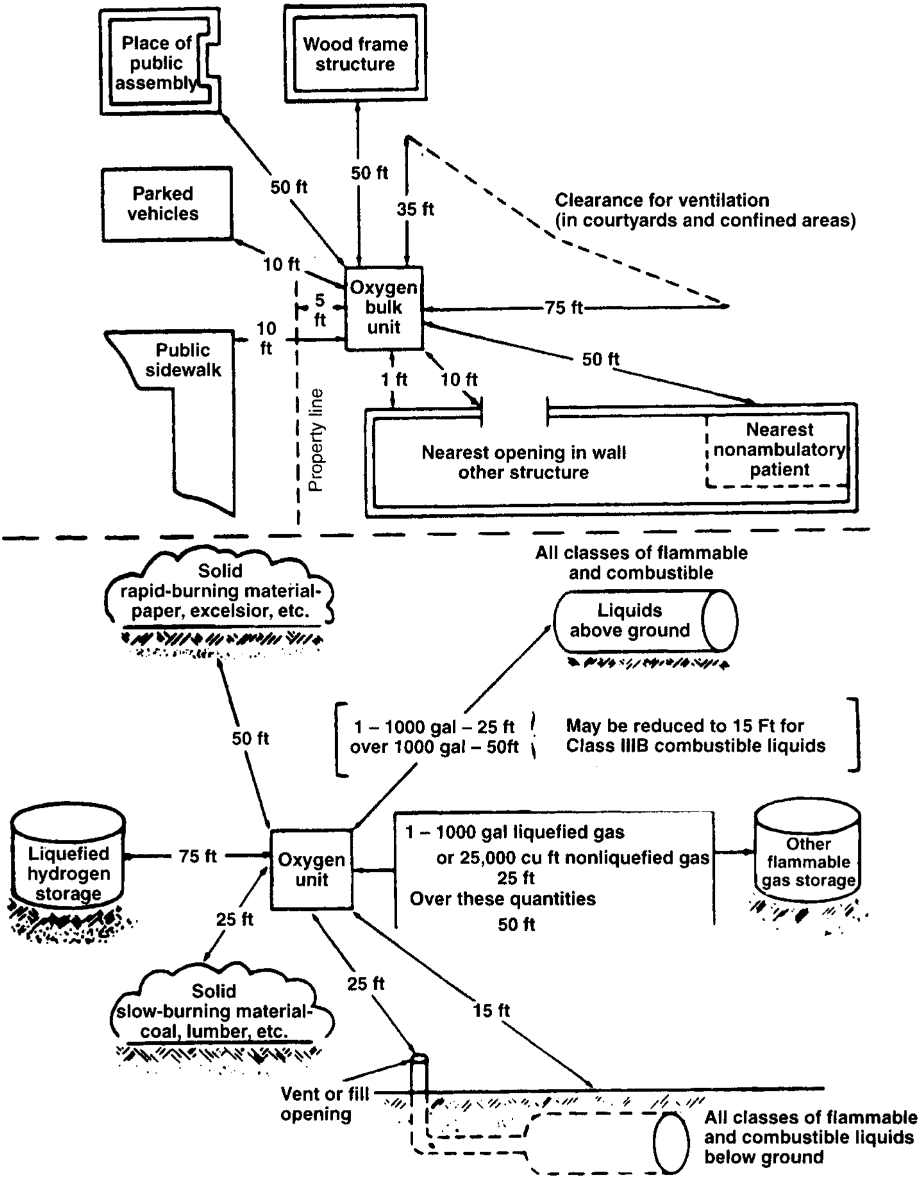


FIGURE 14.33 Separation of bulk oxygen supply.

given in Table 14.32. Vapor pressures for cryogenic storage are given in Fig. 14.35. For reference, the vapor pressure of carbon dioxide, which is also stored as a cryogenic liquid, is included.

A bulk supply of nitrous oxide is defined as an assembly of containers, pressure regulators, safety devices, vaporizers, manifolds, and piping that has a storage ca-

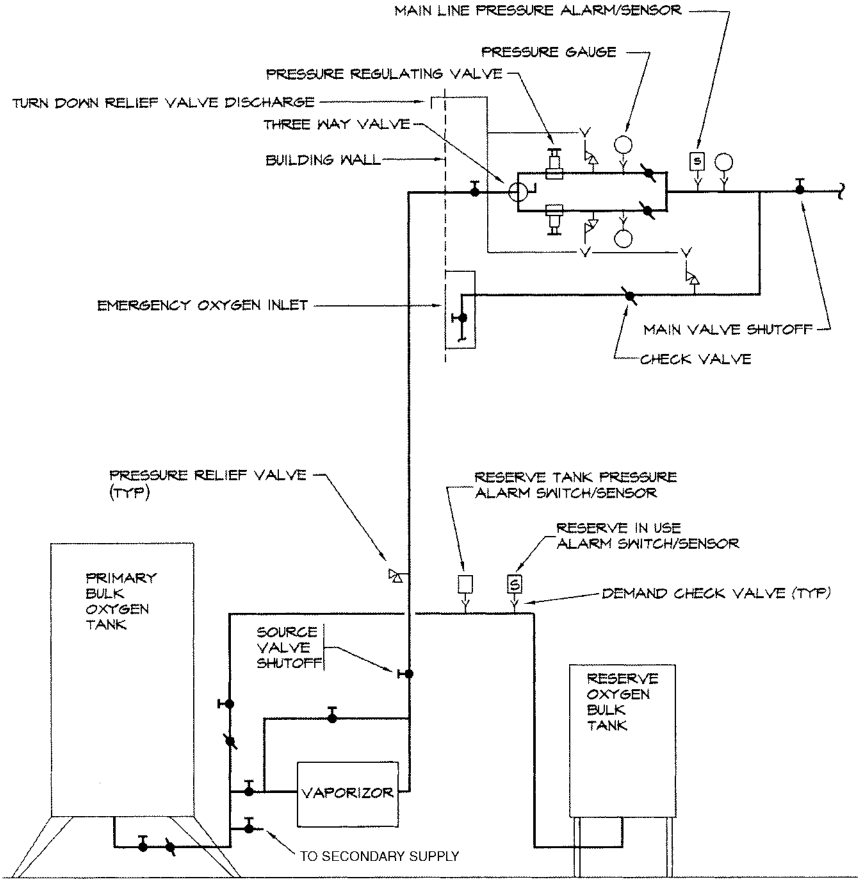


FIGURE 14.34 Schematic detail of bulk oxygen supply on site

TABLE 14.32 Sizing Chart for Nitrous Oxide Cylinder Manifold

(Using 489 ft^3; 13.85×10^3 L cylinders)

	Duplex manifold size			
	Indoor		Outdoor	
Number of anesthetizing locations	Total cylinders	Cylinders per side	Total cylinders	Cylinders per side
4	4	2	4	2
8	6	3	10	5
10	8	4	12	6
12	10	5	14	7
16	12	6	20	10

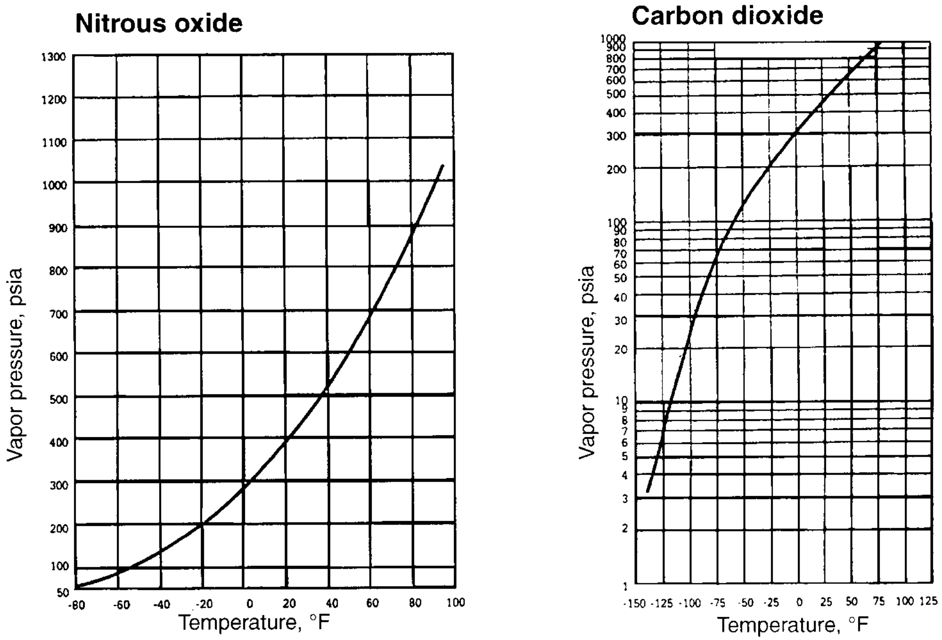


FIGURE 14.35 Vapor pressure versus temperature for nitrous oxide and carbon dioxide.

pacity of 28,000 ft^3 (792,000 L) of gas including unconnected reserves on hand at the same location. A bulk supply is usually considered when the use of gas exceeds about 175,000 ft^3 per year.

For a suggested starting point to determine the number of primary cylinders for a facility, use Table 14.34 consulting with facility staff to establish past or anticipated usage. Another generally accepted criterion for the primary supply for smaller facilities is to use one cylinder for each major operating and delivery room or similar location. The same number of cylinders in the primary supply shall be provided as a reserve bank. A reasonable cycle for changing banks should be about 1 week.

It is recommended that volumes of nitrous oxide over 28,000 ft^3 (800,000 L) should be located outdoors and above ground. If installed inside a building, adequate ventilation and monitors for low oxygen levels should be provided. Precautions are necessary if the nitrous oxide storage area is located outdoors. Since nitrous oxide is stored as a liquid, it depends on the heat received from ambient air to vaporize the liquid to a gas. If very high usage is coupled with low outdoor air temperatures, there is a possibility that the liquid in the storage cylinder will not be vaporized fast enough and the supply pressure will fall to a point where adequate pressure would not be maintained in the distribution system. In this case, a vaporizer or some other method of heating the storage location will be required. The potential supplier of the gas should be consulted regarding past experience in the geographical area where the facility is located.

Cylinder and bulk storage location and separation criteria, as well as the typical storage schematic diagram of the gas supply, are the same as those for oxygen.

Dental offices use nitrous oxide usually at the rate of 1 cylinder for each 50 patients. Ten percent of patients use this gas. Usually the flow rate is 3 L/M, with additional oxygen used at a rate of 6 L/min simultaneously.

Nitrogen

Nitrogen is typically stored as a compressed gas in high-pressure cylinders, with an equal number of cylinders (primary and secondary supply) arranged in banks. The capacity of commonly used high-pressure cylinders is given in Table 14.30. A typical nitrogen supply is schematically illustrated in Fig. 14.31.

There is no general consensus of opinion as to the quantity of nitrogen that might be used over an extended period of time in a typical facility because of the constantly changing requirements of tools using nitrogen, the desire of medical staff to use specific instruments, and the degree of use for inhalation therapy, if any. The largest flow rate (generally between 6 and 15 scfm) will be used in facilities that do orthopedic, thoracic, and neurosurgery procedures. Recommended starting point for these facilities would be 1 cylinder as a primary supply for each room where nitrogen is used. If the expected use is not great, three-fourths cylinder per room is acceptable. An equal number of cylinders shall be provided as a secondary bank. The actual quantity should be decided upon after consultation with facility staff to establish past and anticipated usage. Another consideration is to allow a minimum of 1 week, and up to a 10-day cycle for changing cylinder banks based on the anticipated volume of usage.

The grade of nitrogen used for human respiration must comply with National Formulary (NF) specifications. When used for testing, purging, and for pneumatic tool operation, the required grade is referred to as *oil-free, dry nitrogen.*

Compressed Air

Compressed air can be centrally supplied from a high-pressure cylinder manifold system when little use is expected or from air compressors manufactured and installed expressly for health care facilities. The quality of the air used for medical purposes is referenced to United States Pharmacopeia specifications (USP) and shall conform to Quality Verification level (Grade) N, as described in ANSI/CGA G-7, ‘‘Commodity Specification for Compressed Air,’’ Table 1, Directory of Limiting Characteristics. Because of the necessity that compressed air for inhalation meet USP requirements, all cylinders must be properly labeled, and the air itself is considered a drug. Air that has been reconstituted from oxygen USP and nitrogen NF with a major portion of other elements eliminated is also available and is called *synthetic air.*

The cylinder manifold system arrangement is similar to installations of other compressed gases. The capacity of commonly used high-pressure cylinders is given in Table 14.30. For central supply installations, the most common and economical method of producing compressed air is by means of an air compressor assembly.

Flammable Gas Storage

Flammable medical and laboratory gases shall be stored in interior rooms or enclosures separate from other gases, or outside of the building. Rooms shall be properly vented and have a fire-resistive rating of 1 h. If local authorities or facility laboratory safety personnel agree that a hazard does not exist, this requirement can be waived.

THE SURGICAL-MEDICAL AIR COMPRESSOR ASSEMBLY

Intakes

The compressor intake must be located in an area that will not contaminate the incoming air with the exhaust from any internal combustion engines, HVAC exhausts, room air, any strong localized odors, or any other undesirable contaminants. Accepted practice is to have the air that is taken into the compressor as clean as the general atmo-sphere in the area of the facility (not the room the compressor is in). The intake may also use a different source of air if it is considered better than the ‘‘normal’’ outside air obtained at the building site, such as that from the HVAC filtered supply used for operating rooms. The only stipulation is that it must be available at all times. The intake line or header can be combined for multiple compressors, but the piping and valve arrangement must be capable of completely isolating one of the compressors while the other(s) continues with uninterrupted operation. Generally accepted practice is to design the size of the intake to have a maximum pressure loss of 4 in WC for the entire line, including filters and inlet louvers. The velocity of the intake air must be low enough to prevent the entrance of rain into the louver.

Air Compressors

It has been found that lubricating oil, when decomposed by a malfunctioning compressor, will introduce odors and carbon monoxide into the air supply. The medical air compressor shall be designed to prevent the introduction of contaminants or liquid into the pipeline by either: (a) the elimination of oil anywhere in the compressor or (b) by separation of the oil-containing section from the compression chamber by an area open to the atmosphere, which allows continuous visual inspection of the interconnecting shaft. Examples of (a) are liquid ring, rotary vane, and permanently sealed bearing compressors and of (b) extended head compressors.

With few exceptions, the liquid ring, rotary vane, and sealed bearing reciprocal compressors are the compressors of choice. The little used diaphragm compressor is considered oil free because the compression chamber is separated from the lubricated portion of the compressor by the diaphragm.

Pumps in the (a) category shall have separate sensors that will shut down the pump and activate an alarm if the temperature of the liquid used for sealing becomes excessive. If permanently sealed bearing compressors are used, a high air temperature monitor, with a setting recommended by the manufacturer, shall be provided at the immediate outlet of each cylinder that will shut down the compressor and activate the local and master alarm. If this compressor has water-cooled heads, a high water level in the receiver shall shut down the compressor and activate the local and master alarm. For pumps in the (b) category, the same sensors are required. In addition, a coalescing filter and a charcoal filter, each provided with a color change indicator for hydrocarbons, shall be provided.

With these restrictions, the engineer is free to select any compressor suitable for the flow rate and pressure required for the facility under design. The most often used compressors are rotary vane and oil-free reciprocating compressors.

Each compressor in a duplex arrangement shall have 100 percent capacity, and two of three compressors in a triplex installation shall have 100 percent system capacity. For duplex systems, a lag compressor-in-use alarm shall be installed in the compressor control cabinet. It shall be both visible and audible. This alarm does not have to be repeated in the master alarm panel.

The interconnecting piping between the compressor(s) and devices must be noncorrosive, such as brass or copper. Black and galvanized steel pipe is expressly prohibited.

Automatic alternation of units is required to evenly wear all compressors. However, if larger units are provided with an automatic means to activate additional units to maintain system pressure, manual lead/lag alternation is permitted. Experience has shown that in a significant number of installations, an equal-wear syndrome may exist that will have both units of a duplex installation break down at the same time because of equal wear provided by automatic alternation. Manual alternators have been shown to be preferable in many cases. Operating personnel of the facility should be consulted prior to selection of the alternation method.

It is a requirement that a main shutoff valve be placed after the entire compressor assembly in the immediate vicinity to isolate the building piping system from the source. It must be properly labeled.

Air Dryers

Water vapor is normally removed by a refrigerated air dryer to produce a system dew point of approximately 36°F (2°C). If a lower dew point is required, a desiccant dryer is recommended. Air dryers shall be duplexed, and if an aftercooler is necessary, it too shall be duplexed and provided with a separate condensate trap. A dew point alarm must be provided to signal a dew point reading of higher than 39°F (4°C).

Receivers

A receiver is required for a medical-surgical air compressor assembly. A receiver evens out any momentary variations in air pressure, provides an additional method of eliminating large drops of water in the airstream and provides a reserve capacity that allows compressors to shut down for a time rather than run continuously.

An automatic receiver drain and a sight glass are required on a receiver. The sight glass will provide a method of visually observing the liquid level in the receiver and checking on the operation of the automatic receiver drain. A receiver is not permitted to become a water separator. The receiver shall also be equipped with a safety relief valve and pressure gauge and shall comply with the ASME code for unfired pressure vessels.

Filters and Other Devices

In order to achieve the low contaminant level required by CGA G-7, it is required that the proper in-line filters and other devices be provided to remove them. These filters and devices are selected and sized on the basis of the degree of contaminants in the intake air supply and the desired level of removal. Charcoal filters remove odor. Coalescing filters remove both oil and water vapor. Carbon monoxide is removed if necessary by a catalytic converter that changes it to carbon dioxide, which is acceptable in larger amounts. A particulate filter is necessary to remove small particles released from the charcoal filter and desiccant dryer.

Each of these filters and devices shall be duplexed, with the piping and valve arrangement capable of completely isolating one of the devices while the other continues uninterrupted operation. If this is not economical or practical, each device must be capable of being bypassed and removed from the system without shutting down the entire system. All final line regulators and filters shall be duplexed.

Installation

All of the above components, along with the control panel and alarms, are commonly prepiped and prewired on a skid at the factory and tested. The skid is shipped to the facility and installed with a minimum number of connections and assembly at the site. A typical surgical-medical air compressor assembly is illustrated in Fig. 14.36.

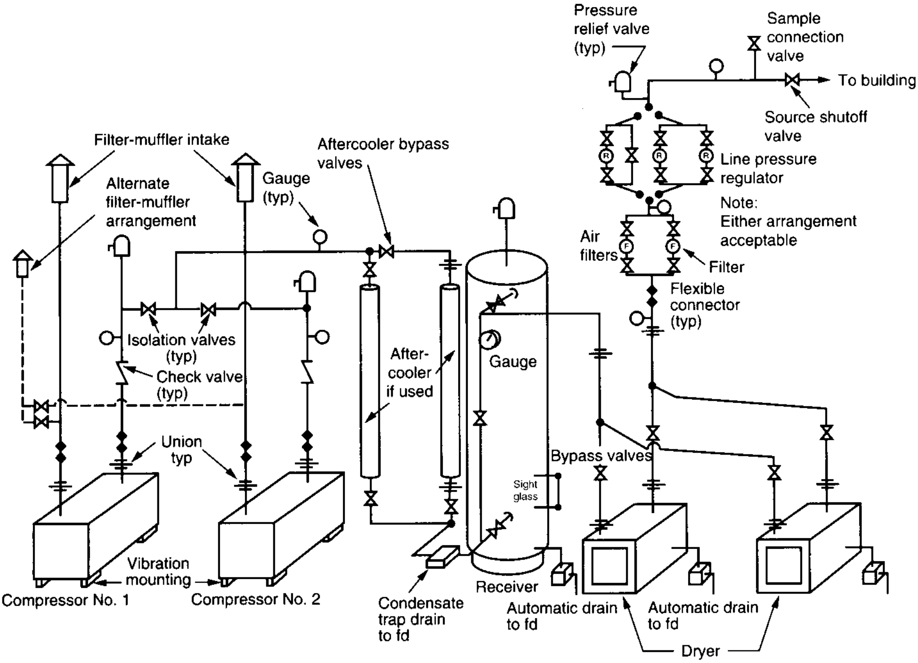


FIGURE 14.36 Typical surgical-medical air compressor assembly. *Note:* Flow schematics that differ may be acceptable as long as they meet the intent of NFPA-99. (*Adapted from NFPA-99.*)

DENTAL AIR COMPRESSOR ASSEMBLY

Any number of compressors can be used. The compressors may be used to power evacuation devices if the system exhaust is closed and is routed directly to the outside. Automatic activation of additional compressors for increased air requirements should be provided.

The intake location is similar, although less restrictive, than the medical compressor. Air intake shall be outside the building when practical, but it could be located in any room where no chemical-based material is stored or used. The system is required to have dry-type intake muffler and/or filters, a receiver, shutoff valves, air dryer(s), and final filter. An appropriate moisture indicator shall be provided downstream of the receiver and upstream of any system pressure regulators. If this compressor is to be used to supply respirable air or otherwise provide life support (such as for a respirator or anesthesia equipment), the compressor shall comply in all respects to the medical-surgical compressor assembly requirements.

The receiver requirements are similar to the medical system. The receiver shall have the necessary controls to assure practical on-off operation of the compressors.

A typical dental air compressor assembly for large facilities is illustrated in Fig. 14.37.

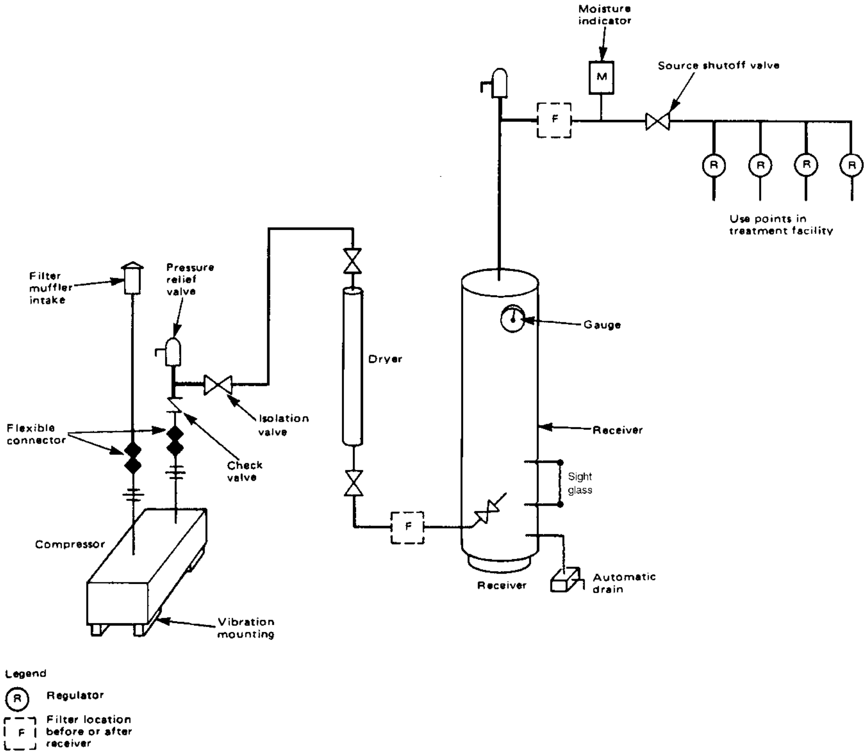


FIGURE 14.37 Typical dental air compressor. (*Adapted from NFPA-99.*)

Alarms

For duplex systems, a lag compressor-in-use alarm shall be installed in the compressor control cabinet. It shall be both visible and audible. This alarm does not have to be repeated in the master alarm panel.

THE DISTRIBUTION NETWORK

System Types

In NFPA-99, there is a reference to level 1, 2 or 3 systems for patient supply. The distinction between them is the amount of gas stored.

Level 1 and 2 systems store an amount larger than 3000 ft^3 (56 m^3) of nonflammable gas, except nitrogen, connected and in storage. Level 3 is a smaller system that does not have more than 3000 ft^3 (56 m^3) of nonflammable gas, except nitrogen, connected and in storage. This can be increased to 5000 ft^3 (143 m^3) if oxygen is used as a liquid in DOT cylinders. Some other restrictions for level 3 systems require that a listed pressure regulator be connected to each cylinder, that it will supply only a single facility or two single treatment facilities. In facilities serving nonhuman use such as veterinary medicine, some provisions need not be followed. In general, most provisions regarding Level 1 installations shall be adhered to.

PIPE MATERIALS, JOINTS, AND INSTALLATION

General

The following general requirements of NFPA-99 regarding the nonflammable piping systems shall be strictly complied with:

1. All piping must be cleaned for oxygen service prior to installation and plugged or capped. Pipe should be purchased in this condition. If piping is contaminated, it must be discarded. Valves, fittings, and other components shall be received cleaned and bagged from the manufacturer or cleaned in accordance with CGA G-4.1 before being installed.
2. Pipe used for pressures of up to 199 psig must be seamless, hard drawn, type K or L, ASTM B-819, and specially marked. When pressures are 200 to 300 psig, only type K shall be used. Other acceptable materials can be used in the manufacture of some medical gas equipment.
3. Joints shall be brazed, and only wrought copper and copper alloy fittings (ASTM B-16.22) are permitted. No flux is allowed. Cast fittings are specifically prohibited. Other jointing methods are permitted, such as memory-metal couplings or other approved joints that have the same properties as a brazed joint. Valves and fittings having flared or compression joints are specifically prohibited.
4. Flexible hoses and connectors shall not be concealed or penetrate the floor, walls, ceilings, or partitions and must have a minimum burst pressure of 1000 psig (7000 kPa).
5. Requirements for hangers and supports are very specific, with distances between supports delineated in tables based on types of service.

6. Extensive detail has been written in NFPA-99 regarding brazing methods, procedures, and qualification of mechanics.

Valves and Valve Locations

Valves provide the capability of shutting down various parts of a system for maintenance or emergencies with the least interruption of other areas or parts of the system as a whole. Valves shall be of the one-quarter-turn type (ball or butterfly) with an indicating handle. All valves shall be properly marked and located so that they are in full view at all times, not behind doors or other movable objects that may hide them. Valves that are placed in locations accessible to other than authorized personnel shall be installed in valve boxes with removable or frangible windows.

Valves intended to isolate existing systems for maintenance or from new systems are permitted. These control valves shall be properly labeled and either locked open or located in a secure area.

Anesthetizing locations and other critical life support areas such as critical and cardiac care and postanesthesia recovery areas shall be supplied directly from a riser or supply with no intervening valves except for zone valves. A zone valve for each individual gas shall be located immediately outside all of the above areas. These zone valves shall not control any other room or area.

VALVES

General

1. All valves shall be 3-piece, full size port bail valves, ¼ turn with extensions for brazing, indicating handle.
2. The valve shall be constructed with bronze or brass body.
3. Vacuum valves can be butterfly valves.
4. All valves shall be capable of being locked or latched open or closed as required.
5. Valves for nonflammable medical gas shall not be located in the same zone valve box as flammable gas.

Source Valve

A source valve shall be installed on the immediate outlet of source assembly to permit the entire source of supply, including all accessory devices, to be isolated from the piping system. The source valved shall be located in the immediate vicinity of the source equipment and shall be labeled ‘‘source valve for the source name.’’

Main Valve

The main supply line shall be provided with a main line shutoff valve to permit shut-down of the entire system without having to go to the source. It shall be located downstream of the source valve and outside of the source room, enclosure or where the main line first enters the building. The valve shall be located to permit access by authorized personnel only (similar to in a ceiling or behind a locked access door. The valve shall be labeled ‘‘main valve for the source name serving (name of the building)’’.

Please note that the main valve is not required where the source valve is accessible from within the building.

Riser Valve

Each riser supplied from the main line shall have a shutoff valve adjacent to the connection. They shall be accessible and shall not be obstructed. These valves shall be labeled ‘‘RISER FOR NAME OF MEDICAL GAS. SERVING THE FLOORS __ AND THE NAME OF THE AREA SERVED BY THIS PARTICULAR RISER.’’

Service Valves

A service shutoff valve shall be installed where the lateral branches off the riser prior to any zone valve assembly on that branch. Only one valve is required on each branch no matter how many zone valves are installed on that branch. The main purpose of these valves is to allow facility service personnel to make changes in the piping system on that floor without having to shut down the entire facility. These valves shall be installed in a locked chase or located in a secure area, locked open. They shall be labeled with a tag that says: ‘‘CAUTION: NAME OF MEDICAL GAS. DO NOT CLOSE EXCEPT IN CASE OF EMERGENCY. THIS VALVE CONTROLS SUPPLY TO __.’’

Zone Valves

Station inlets and outlets shall not be supplied directly from a riser unless a manual shutoff valve is located in the same story between the riser and the inlet/outlet. A wall must intervene between the riser valve and the inlet/outlet zone valve. This valve shall be readily operated from a standing position in the corridor on the same floor that it serves. Each lateral branch line serving patient rooms shall be provided with a zone valve that controls the flow of medical gas to the patient rooms, operating room or other anesthesia location. Zone valves shall be so arranged that shutting off the supply to medical gas will not affect the supply to the rest of the system. A pressure/vacuum gauge shall be provided on the patient side of each zone valve. These boxes shall not be located in closed rooms or closets or behind normally open doors, or otherwise hidden from view.

Zone valves shall be located immediately outside each vital life support or critical care area and each anesthesia location. They shall be provided for each medical gas/vacuum location so as to be readily accessible in cases of emergency. Valves shall be protected and marked ‘‘CAUTION: NAME OF MEDICAL GAS. DO NOT CLOSE EXCEPT IN CASE OF EMERGENCY. THIS VALVE CONTROLS SUPPLY TO __.’’

All medical columns, hose reels, ceiling tracks, control panels and other special installations shall be located on the patient side of the valve.

In-Line Valves

In-line valves are provided to isolate piping for maintenance or modification. They shall be located in a secure area, locked open and be identified "CAUTION: NAME OF MEDICAL GAS. DO NOT CLOSE EXCEPT IN CASE OF EMERGENCY. THIS VALVE CONTROLS SUPPLY TO __."

Shutoff Valves

Shutoff valves are provided for the connection of future piping. Pipe ends shall be closed with a brazed cap and tubing allowance that will allow future connections and re-brazing. Valves shall be locked closed and they shall be located in areas accessible only to authorized personnel.

Pressure Gauges

Pressure gauges shall be installed in the following locations mandated by NFPA-99:

1. Gauges shall be provided downstream of each lateral branch line shutoff valve.
2. Gauges shall be provided in the main line adjacent to the sensor unit in cryogenic storage reserve line.
3. Gauges shall be provided downstream of each room shutoff valve for each individual service.
4. It is recommended that pressure gauges be installed on either side of filter assemblies to visually determine pressure drop.
5. It is recommended that pressure gauges be installed on receivers used for compressed air.
6. For nitrogen systems only, it is common practice to provide an adjustable pressure-regulating valve with gauges in the valve box for this service to allow for the use of various instruments in the OR if this is a facility requirement.

Alarms

Because of the importance to life support provided by the various gas systems, alarms are critical in order to warn operating personnel of impending problems and to immediately alert them to problems or emergencies that do arise. Visual and audible warnings strategically located will provide this ability. All of the alarms are both audible and *noncancellable visual* unless indicated otherwise. This means that the visual portion of the alarm cannot be turned off at the alarm location but must be corrected at the source of trouble, and then reset. The audible alarm may be turned off because of the prolonged distraction that it could cause at a switchboard or nurses' station. The master alarm power source shall be connected to the life safety branch of the emergency electrical power system.

Alarms are divided into two categories, master alarms and area alarms. Master alarms monitor the operation and condition of the system supply or sources and respond to trouble that will affect the facility as a whole. They are required to be located in two places to guarantee continuous, 24-hour-a-day, responsible observation and also to provide the ability to immediately notify appropriate personnel that the alarm has tripped. Such locations are usually at the main telephone switchboard, security office, or the principal working area of the individual responsible for facility maintenance. If the alarms are connected to a computer for the building management system, the computer is not considered an acceptable panel. Area alarms provide warnings for anesthetizing and other critical care areas and are intended to be located at or near nurses' stations or in areas that are frequently used by hospital personnel. They must be installed in a location that is in continuous and unobstructed view.

Master alarm functions shall monitor the operation and condition of the source of supply, the reserve, if any, and pressure in the main line of each system. Central liquid or gaseous supply and/or reserve shall have the following alarm functions:

1. Central supply line pressure high: The pressure sensor shall be located on the pipe distribution side of the main line shutoff valve.
2. Central supply line pressure low: The pressure sensor shall be located on the pipe distribution side of the main line shutoff valve.
3. Liquid level of primary supply low, reorder: This is a normal condition and does not constitute an emergency.
4. Emergency reserve in use.
5. Emergency reserve line pressure low: This alarm is considered an extreme emergency condition. For a cryogenic source, it is initiated when the liquid level in the reserve is reduced to one-half of its full volume. If the source is a compressed gas, it is initiated when the pressure lowers to 500 psig.
6. For cryogenic storage used as a reserve, a reserve failure alarm shall be provided. In addition, an alarm shall be installed to indicate when the reserve capacity is reduced to 1 day's supply and if the gas pressure in the reserve unit falls below the set point established by the facility as a minimum necessary for the system to function properly.
7. When check valves are not installed in each cylinder supply of the reserve bank, an alarm should sound when the reserve supply is reduced to 1 day.
8. All alarms for the air compressor source, including the dew point monitor, shall be repeated in the master alarm panel.
9. For air compressors with water-cooled heads, a high water level in the receiver shall shut down the compressor and activate the master alarm and be repeated in the local compressor alarm panel.

Examples of area alarm functions are:

1. An alarm, activated by a pressure switch, shall be installed in each line supplying specific anesthetizing and critical care area branch lines to annunciate 5 percent increases or decreases from that considered as the normal operating pressure range.
2. Alarms for air compressors are required to be included as part of the local compressor panel installed on or near the compressor. For duplex systems, a lag compressor-in-use alarm shall be installed in the local compressor alarm panel. It need not be repeated in the master alarm panel. For air compressors with water-cooled heads, a high water level in the receiver shall shut down the compressor and the alarm repeated in the local compressor alarm panel.

TABLE 14.33 Summary of Medical Gas System Alarm Requirements

Source equipment	Change-over	Reserve in use	Reserve failure	Reserve low	Dew point high
Manifolds	Yes	NA	No	Note	No
Manifolds with reserve	Yes	Yes	No	Note	No
Cryogenic bulk gas units (VIE) with cryogenic reserve	Yes	Yes	Yes	Yes	No
Cryogenic bulk gas units (VIE) with cylinder reserve	Yes	Yes	No	Note	No
Air compressors	No	No	No	No	Yes
Vacuum pumps	No	No	No	No	No

Pipeline	High pressure or vacuum	Low pressure or vacuum
All pressure gas systems	Yes	Yes
Vacuum systems	No	Yes

This table has been added for the convenience of the user of the document.

Note: This signal is required only where cylinder reserves have no check valves for each cylinder lead.

Table 14.33 is a general summary of the master alarm signal requirements for all medical gases. Refer to the text of NFPA-99 for complete provisions.

Testing by Installer

All tests and flushing of compressed medical gas systems shall be conducted with oil-free, dry nitrogen. All of the following tests are mandated by NFPA-99. For a more detailed description of these tests, refer to that standard.

Pressure tests shall be conducted in two stages. The first is done at a pressure of 150 percent of system pressure, but not less than 150 psig (350 kPa) before closing in the walls and installation of alarms, manifold gauges, and pressure relief devices. The source shutoff valve shall be closed, and the entire system is visually observed and each joint manually tested with soapsuds, or other methods compatible with service gas, for leaks. Any leaks are repaired and the system is retested.

After the first-stage test is complete, the piping system is blown out to eliminate particulates. The final test is done to the entire system with all components installed. This is accomplished by disconnecting the test source and allowing the system to stand for 24 h with a pressure of 20 percent above system pressure. No leakage is allowed except to accommodate variations in ambient pressure. Any leaks are repaired, and the system is retested.

After retesting is required, the system is again flushed to remove all traces of debris. Have the full flow of the purge gas pass through a white cloth at the terminals until no trace of particulates is observed. Accepted practice is to use a volume of five times the volume of the pipe being flushed.

After pressure testing, a cross-connection test, to assure that no cross connections with any other gas or vacuum system has occurred, must be done. This requires that all other systems be reduced to atmospheric pressure and the system under test be pressurized to 50 psig (350 kPa). Each station outlet for all medical gas systems shall be operated in turn to assure that the test system gas is not being discharged from another outlet.

System Testing and Purging by Third Parties

After the tests conducted by the installer, a third party experienced in the field of medical gas pipeline testing shall verify system integrity with the following tests.

A cross-connection test, similar to the installer test, shall be conducted. In addition, with all medical-surgical systems in operation, each system installed shall be pressurized to different pressures and the outlets checked to assure that the proper pressure from each individual outlet is read on a gauge.

A valve test shall be performed to verify that the proper rooms or areas are controlled by the valve being tested.

A flow test of all station outlets shall be conducted to assure that each system outlet delivers required pressure and stays within required pressure drop during the test.

All alarm and warning systems shall be tested to assure the proper functioning of all of the separate alarms. This includes observation of pressure gauges in the system to verify that the alarm function is initiated at the desired reduction of pressure where applicable.

In order to ensure that all particulates are removed from inside the piping system, a purge flow of at least 225 sLpm (8 scfm) shall be delivered from each outlet, and the cleanliness shall be verified by filtering a minimum of 35 ft^3 of test gas through a clean, white filter. After this test, the system shall be purged of the test gas and the system gas introduced into the piping system.

The purity of each system gas shall be verified by testing for dew point, total hydrocarbons, and halogenated hydrocarbons. The maximum allowable variation shall be as described in NFPA-99.

An operational pressure test shall be performed for each system at all station outlets, maintaining the system pressure while the flow rate described in the reference standard is flowing.

A concentration test of all medical gas systems shall be conducted to verify that the minimum concentration of each gas is in accordance with the table appearing in the reference standard.

The air compressor discharge shall be tested for purity and to verify the minimum concentration of contaminants specified in the reference standard.

After all of the above have been completed, the systems are now ready for use. It is recommended that the systems remain pressurized after testing.

SYSTEM AND EQUIPMENT SIZING

Following are the procedures necessary to calculate the size of the various system supply sources and the individual piping systems. A discussion of each procedure follows.

1. Locate and count the number of station outlets for all of the individual systems, and separate them into various areas such as operating rooms, critical and cardiac care areas, and postoperating and postanesthesia recovery. This separation will allow a common flow rate and diversity factor for ease of calculations.
2. Determine or select the location of the supply source for the various systems.
3. Determine the operating pressure requirements for the distributing piping network and at the farthest use point for each of the various systems. With this

information known, determine the total allowable pressure loss desired for the entire system under design. The pressure loss is usually 5 psi.

4. Obtain the allowable flow rate for each of the various station outlets, and assign a diversity factor for each area of the facility to determine how many outlets would be used at the same time.
5. Using the above information, select the type, capacity, and physical size of the source equipment assembly. This will include the oxygen tank or manifold size, air compressor assembly, and nitrous oxide and nitrogen manifold assemblies.
6. Route the various piping systems from the source or storage area to all station outlets or use points. Measure the actual distance along the run of pipe to the farthest point of the system. To the actual run add an additional 50 percent of the measured distance as an allowance for valves, fittings, and so on. This is the developed length. Knowing the total allowable pressure drop for the system, calculate the allowable pressure loss through the length of piping required by the specific pipe sizing chart selected for the project. System design considerations are discussed later in this section.
7. Locate the valves and alarm panels. This shall include section, area, and room valves. This is necessary to give the facility planner enough information to provide space for their installation.

Number of Outlets

The first consideration is to locate and count all of the outlets, often called *station outlets,* for each respective medical gas system. This is usually done by consulting a ‘‘program’’ prepared by the facility planner. This program is a list of all rooms and areas in the facility and the services that are required in each room or area. If a program has not been prepared, the floor plans for the proposed facility shall be used.

There is no code that specifically mandates the exact number of station outlets that must be provided in various areas or rooms for all health care facilities. If fact, there is no clear consensus of opinion among medical authorities or design professionals as to how many station outlets are actually required in all the facility areas. Guidelines are published by the AIA, NFPA, and ASPE that recommend the minimum number of station outlets for various services in specific areas.

The recommendations most often used in determining the number of station outlets for hospitals is the desire to be accredited by the JCAHO. Accreditation is required for Medicare and Medicaid compensation. The JCAHO publishes a manual that refers to the AIA guidelines for the minimum number of station outlets for oxygen, compressed air, and vacuum that must be installed in order to obtain accreditation. If this is a factor for the facility, these requirements are mandatory. Other jurisdictions, such as state or local authorities, may require plans to be approved. These approvals may require adhering to the state or local requirements.

If accreditation or approval of authorities is not a factor, the number and area locations of station outlets are optional. The actual count will then depend upon requirements determined by each individual facility or another member of the design team using both past experience and anticipated future use, often using the guideline recommendations as a starting point. Table 14.34 provides the AIA recommendations. Table 14.35 provides generally recommended guidelines for the minimum number of facility station outlets that are a compilation from other

TABLE 14.34*a* AIA Guidelines for Vacuum and Air Systems for Hospital Facilities Station Outlets for Oxygen, Vacuum (Suction), and Medical Air Systems in Hospitals[1]

Location	Oxygen	Vacuum	Medical Air
Patient rooms (medical and surgical)	1/bed	1/bed	—
Examination/treatment (medical, surgical, and postpartum care)	1/room	1/room	—
Isolation—infectious and protective (medical and surgical)	1/bed	1/bed	—
Security room (medical, surgical, and postpartum)	1/bed	1/bed	—
Critical care (general)	3/bed	3/bed	1/bed
Isolation (critical)	3/bed	3/bed	1/bed
Coronary critical care	3/bed	2/bed	1/bed
Pediatric critical care	3/bed	3/bed	1/bed
Newborn intensive care	3/bassinet	3/bassinet	3/bassinet
Newborn nursery (full-term)	1/4 bassinets[2]	1/4 bassinets[2]	1/4 bassinets[2]
Pediatric and adolescent	1/bed	1/bed	1/bed
Pediatric nursery	1/bassinet	1/bassinet	1/bassinet
Psychiatric patient rooms	—	—	—
Seclusion treatment room	—	—	—
General operating room	2/room	3/room	—
Cardio, ortho, neurological	2/room	3/room	—
Orthopedic surgery	2/room	3/room	—
Surgical cysto and endo	1/room	3/room	—
Post-anesthesia care unit	1/bed	3/bed	1/bed
Anesthesia workroom	1 per workstation	—	1 per workstation
Phase II recovery[3]	1/bed	3/bed	—
Postpartum bedroom	1/bed	1/bed	—
Cesarean/delivery room	2/room	3/room	1/room
Infant resuscitation station[4]	1/bassinet	1/bassinet	1/bassinet
Labor room	1/room	1/room	1/room
OB recovery room	1/bed	3/bed	1/room
Labor/delivery/recovery (LDR)[5]	2/bed	2/bed	—
Labor/delivery/recovery/postpartum (LDRP)[5]	2/bed	2/bed	—
Initial emergency management	1/bed	1/bed	—
Triage area (definitive emergency care)	1/station	1/station	—
Definitive emergency care exam/treatment rooms	1/bed	1/bed	1/bed
Definitive emergency care holding area	1/bed	1/bed	—
Trauma/cardiac room(s)	2/bed	3/bed	1/bed
Orthopedic and cast room	1/room	1/room	—
Cardiac catheterization lab	2/bed	2/bed	2/bed
Autopsy room	—	1 per workstation	1 per workstation

[1] For any area or room not described above, the facility clinical staff shall determine outlet requirements after consultation with the authority having jurisdiction.

[2] Four bassinets may share one outlet that is accessible to each bassinet.

[3] If Phase II recovery ara is a separate area from the PACU, only one vacuum per bed or station shall be required.

[4] When infant resuscitation takes place in a room such as cesarean section/delivery or LDRP, then the infant resuscitation services must be provided in that room in addition to the minimum service required for the mother.

[5] Two outlets for mother and two for one bassinet.

TABLE 14.34*b* Station Outlets for Oxygen, Vacuum, and Medical Air in Outpatient Facilities

Location	Oxygen	Vacuum	Medical air
Examination	0	0	—
Treatment	0	0	—
Isolation	0[1]	0[1]	—
Pre-procedure examination	0[1]	0[1]	—
Operating room		1	
Class A—minor surgical procedure room	1	2	—
Class B—intermediate surgical procedure room	2	3	—
Class C—major surgical procedure room	2	1	—
Post-anesthesia recovery	1	0[1]	—
Step-down recovery area	0[1]	3	—
Cysto procedure	1		—
Emergency		1	
Trauma/cardiac room	1	0[1]	1
Cast room	0[1]	2	—
Catherization room	1	2	2
Birthing room			—
Endoscopy	2	3	
Procedure room		—	—
Decontamination room	2	0[1]	—
Holding/prep/recovery area	—		—
	0[1]		

[1] Portable or hard-piped source should be available for the space.

sources. Information in this table is now considered obsolete but is provided for design engineers who may have to refer to previous guidelines for renovations of existing facilities that used this table.

Locating the Source of Supply

Oxygen supply shall be located in accordance with NFPA-50. The actual location shall be selected by the facility planner in conjunction with the owner and the design team, allowing adequate access for cylinder replacement, cylinder storage, and bulk tank filling by truck.

Nitrous oxide cylinder storage should not be located outdoors in colder climates due to past bad experience with cold weather operating problems. The room where the source is located shall be well ventilated, with adequate space allowed around the installed manifold to easily change cylinders.

The location of the air compressor has been previously discussed.

TABLE 14.35 Generally Recommended Number of Station Inlets and Outlets

Room	O_2	Vac	N_2O	Air	N_2	Evac	Typical uses
Anesthesia workroom	1	1	*	1			Equipment repair testing
Animal oper. (research surgery)	1	1	*				Animal anesthesia and surgery
Animal research lab	1	1		1			Routine animal care
Autopsy	1	1					Suction waste materials from body
Bed, holding	1	1					Cardiac arrest, O_2 therapy
Biochemistry	X	1		1			Standard lab use*
Biochem. lab	X	1		1			Standard lab use*
Biophysics/biochemical	X	1		1			Standard lab use*
Blood processing		1		1			Standard lab use*
Blood receiving (blood donors)	1	1		1			Emergency use
Cardiac catheterization room	1	2					Cardiac arrest and other emerg.
Chem. analysis lab (sm. lab in hosp.)		1		1			Standard lab use*
Chemical lab		1		1			Standard lab use*
Constant temp room (microbiology lab)	1		1	X			Standard lab use*
Cystoscopy	1	3				1	Emergency use
Deep therapy	1	2					Cardiac arrest and other emerg.
Decontamination room (attached to inhalation therapy dept.)	1	1		1			Equipment testing
Demonstration room (inservice training)	1	1					Demo. equip. to new empl. and students
Dental repair	1	1		1	X		Power drills (dental)
Dispensary (minor surgery, first aid, student hlth and exams)	*			*			Emergency use
EEG (electroencephalograms)	1	1					Cardiac arrest and other emerg.
ECG (electrocardiogram)	1	1					Cardiac arrest and other emerg.
EMG (electromyogram)	1	1					Cardiac arrest and other emerg.
Ear-nose-throat exam		1		1			Aspiration, topical spray
Electron microscopy		1		1			Standard lab use*
Examination room	1	1		1			Drive air tools and vacuum cleaning
Emergency room	1	2		1			Cardiac arrest and other emergencies
Exam room and proctoscopic	1	1		1			Cardiac arrest and other emergencies
Experimental lab	X	1		1			Standard lab use*
Eye examination	1	1					Stock and cardiac arrest
Fluoroscopy (x-ray)	1	2					Cardiac arrest and other emergencies
Full-term nursery	1	2		1			Incubators, respirators
General physiology lab	1	1		1			Standard lab use* plus teaching
Heart catheterization lab	1	1		1			Cardiac arrest and other emerg. respir.
Hematology		1		1			Standard lab use*

(*Continued*)

TABLE 14.35 Generally Recommended Number of Station Inlets and Outlets (*Continued*)

Room	O_2	Vac	N_2O	Air	N_2	Evac	Typical uses
High-level radioisotope (x-ray dept.)	1	2		1			Cardiac arrest and other emergencies
Holding pre-OR or	1	1					
Holding nursery	1			1			
Intensive care areas	2	3		1			For critically ill
LDRP (labor, delivery, recovery, postpartum)	1	2		1			
Isolation (infectious and contagious diseases)	1	1		1			Patient care
Isolation room (patient room for contagious)	1	2		1			Oral, gastric, or thoracic
Lab annex		1		1			Pull waste evac. tubing drying apparatus
Lab cleanup area		1		1			Drying glassware
Lab, workroom		1		1			Standard lab use*
Labor rooms, O.B.	1	1	*				Analgesia, patient care
Linear accelerator vault	1	1		1			
Low-level radiation (x-ray dept.)	1	2		1			Cardiac arrest and other emergencies
Microbiology		1		1			Standard lab use*
Multiservice room	1	1					Cardiac arrest and other emergencies
Neonatal	3	4		3			
Neurological pharmacy teaching lab	1		1				Standard lab use*
Neurological physiology teaching lab	1	1		1			Standard lab use*
Nursing floor	1	2		1			Therapy, oral, gastric; IPPB, aerosols
Observation	1	1					Cardiac arrest and other emergencies
Obstetrics (delivery room)	1	3	*				Analgesia, anesthesia, patient care
Operating room (surgery, major and minor)	2	3	1	1	*	1	Patient care
Oral lab (dental)	*	1	*	1	*		Standard lab use*
Orthopedic exam room	1	1					Cardiac arrest and other emergencies
Pathology (doctor's office special lab tests)		1		1			Standard lab use*
Patient room	1	1		1			Patient care
Pharma. room (drug prep.)		1		1			Standard lab use*
Premature nursery and obs.	2	1		1			Incubators, respirators
Private and semiprivate	1	2		1			Patient care
Private recovery room (same as regular recovery)	1	3		1			*Note:* Need 1 more Vac for thoracic
Radiochemical lab		1		1			Standard lab use*
Radioisotope room (research room for animal lab)		1		1			Standard lab use*

TABLE 14.35 Generally Recommended Number of Station Inlets and Outlets (*Continued*)

Room	O_2	Vac	N_2O	Air	N_2	Evac	Typical uses
Recovery beds (postanesthesia)	2	3		1			2 thoracic, 1 oral, 1 gastric or wound
Respiratory therapy	1	1		1			For outpatient treatments IPPB
Scanning room (part x-ray)	1	2					Cardiac arrest and other emergencies
Security nursing (psychiatric violent patients use lock box)	1	1		1			Patient care
Serology		1		1			Standard lab use*
Standard x-ray rooms	1	2		1			Cardiac arrest and other emergencies
Sterilization (CS or OR)	1	1		1			Equipment testing
Surgical preparation room	1	1		1			Premedication for anesthesia
Teaching lab	1	1		1			Standard lab use*
Treatment room	1	1		1			Special therapy
Urinalysis		1		1			Standard lab use*
Workroom for labs		1		1			Standard lab use*

*One outligsut per area.

X Consult owner for number and location.

Source: Courtesy of ASPE.

Flow Rate and Diversity Factor

Each individual station outlet must provide a minimum flow rate for proper functioning of connected equipment under design conditions. The flow rates and diversity factors vary for individual station outlets in each system.

The flow rate from the total number of outlets without regard for any diversity is called the *total connected load.* If the total connected load were used for sizing purposes, the result would be a vastly oversized system since not all of the outlets in the facility will be used at the same time. A diversity, or simultaneous use factor, is used to allow for the fact that not all of the outlets will be used at once. It is used to reduce system flow rate in conjunction with the total connected load for sizing mains and main branch piping to all parts of the distribution system. This factor varies for different areas throughout any facility.

The estimated flow rate and diversity factors for various systems, area station outlets, and pieces of equipment are as follows:

1. For oxygen, refer to Table 14.36.
2. For nitrous oxide, refer to Table 14.37.
3. For low-pressure compressed air, refer to Table 14.38.
4. For high-pressure nitrogen and compressed air, refer to Table 14.39.

System Pressure and Design Pressure Losses

Low-Pressure Oxygen, Nitrous Oxide, Carbon Dioxide, and Compressed Air. The minimum design pressure required at the most remote outlet with maximum flow rate for low-pressure systems is 50 psig (340 kPa). This figure has been

TABLE 14.36 Flow Rate and Diversity Factor for Oxygen Outlets

Location	Simultaneous use factor, %	Volume, Lpm
First OR (far end of a section of piping and all individual branches to ORs)	100	50 per OR
Each additional OR (on a section of piping)	100	10 per OR
Emergency rooms	100	Same as OR
Trauma rooms	100	Same as OR
LDRP rooms	100	20 per room
Delivery rooms	100	Same as OR
Cystoscopy and special procedures rooms	100	Same as OR
Recovery rooms (postanesthesia recovery)		10 per outlet
1–8 outlets	100	
9–12 outlets	60	
13–16 outlets	50	
additional outlets	45	
Intensive care (ICU) rooms	100	30 per outlet
Neonatal		
Pediatric		
Medical-surgical		
Coronary care (CCU) rooms	100	30 per outlet

Simultaneous use factors for other spaces*

The first outlet on the end section of piping is 20 Lpm. For additional outlets on the section of piping, add 10 Lpm with the flollowing use factors.

No. of outlets	Simultaneous use factor, %	Volume, minimum Lpm
1–3	100	—
4–12	75	45
13–20	50	115
21–40	33	125
40 and over	25	155

*“Other spaces” include the following: patient rooms (medical and surgical) (bedside outlets), labor rooms, nurseries, examination and treatment rooms, OR bed holding areas, surgical preparation rooms, blood donor rooms, anesthesia workrooms, plaster (fracture) rooms, cardiac and heart catheterization rooms, deep therapy rooms, inhalation therapy rooms, electroencephalogram (EEG) rooms, electrocardiogram (ECG) rooms, electromyogram (EMG) rooms, fluoroscopy rooms, high-level radioisotope rooms, low-level radiation rooms, x-ray rooms, and endoscopy rooms.

TABLE 14.37 Flow rate and Diversity Factor for Nitrous Oxide Outlets

Location	Volume, Lpm
First OR (far end of piping and all individual branches to ORs)	30 per OR
Second OR (on a section of piping)	20 per OR
Each additional OR (on a section of piping)	15 per room
Delivery rooms	20 per room
Emergency rooms	20 per room
Trauma rooms	20 per room
Anesthesia workrooms	15 per room
Plaster (fracture) rooms	20 per room
Endoscopy rooms	15 per room
Dental surgery	15 per room

universally accepted by health care equipment manufacturers and design professionals for system design purposes.

There is a generally accepted ‘‘allowable’’ maximum friction loss for the piping distribution system (after the source) of 5 psig (34 kPa). This figure is considered a reasonable one for design purposes, but there is no code or other mandate that prevents a small deviation from this figure. For short runs of branch piping, another generally used figure is 10 percent of the available pressure. All of the above deviations shall provide a minimum of 50 psig (340 kPa) at the outlet.

High-Pressure Nitrogen and Compressed Air. The minimum pressure required at the most remote outlet with maximum flow rate is dependent on the specific tools utilized by health care personnel. Currently used surgical room equipment requires a pressure range of from 160 to 200 psig (1000 to 1360 kPa) at the tool. There are also some tools used for precision work that use a much lower pressure of 25 to 50 psig (75 to 345 kPa). Dental pneumatic tools require 30 to 50 psig pressure.

There is a generally accepted average friction loss for the entire piping distribution system (after the source) of 10 percent of the design source pressure psig (136 kPa). Since the source of high-pressure gases is often a cylinder supply, the regulator installed should be capable of being adjusted over a wide range of pressure in the event that higher or lower operating pressures are required in the future. For high-pressure air compressors, the system regulator shall have the same capability.

There are no mandated purity requirements for gases used to operate surgical pneumatic tools. Oil-free air should be used and tool manufacturers consulted regarding maximum particulate size and dew points that are acceptable. NFPA-99 requires copper type ‘‘K’’ for pressures over 200 psig.

Pipe Sizing

The piping network is sized using the flow rate along each pipe run that has been adjusted by the diversity factor and the allowable friction loss for the system. Following is a system sizing procedure:

1. Locate all of the outlets and uses for each system on plans.
2. For each system, start with the most remote point, and work toward the mains. Count the number of outlets, determine the flow rate required from each outlet,

TABLE 14.38 Flow rate and Diversity Factor for Low-Pressure Medical Air Outlets

	Design flow in scfm (free air)				
Air outlet/equipment	Per unit	Per room	Per bed	Per outlet	Simultaneous-use factor, %
Anesthetizing Locations:					
Special surgery and cardiovascular		0.5			100
Major surgery and orthopedic		0.5			100
Minor surgery		0.5			75
Emergency surgery		0.5			25
Radiology		0.5			10
Cardiac catheterization		0.5			10
Ventilators	3.5				100
Delivery rooms		0.5			100
Acute Care Locations:					
Recovery room/surgical (postanesthesia)			2		25
ICU/CCU			2		50
Emergency rooms			2		10
Neonatal ICU			1.5		75
Dialysis units			0.5		10
Recovery rooms/OB		2			25
Ventilators	6				100
Subacute Care Locations:					
Nursery			0.5		25
Patient rooms (where shown)			0.5		10
Exam and treatment		1			10
Preop holding				1.5	20
Respiratory care		1			50
Pulmonary function lab				1	50
EEG and EKG				1	50
Birthing and LDRP		1			50
Patient isolation room			0.5		25
Other:					
Anesthesia workroom		1.5			10
Respirator care workroom	1.5			10	
Nursery workroom		1.5			10
Equipment repair		1.5		1.5	10
Med. laboratory				1.5	25
Autopsy		1			100
Sterile supply		1			10
Plaster room		1			50
Pharmacy		1			10
Dental, high pressure (50 psig)		2 per chair		2	100
Dental, low pressure (30 psig)		1 per chair		3	100

1 scfm = 0.03 m^3/min.

TABLE 14.39 Flow Rate and Diversity Factor for High-Pressure Outlets

No. of outlets	Simultaneous use factor, %
1–7	100
8–20	75
21–over	50

Note: Surgical pneumatic tools use a flow rate of up to 15 scfm (425 sLpm) for modern instrument design at 225 psig.

and establish the diversity factor (Tables 14.36 to 14.39) This information should be recorded in a convenient form for later use when using the pipe sizing tables.

3. Calculate the adjusted flow rates from all outlets of each system by multiplying the flow rates by the diversity factors. Add all of the adjusted flow rates for the entire system together to find the required system capacity. It is now possible to select the source equipment capacity and the physical equipment sizes for each of the systems.
4. Locate the gas storage area and physically lay out the cylinders, manifold, tanks, and so on. All necessary separation, ventilation, and venting requirements shall be followed.
5. Establish a general layout of the system from the storage area to the farthest outlet or use point. Measure the actual distance along the run of pipe. To the actual run add an additional 50 percent of the measured distance to allow for fitting allowance. If a more accurate calculation is desired, use Table 14.15 to calculate the loss through each fitting. This is the total equivalent run of pipe.
6. Determine all of the necessary regulators, filters, purifiers, and so on necessary for each system in order to establish a combined allowable pressure drop through each of them and the assembly as a whole.
7. Establish the gas pressure required at the farthest outlet for each system and the allowable pressure loss for the entire system.
8. Dividing the total run of pipe (in 100s of feet) by the allowable system friction loss will establish the allowable friction loss per 100 ft of pipe.
9. Calculate the adjusted flow rate of gas through each branch, starting from the farthest outlet back to the source (or main) using the allowable flow rate from each station outlet and the appropriate diversity factor. For specific equipment, obtain the probable diversity of use from the end user.
10. Depending on the type of compressed gas, enter the appropriate pipe sizing table. Table 14.40 provides pipe sizing data for low-pressure oxygen, nitrous oxide, and compressed air. Table 14.41 provides pipe sizing data for 160 psig (1100 kPa) nitrogen and compressed air. Table 14.42 provides pipe sizing data for 225 psig (1500 kPa) nitrogen and compressed air. Using the adjusted flow rate, read across to find a figure that equals but does not exceed the allowable friction loss. Then, read up to find the size. In some cases, the diversity factor for the next highest range of outlets may result in a smaller size pipe than the range previously calculated. If this occurs, do not reduce the size of the pipe—keep the larger size previously determined.

TABLE 14.40 Pipe Sizing Table for Low-Pressure Oxygen, Nitrous Oxide, and Compressed Air

(In psig loss per 100 ft of pipe at 55 psig)

Gas flow, scfm (Lpm)	Nominal pipe sizes, in								
	½	¾	1	1¼	1½	2	2½	3	4
1.8 (50)	0.04 (0.3)								
3.5 (100)	0.16 (1.1)								
4.4 (125)	0.25 (1.7)								
5.3 (150)	0.33 (2.3)	0.04 (0.3)							
6.2 (175)	0.48 (3.3)	0.06 (0.4)							
7.1 (200)	0.63 (4.3)	0.07 (0.5)							
8.8 (250)	0.99 (6.8)	0.11 (0.8)							
10.6 (300)	1.41 (9.7)	0.16 (1.1)	0.04 (0.3)						
14.1 (400)	2.51 (17.3)	0.29 (2.0)	0.07 (0.5)						
17.7 (500)	3.92 (27.0)	0.45 (3.1)	0.11 (0.8)						
26.5 (750)		1.02 (7.0)	0.24 (1.7)						
35.3 (1,000)		1.80 (12.4)	0.42 (2. 9)	0.13 (0.9)	0.05 (0.3)				
44.1 (1,250)		2.81 (19.4)	0.66 (4. 6)	0.21 (1.5)	0.09 (0.6)				
53.0 (1,500)			0.95 (6.6)	0.30 (2.1)	0.12 (0.8)				
70.6 (2,000)			1.05 (7.2)	0.67 (4.6)	0.22 (1.5)	0.05 (0.3)			
88.3 (2,500)				0.83 (5.7)	0.34 (2.3)	0.08 (0.6)			
105.9 (3,000)				1.19 (8.2)	0.49 (3.4)	0.11 (0.8)			
141.2 (4,000)				2.11 (14.5)	0.88 (6.1)	0.20 (1.4)	0.06 (0.4)		
176.6 (5,000)				3.30 (22.8)	1.36 (9.4)	0.32 (2.2)	0.10 (0.7)		
264.8 (7,500)					3.10 (1.4)	0.71 (4.9)	0.22 (1.5)	0.09 (0.6)	
353.1 (10,000)						1.27 (8.8)	0.40 (2.8)	0.16 (1.1)	
529.7 (15,000)						2.82 (19.4)	0.89 (6.1)	0.35 (2.4)	0.08 (0.6)
706.2 (20,000)						5.00 (34.5)	1.58 (10.9)	0.63 (4.3)	0.15 (1.0)
882.8 (25,000)							2.47 (17.0)	0.98 (6.8)	0.23 (1.6)
1059.3 (30,000)							3.55 (24. 5)	1.40 (9.7)	0.31 (2.1)
1412.4 (40,000)								2.48 (17.1)	0.59 (4.1)
1765.5 (50,000)								3.90 (26.9)	0.92 (6.3)

1 psi = 7 kPa.

TABLE 14.41 Pipe Sizing Table for 125 psig Pressure Nitrogen and Compressed Air, scfm
(In psig loss per 100 ft of pipe at 125 psi; Schedule 40 steel pipe)

Gas flow, scfm	Size, in ½	¾	1	1¼	1½	2	2½
6	0.102	0.023					
8	0.161	0.041					
10	0.283	0.064	0.017				
15	0.636	0.144	0.038				
20	1.131	0.255	0.067	0.016			
25	1.768	0.399	0.105	0.025			
30	2.546	0.574	0.152	0.037	0.016		
35	3.465	0.782	0.206	0.050	0.022		
40	4.526	1.021	0.270	0.065	0.029		
45	5.728	1.292	0.341	0.083	0.036		
50	7.071	1.596	0.421	0.102	0.045		
60	10.183	2.298	0.607	0.147	0.065	0.018	
70	13.860	3.128	0.826	0.200	0.088	0.024	
80		4.065	1.079	0.261	0.115	0.031	0.013
90		5.170	1.365	0.330	0.145	0.040	0.016
100		6.383	1.685	0.408	0.180	0.049	0.020
125		9.973	2.633	0.637	0.281	0.077	0.031
150		14.361	3.792	0.918	0.404	0.110	0.045
175			5.162	1.249	0.550	0.150	0.062
200			6.742	1.632	0.716	0.196	0.061
225			6.533	2.065	0.909	0.248	0.102
250			10.534	2.550	1.122	0.306	0.126
275			12.746	3.085	1.358	0.371	0.152
300			15.169	3.671	1.616	0.441	0.181
325				4.309	1.896	0.518	0.213

1 psi = 7.0 kPa.

The piping network for a high-pressure gas system is sized using the following system design procedure. First, the following information must be obtained or calculated:

1. Determine the maximum pressure for the system based on the tools expected to be used at the facility. The range of acceptable pressure the tools must have at the tools themselves to operate at maximum effectiveness shall be obtained from the manufacturer. For preliminary estimates, a range within ±5 percent of the recommended pressure will be acceptable. The higher pressure would be used for design purposes to provide a safety factor. Additional pressure, usually 20 psig (140 kPa), shall be available at the terminal connection to provide for final adjustment and losses through the connecting hose, lubricator, and any other accessory equipment at the tool recommended by the manufacturer.

2. Establish the source and type of compressed gas for the system. The most often used gases are either nitrogen or compressed air. Economics should be the deciding factor in the selection of source gas since there is no medical or technical reason to choose one over the other. For existing facilities, if a separate high-

TABLE 14.42 Pipe Sizing Table for 175 psig Pressure Nitrogen and Compressed Air, scfm
(In psig loss per 100 ft of pipe at 175 psi; Schedule 40 steel pipe)

Gas flow, scfm	Size, in						
	½	¾	1	1¼	1½	2	2½
6	0.075						
8	0.173	0.030					
10	0.208	0.047					
15	0.469	0.106	0.028				
20	0.833	0.188	0.050				
25	1.302	0.294	0.078	0.019			
30	1.875	0.423	0.112	0.027			
35	2.552	0.576	0.152	0.037			
40	3.333	0.752	0.199	0.048	0.021		
45	4.218	0.952	0.251	0.061	0.027		
50	5.208	1.175	0.310	0.075	0.033		
60	7.499	1.692	0.447	0.108	0.048		
70	10.207	2.303	0.608	0.147	0.065	0.018	
80	13.331	3.008	0.794	0.192	0.085	0.023	
90	16.872	3.807	1.005	0.243	0.107	0.029	
100	20.830	4.700	1.241	0.300	0.132	0.036	
125		7.344	1.939	0.469	0.207	0.056	0.023
150		10.576	2.793	0.676	0.297	0.081	0.033
175		14.395	3.801	0.920	0.405	0.111	0.045
200		18.801	4.965	1.202	0.529	0.144	0.059
225			6.284	1.521	0.669	0.183	0.075
250			7.757	1.878	0.826	0.226	0.093
275			9.387	2.272	1.000	0.273	0.112
300			11.171	2.704	1.190	0.325	0.134
325			13.110	3.173	1.396	0.381	0.157

1 psi = 7.0 kPa.

pressure compressed air system is not practical or economical, a separate cylinder nitrogen supply is generally provided although compressed air cylinders at a lower cost could also be used.

3. Ascertain the allowable friction loss of gas in the piping system (after all source valves, dryers, and pressure regulators if supplied) to achieve the pressure required at the tool. There is a generally accepted, average friction loss for the entire piping distribution system of 10 percent of the piping system pressure. The terminal regulator installed in each OR should be capable of being accurately adjusted over a wide range of pressure, often as low as 30 psig (210 KpA), in the event that lower operating pressures are required for different tools.

4. Determine the total equivalent run of piping. A conservative estimate is found by adding 50 percent to the measured run of the piping.

5. Determine the simultaneous use factor. This factor is the most problematic of the criteria since there is no method of determining an accurate figure universally applicable to every project. Personnel at each individual facility must be consulted as to the number of ORs in use at any one time, the type of operations performed, and the length of those operations. In this manner some idea of how many tools would be in simultaneous use could be determined. An extreme case is hip replacement, where 90 min of actual running time of a pneumatic tool has been documented.

A project design procedure will now be presented, using as an example a facility with 10 operating rooms, proposed tools requiring 15 scfm at each tool, and a pressure requirement of 200 psig at the tool itself.

1. Locate all of the proposed outlets on plans in conjunction with the owner, architect, or developed program. If there are multiple outlets in a single OR, only one tool will be in use at once unless the facility or program instructs otherwise.

2. Locate the gas source. If it is a storage area, physically lay out the cylinders, manifold, tanks, and so on. All necessary separation, ventilation, and venting requirements shall be provided. Refer to Fig. 14.23 for dimensions and layout of cylinder banks and Fig. 14.22 for cylinder sizes if not 9½-in diameter.

3. Calculate the storage requirements of cylinders or air compressor capacity. For a central compressor, the maximum scfm and pressure has to be calculated. For scfm calculations, add all of the outlets together, assign a maximum scfm value to each, determine the use factor, and calculate the maximum scfm for the system. To this add all other requirements such as dryers, and so on. The pressure is based on the maximum pressure required by the tools, the allowable friction loss, and the additional pressure at the outlet. Select a compressor based on these values with an allowance for additional scfm to accommodate future expansion if desired.

As an example, select a compressor for 10 ORs. First, 10 ORs × 15 scfm each equals 150 scfm. Referring to Table 14.38, a use factor of 75 percent is established, giving an adjusted scfm requirement of 113 scfm for tools. The pressure is based on a requirement for 200 psig at the tool, 20 psig friction loss allowance (10 percent of 200 psi), and an allowance of 20 psig for losses at the tool. This gives the selection criterion for the compressor of 113 scfm at 240 psig only for tools.

The selection of the number of cylinders in a central supply is based on the space available, the OR gas use requirements of the facility, and the supplier's ability or desire to constantly deliver cylinders to the facility, often every day. If the facility uses a large number of cylinders, a central compressed air system is considered very cost effective.

4. Establish the piping layout of the system on plans from the source to the farthest outlet or use point. Measure the actual distance along the run of pipe. To the actual run add an additional 50 percent of the measured distance as a fitting allowance. This figure is the equivalent run of pipe.

5. It is now possible to size the piping network. Pipe is sized using the flow rate and the allowable friction loss. This loss must be in the same units as the pipe sizing chart selected. The charts provided here are in psig loss per 100 ft of pipe run.

Starting with the most remote point, work toward the mains and source, and count the number of outlets on each branch and main. Using the maximum flow rate from each outlet in conjunction with the diversity factor, establish an adjusted flow rate at each connection with any outlet or pipe. These connections are each called a *design point.* This information should be recorded in a convenient form for later use when using the pipe sizing tables. The adjusted scfm for each design point is calculated separately.

Next, calculate the friction loss in psi/100 ft of pipe. This is done by calculating the equivalent run of pipe and dividing the run by 100. This figure in turn is divided into the psig loss allowable for the entire system. As an example, suppose the total equivalent run is 650 ft. This becomes a figure of 6.5. Design criteria has established an allowable loss of 20 psig for the system. Thus 6.5 divided into 20 gives a figure of 3.07 (say 3.0) psi/100 ft of pipe as the allowable friction loss.

Table 14.41 provides pipe sizing data for a 125 psig system, Table 14.41 provides pipe sizing data for a 175 psig system, and Table 14.43 provides pipe sizing data for a 250 psig system. For each design point, find the adjusted flow rate on the appropriate pipe sizing chart and read straight across to find a figure that equals the allowable friction loss. Then, read up to find the pipe size. In some cases, the

TABLE 14.43 Pipe Sizing Table for 250 psig Pressure Nitrogen and Compressed Air, scfm

(In psig loss per 100 ft of pipe at 250 psi; Schedule 40 steel pipe)

Gas flow, scfm	Size, in							
	½	¾	1	1¼	1½	2	2½	3
6	0.054							
8	0.096							
10	0.149	0.034						
15	0.336	0.076						
20	0.597	0.135	0.036					
25	0.933	0.211	0.056					
30	1.344	0.303	0.080					
35	1.829	0.413	0.109	0.026				
40	2.388	0.539	0.142	0.034				
45	3.023	0.682	0.180	0.044				
50	3.732	0.842	0.222	0.054				
60	5.374	1.213	0.320	0.078	0.034			
70	7.315	1.651	0.436	0.105	0.046			
80	9.554	2.156	0.569	0.138	0.061			
90	12.092	2.729	0.721	0.174	0.077			
100	14.928	3.369	0.690	0.215	0.095	0.026		
125	23.325	5.263	1.390	0.336	0.146	0.040		
150		7.579	2.001	0.484	0.213	0.058		
175		10.316	2.724	0.659	0.290	0.079	0.033	
200		13.474	3.558	0.861	0.379	0.103	0.043	
225		17.053	4.503	1.090	0.450	0.131	0.054	
250		21.054	5.559	1.346	0.592	0.162	0.066	
275		25.475	6.727	1.628	0.717	0.196	0.080	0.026
300		30.317	8.006	1.938	0.853	0.233	0.096	0.031
325			9.396	2.274	1.001	0.273	0.112	0.036
350			10.897	2.637	1.161	0.317	0.130	0.042
375			12.509	3.027	1.332	0.364	0.150	0.048
400			14.232	3.445	1.516	0.414	0.170	0.054
425			16.067	3.889	1.711	0.467	0.192	0.061
450			18.013	4.360	1.919	0.524	0.215	0.069

1 psi = 7.0 kPa.

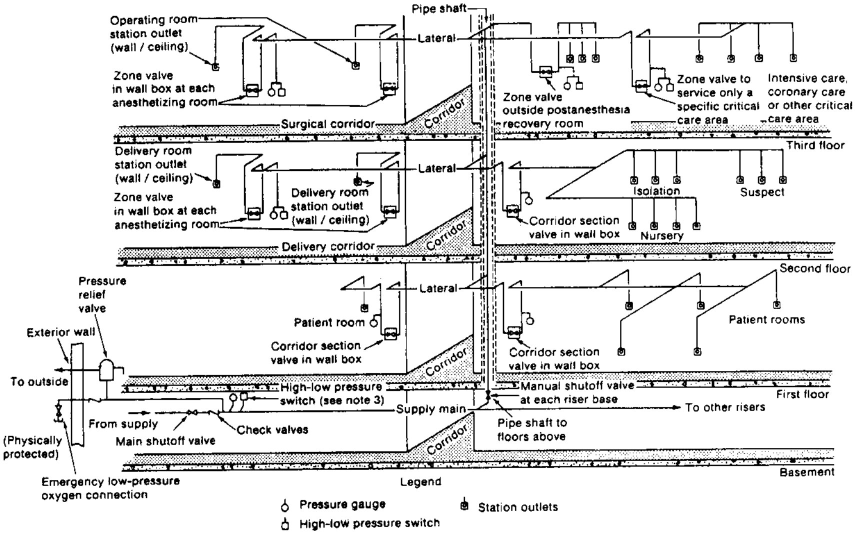


FIGURE 14.38 Schematic detail of typical medical gas systems. (*Adapted from NFPA.*)

diversity factor for the next highest range of outlets may result in a smaller size pipe than the range previously calculated, If this occurs, do not reduce the size of the pipe—keep the larger size previously determined.

Tables 14.41 to 14.43 have been calculated using steel pipe. Reduce pressure by 5 percent for use with copper pipe.

System Design Considerations

The size actually assigned to a pipe is a compromise between ‘‘normal’’ usage and possible ‘‘emergency’’ conditions. This philosophy will certainly result in oversized pipe if ‘‘emergency’’ conditions are used as a basis for design. The main argument for not oversizing the piping system is that it costs more. If this argument is taken in perspective, the small cost of slightly oversizing the medical gas piping system as a percent of the total construction cost of the facility is almost nothing. Another reason for oversizing is to allow for future changes or expansion, where the cost of adding another pipe or replacing a smaller pipe with a larger one will be many times the cost of larger sizing during the initial construction. Good practice is to have the smallest size branch ½ in, submains should be a minimum of ¾ in size, and main size no less than 1 in. This is to allow for future expansion and renovations without the need to replace piping.

A schematic diagram of typical medical gas systems adapted from NFPA-99 is given in Fig. 14.38. Refer to the text of this code for exact requirements.

DENTAL COMPRESSED AIR

GENERAL

Compressed air for dental purposes is used to power pneumatic tools such as drills and for general dentistry purposes such as quickly drying areas to be bonded. Compressed air is usually supplied by a small, dedicated compressor.

CODES AND STANDARDS

NFPA-99, Health Care Facilities, is the code governing the installation of the dental compressed air piping system.

SYSTEM COMPONENTS

Components of the system are illustrated in Fig. 14.34 and depend on the size of the system. Small units serving one or two dental chairs consist of only a compressor that runs continuously with no other ancillary equipment. Larger units serving multiple installations shall conform to the surgical-medical compressed air system.

REQUIRED PRESSURE AND FLOW RATE

Dental tools use both high- and low-pressure air. High-pressure tools such as drills use a flow rate of 2 scfm and a pressure of 50 psig (345 kPa). Low-pressure handpieces used for cleaning and by hygienists use a flow rate of 3 scfm and a pressure of 30 psig (210 kPa). Refer to Table 14.44 for use factors. Surgical tools may require 100 psig (700 kPa).

TABLE 14.44 Flow Rate and Diversity Factor for Dental Air

No. of outlets	Simultaneous use factor, %
4	100
5–10	75
11–over	50

SYSTEM DESIGN CONSIDERATIONS

Dental chairs have an integral air pressure regulating arrangement as part of the chair, and factory-installed distribution lines to the outlets found on the chair. It is generally accepted practice to provide a pressure in a range of 80 to 100 psig (550 to 700 kPa) to the regulator.

INDUSTRIAL SPECIALTY GASES

This subsection will discuss the generation and use of carbon dioxide and nitrogen on a larger scale.

GENERAL

Carbon Dioxide

The vast majority of CO_2 used for industrial purposes is obtained as a by-product of another process. Carbon dioxide is used to freeze foods and for pH control in various industries. It is also used for fumigation, as a replacement for mechanical refrigeration, cleaning, and solvent extraction. The most attractive characteristics of CO_2 are that it is environmentally benign, creates no long-term health hazard, is easy to handle, and requires few safety precautions.

The standard most commonly used is CGA G-6.1, Standard for Low Pressure Carbon Dioxide Systems at Consumer Sites.

There are three grades of purity available. Food, or standard grade, which is 99 percent pure, is the most often used grade. The most pure is that employed for laboratory work and other specialized uses, and it is discussed earlier in this chapter. The least pure, with no purity requirements, is that used for general industrial purposes such as in fracturing rock in oil recovery operations. CO_2 is usually delivered and stored at 0°F (−18°C).

Following are common uses:

1. At 90°F and 1100 psig (32°C and 7600 kPa), CO_2 reaches its supercritical state where it becomes a dense gas with the versatile solvent properties of a liquid.

2. CO_2 is widely used for pH control, replacing sulfuric acid. CO_2 acts like sulfuric acid on a mole-for-mole basis. It is estimated that 44 lb of CO_2 is equivalent to 98 lb of sulfuric acid in neutralizing any solution with a pH above 8.3. The ratio is less as the pH decreases.

3. Fumigation of grain in silos is another common use. CO_2 is stored as a liquid and is introduced into the silo as a gas from the top, from where it migrates down. General use is at the rate of 0.15 to 0.20 lb/bushel of grain.

4. To keep food frozen in trucks and railcars, liquid CO_2 is injected into an overhead bunker or storage area where it expands into a mixture of gas and ‘‘dry ice.’’ This melts over the length of the shipment.

5. CO_2 is used for carbonation in the soft drink industry.

Carbon dioxide is stored on-site in bulk tanks that will be discussed later in this section. Other equipment may include high-pressure transfer pumps and recovery systems which compress, purify, and liquefy CO_2 that is to be recycled.

The piping material most commonly used on tanks is Schedule 80 carbon steel, with forged steel fittings and ball valves at the inlet and outlet. Pipe distribution systems for cryogenic service are carbon steel, stainless steel, brass and copper that is insulated with 3 to 4 in of rigid, closed cell urethane and has a jacket. Piping for CO_2 gas is carbon steel in plants where high purity is not required and where physical strength is necessary. For other facilities such as food processing and pharmaceuticals, copper type L or stainless steel is preferred. If sterilization is required, stainless steel is used almost exclusively.

The K factor on the closed cell insulation should not exceed 0.15 for 2 lb/ft^3 density at 75°F. Commonly used jacket materials are PVC, polypropylene, and stainless steel flex. The most often used pipe combinations are type K copper tubing with brazed joints, 4-in polyurethane insulation, and PVC jackets. Allowance must be made for expansion of the pipe due to the large difference in temperature between ambient air temperature and the cold of liquid CO_2 that is about 0°F (−17°C). Valves shall be bubble tight, with operating pressures of 1500 psig for sizes up to ¾ in, 1000 psig for sizes to 1½ in, and 750 psig for sizes to 4 in. Valve materials are recommended to be stainless steel or a combination of steel and brass.

Safety valves must be provided on the tank to vent gas to atmosphere at a pressure of 10 percent over the highest working pressure. Another precaution is to prevent the withdrawal of gas at too high a flow rate. This will lower the pressure in the tank enough to turn the liquid into a solid in the tank or piping system. To prevent this, many installations use a separate pressure-building vaporizer that takes liquid from the tank, vaporizes it, and returns it back to the gas zone in the tank so that the vapor will maintain enough pressure in the tank to prevent solidification.

Precautions must be taken to sound an alarm when the concentration of CO_2 reaches a level of 3 percent in air. OSHA permits a 1 percent level for 8 h and 3 percent for only 15 min. Where large quantities are stored or where pipelines may leak indoors, a continuous CO_2 monitor and an oxygen depletion monitor should be provided to give both an audible and visual alarm. All areas must be properly exhausted.

Nitrogen

Nitrogen is one of the most often used gases for industrial purposes. It is inert, tasteless, and colorless as well as abundant and relatively inexpensive. Common uses for nitrogen gas are inerting, testing, sparging foods, and in the electronics industry for manufacturing various components. In cryogenic form it is used in blood and tissue preservation as well as for biological preservative functions and in various industrial processes.

When the demand for nitrogen exceeds about 15,000 ft^3 per month, on-site generation of nitrogen should be considered. If the demand exceeds 25,000 ft^3 per month, on-site generation is clearly desirable. On-site production will provide a more consistent gas with higher purity than the gas available from bulk liquid supply.

Several on-site production methods are commonly used. Pressure swing adsorption units produce only gas. In this method, air is first compressed, and it then passes through initial filters to remove moisture and other contaminants. It is then fed through a porous, solid molecular sieve adsorption bed that removes oxygen and other trace gases. Typically, the adsorption beds are composed of carbon material, with two separate beds provided. When the pressure is reduced, the adsorption beds give up their impurities to atmosphere. Duplex beds allow continuous operation. After passing through a final filter, the nitrogen is ready for use. Reserves to allow for peaking and backup could be stored in a separate reserve tank.

Another type is the single-column, cryogenic air separation unit, which can utilize either an air-expansion or waste-expansion cycle. Comparing the two basic cycles, waste expansion is more power efficient at product pressures of between 90 and 120 psia (600 and 800 kPa), and air expansion is more efficient at pressures of between 35 and 65 psia (250 and 450 kPa). A hybrid cycle, utilizing a molecular sieve to purify the incoming air, may be used to increase efficiency.

ACKNOWLEDGMENTS

Strachan McCoe Inc.
Hankison Corp.
George Koechine
John Quigg
McCarthy and Robinson Company, Toronto, Canada
Dollinger Silenciers, Peter Sulman
Mirza Z. Hassan, Byrne Compressed Air Equipment Co.
Ingersol Rand, Inc.
Ed Murphy, Pall Pneumatic Equipment Corp.
Charles Levitt, Nash Pump Co., Inc.
Leah Clark, RN, North Shore Medical Center, Vice President/Chief Nursing Officer
Derik Smith
Bill Bledsoe
Steve Waldman, Hill-Rom

REFERENCES

AIA: *Guidelines for Construction and Equipment of Hospital and Medical Facilities,* 1992–1993.

ASPE Data Book, vol. 2. 1981–1982.

Casillo, Antonio, ‘‘Sizing Air Compressors,’’ *Plant Engineering,* December 1984.

Compressed Air Fundamentals, Ingersoll-Rand Company.

Compressed Gas Institute: *Compressed Air and Gas Handbook,* 4th ed.

Cunningham, E. R.: ‘‘Air Compressors,’’ *Plant Engineering,* May 1980.

Ferrara, A. J.: ‘‘Design for Compressed Air,’’ *Air Conditioning, Heating and Ventilating,* 1964.

Foss, R. Scott: ‘‘Fundamentals of Compressed Air Systems,’’ *Plant Engineering,* May 1981.

Frankel, M.: ‘‘Compressed Air Systems,’’ *Plumbing Engineer,* Sept.–Oct., 1986.

Galus, T.: ‘‘How Much Air-Drying Equipment Is Necessary?’’ *Hydraulics and Pneumatics Magazine,* April 1989.

‘‘Guide To Compressor Selection,’’ *Compressed Air Magazine,* 1978.

NAVFAC DM—3.5. *Compressed Air and Vacuum Systems,* March 1983.

Stanton, W. M.: ‘‘Industrial Air Compressors,’’ *Actual Specifying Engineer.*

TM 5—810-4. *Compressed Air,* December 1982.

Ulrich, William B.: ‘‘Air and Water Can Be a Nasty Mix,’’ *Machine Design Magazine,* March 1993, pp. 71–75.

Varigas Research, Inc.: *Compressed Air Systems,* 1984.